FIREWORKS
Principles and Practice
3rd Edition

by

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CHEMICAL PUBLISHING CO., INC.
New York, N.Y.

Chemical Publishing Co., Inc.

New York

ISBN 0-8206-0354-6

1st Edition, 1972
2nd Edition, 1992
3rd Edition, 1998

Printed in the United States of America

Preface to the Third Edition

The idea of this book took place thirty years ago, and it is gratifying that it still has a place in the firework world.

The original intention was to produce a straightforward description of firework manufacture in the Western World. It was an attempt to describe what had happened in the past and to make suggestions for good practice at the present time.

It was also an attempt to be fairly basic and thereby not offend friends and competitors in the trade who had to make an attempt to make a living at fireworks. Amateurs have wonderful enthusiasm and like true scientists need to know everything—for its own sake. They also want to share findings with everyone else. However, this is in complete contrast to commerce, where survival may depend on the quality of the product or the price at which it might be produced. Needless to say this "edge" can be very costly in terms of hours of research and capital expenditure.

Recent years have seen the decline of the Western firework industry. The story is the same for almost every country where it has become uneconomical to make small fireworks compared to the price at which they can be bought from China. In the U.K., for example, there were ten manufacturers of small-shop fireworks in 1960, but there are none left in 1998. In the U.K. only Kimbolton Fireworks makes a full range of display fireworks with two other firms making special effects for the stage, etc.

Much of the material from the Far East is cheap and only partly reliable. It is also a boon to the ever-increasing numbers of unspecialized (and often legally ignorant) importers who bring in and distribute explosives in much the same way as bananas. The Civil Service, in the

U.K. at least, has been less than effective in the control of these illegalities in latter years. It was not so in the past, and while the EEC gets the blame for most things, it is clear that some of our partners in the EEC are much better 'at looking after their own' than is the case in the U.K.

This industrial decline is a great tragedy, but it is generally agreed that there will be a place for the present for those manufacturers able to make a good quality product. Those people willing to make this capital outlay need a Civil Service which creates a level playing field. In 1998 a high profile manufacturer is constantly bombarded with rules, regulations, bureaucratic nonsense, and more and more costs at every stage. Every sizeable company has to employ unproductive safety advisers, subscribe to suppliers of safety information, make space for records and risk assessments. No one can deny that the **simple** desire for good health and safety management is laudable. In reality it has become a burden with those working in it leaving no stone unturned and sometimes reaching absurdum as they justify their existence. In the meantime companies disappear or transfer their production to the Third World. All this time, the importers increase in number and have the financial gain.

It is difficult to predict what the next few years will bring. Importations from the Far East will increase, but it is clear that there are far too many Chinese exporters. Most of them are selling much the same products, and it is always more important to remain competitive than to produce superior products. A Chinese supplier may well sell the same products to several people in a limited market—a policy doomed to a very limited lifespan for obvious reasons.

Once again I am grateful to the many friends who have helped to make this edition possible. In particular to friends mentioned in Chapter 1 who have filled out the details about the firework scene in their own countries.

I would particularly mention Dr Takeo Shimizu (b. 1912) whom I have known for over thirty years and who has been absolutely prolific in his research for the firework trade. What would we have done without him?

Mention must also be made of the late Chris Philip who died in January 1998. The importation fireworks in the U.K had always been a major problem because of the prohibition on the admixture of chlorates and sulfur. However, Chris Philip set out to challenge a somewhat negative attitude towards importation at that time. A total ban had been easy to control, but his success then has done no favours to the home-

based industry some thirty years later. It has not shaken the Government into being more proactive in controlling the quality of what can be sold from abroad up to 1997 either.

Nearer home I am grateful to Mark Lancaster, Dr Tom Smith, Tony Cardell, Roy Butler, and John Bennett, the Editor of the excellent U.K. magazine 'Fireworks'. This magazine has done so much to encourage an interest in fireworks and to keep some of the history intact. Lastly, to my wife Kath who has always maintained that I eat and sleep fireworks and talk about them in bed—sometimes.

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Preface to Second Edition

It is now over sixteen years since this book was first put together. Progress there has been, but fundamentally fireworks are much the same as before. Over the last few years one or two important new books have been published along with a number of useful essays on individual topics. Reference has been made to these in the bibliography.

I am grateful to a number of friends who have helped with this revision particularly Robert Cardwell the Editor and creator of Pyrotechnica. Robert has done much to further the firework cause by the production of this interesting and scholarly periodical. I am grateful to him for revising our notes on the contemporary American firework industry. Similarly Bill Withrow of Euless, Texas, a good friend over the years has been tireless in his help and encouragement to get this book completed. Mention must also be made of the late Max P. Vander Horck. Max did so much to encourage the writing of the First Edition and when it was completed he maintained that if Weingart's Pyrotechnics was the firework maker's Bible, then 'Fireworks, Principles and Practice' was the New Testament.

I am also grateful to Dr. Tom Smith, Mr. L. Jackson and to Mark Lancaster for their help with photographs and drawings, to Tony Cardell and Walter Zink for some extremely helpful information, to Mrs. G. Crocker for allowing material to be used from the Gunpowder Mills Study Group and to Mr. J. Salmon for his excellent drawings of the Faversham Gunpowder Mills.

Last and not least to Mr. Bryan Earl who kindly allowed me to quote from his splendid, scholarly work 'Cornish Explosives'.

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Preface

For many years Weingart's "Pyrotechnics" has been regarded as the amateur firework enthusiast's Bible, and it was news of the re-print of this work in 1968 which prompted the writer to suggest a revision of it. As it happened the suggestion came too late with the result that a new work has evolved.

From the beginning the writer was anxious to share the task of writing this work, and accords grateful thanks to the other three contributors:- Dr. Shimizu, who very willingly translated part of his book "Hanabi" from the original Japanese. The script of chapter 19 is more or less as he translated it, and a great credit to him. To the best of our knowledge this was the first treatise on Japanese firework manufacture in the English language.

Ronald Hall, one of my long-standing firework friends who has long experience as a chemist in the explosives and firework industries. Has also been responsible for the introduction of polymerizing resins into commercial firework manufacture and is especially interested in forensic aspects of explosives.

Last but not least my thanks go to my teaching colleague and friend Roy Butler; an able firework maker who has given even more of his time to write a precis of available historical records, adding also more up-to-date material.

Turning to the general preparation of the book, I would like to express grateful thanks to Peter Smout Esq., M.A., Senior Master at Kimbolton School who has so kindly read through the script and made many helpful suggestions.

Helpful comments have also been made by Peter Watson, Esq., B.Sc. Senior Chemistry Master at Kimbolton School, Dr. Herbert Ellern, the

author of Military and Civilian Pyrotechnics, and Mr. J. Barkley and Mr. J. Wommack, two other American friends. My wife, Kathleen Lancaster, B.A.Dip.Ed., has kindly assisted with drawings and diagrams along with P.R. Lambert, a member of the School Sixth Form.

In particular also my grateful thanks go to Edwin Bailey who kindly used his printer's expertise to convert many of the drawings into a suitable form for printing.

Several commercial firms have been kind enough to supply technical information. These were Imperial Chemical Industries, Albright and Wilson Ltd., Frederick Allen & Sons Ltd., Anchor Chemical Co. Ltd., F.W. Berk & Co., Ltd., Columbian International Ltd., Du Pont de Nemours & Co., K. W. Chemicals Ltd., W.S. Lloyd Ltd., Magnesium Elektron Ltd., Chas. Page & Co. Ltd., L.R.B. Pearce Ltd., A.F. Suter & Co. Ltd. and Bush Beach, Segner Bayley. I would like to express my gratitude to all those people who helped me along the firework road in those early days when help was required to cross the threshold which separates amateur and professional firework manufacture. In particular I would mention the Greenhalgh Family of Standard Fireworks Ltd., Huddersfield, along with W. Stott Esq. and J. Seymour Esq. who also live in Huddersfield, my native town. Kindly friends abroad include Walter Zink of Zink Feuerwerk, Weco of Eitorf, Lünig of Stuttgart; Nico of Trittau, Hamburg; Moog of Wuppertal; Hamberger of Oberried and the Barfod Family of the Tivoli Gardens in Denmark.

Lastly, and in more recent times, gratitude is due to Pains-Wessex Ltd. to whom I was Firework Consultant from 1963 to 1977 and to John Decker F.C.A. and David A.S. Little for their help and friendship.

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Introduction

It is illegal to manufacture fireworks in most countries unless a license has been obtained from the government. This is absolutely right, for nowhere else does the old saying "that a little knowledge is a dangerous thing" apply more than here, perhaps with disastrous effects. Accidents occasionally happen in the most experienced hands and old and hardened manufacturers shudder at some of the experiments of the uninitiated.

Why then write a book about fireworks?

There is a need for an up-to date description of general firework practice. Firework manufacture may be a mixture of chemistry and cooking, but is an important branch of pyrotechnics. All the books in existence lack either accurate detailed information or publish information that may be incorrect, dangerous or useless. Naturally this has been deliberate because firework manufacture has been in the hands of private families and is still more or less tied up with money and competition. This is a pity, but like so many commercial enterprises, considerable sums of money are invested in plants or research and returns are naturally expected. Indeed, the writer has done little more than skim over the surface, quite deliberately; nevertheless all the compositions are typical of those in use in Europe and are reasonably safe as such things can be. Clearly the intention of this book has been to attempt to show that much of the available printed information is dangerous.

Over the last few decades the attitudes of the manufacturers have changed. In the past each one regarded his compositions as a great secret, the "boss" himself frequently doing the mixing and giving the chemicals false names to fool the industrial spies. All this has more or less gone. Chemical suppliers became fewer and larger, selling the same material to everyone; gunpowder manufacture is virtually a monopoly, workers in some countries change their employment from one company to another.

Most good firework makers share the same basic formulations; only the finer points and the techniques are more or less secret and naturally these are details which do not reach publication. In any case half the battle of firework manufacture is experience, namely the constant observation of the burning characteristics, and performance of fireworks and consequently the experience of knowing what adjustments to make and what to look for.

In the opinion of the writer, the argument that explosive information should not be published, does not hold water. Determined people can get a good deal of information, for there is plenty of it in print, and after all, legal and other restrictions make it very difficult for anyone to start manufacture.

The writers naturally would be greatly disturbed to feel that this book has caused anyone to damage people or property but such risks have to be taken at all levels of life. Fireworks are dangerous but so are domestic electricity supplies, oil burning heaters, pans of boiling fat, gasoline pumps, gas supplies, children's bicycles on roads . . . the possibilities are endless.

From time to time attempts are made to ban the sale of fireworks to the public. Recent voting in Great Britain indicate that the majority of the voters were against such a move, and quite rightly so. After all people have the right to act responsibly and should be free to exercise their responsibility in this direction. Britain, in common with most European countries, has rigid legislation and inspection of firework manufacture and an agreement amongst manufacturers that flash crackers and certain dangerous fireworks should not be sold to the general public. The result is that a fairly wide range of fireworks can be purchased in the shops at certain times of the year, and display fireworks can be organized by people with specialized experience. The U.S.A. could do well to benefit from our experience, for it would appear that a country priding itself on its freedom can nevertheless allow some bureaucratic fire marshall or other excited group to bring in legislation to outlaw fireworks in individual states. The result appears to be that it encourages people to buy fireworks over the border in a more permissive state and fire them illegally. Restrict the dangerous explosive items by all means, but "safe and sane" as the Americans put it, covers *very* much more than sparklers.

The Germans say in effect that once a person has smelt black powder, he will be with it for the rest of his life. There is undoubtedly some truth in this, for real fireworkers all over the world love to get together and talk about the fascination of this, their mutual interest. It is to be hoped that it will always be possible to strike a happy balance between the enthusiast and the legislation.

In recent years while pyrotechnics have been striding ahead, the art of firework manufacturing appears to be relatively static and old-fashioned. Nevertheless this should not be a matter exciting too great a concern, for the firework maker can only display his art on those grand and comparatively rare occasions when large sums of money are spent on a single display. The burst of an 8" golden octopus, crossette shell or a Japanese chrysanthemum will still thrill people for many years to come, in spite of the fact that the composition may be primitive. Public taste will not have the opportunity to become bored by those fireworks which really display the maker's art.

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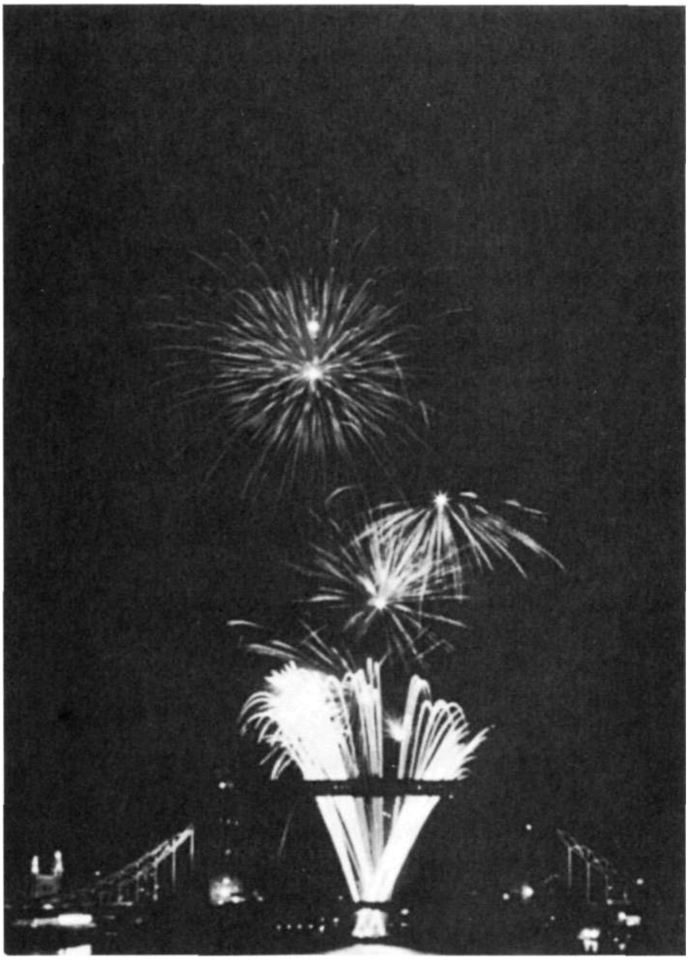

Fireworks on the Thames, London, England

1

THE HISTORY OF FIREWORKS

R.E.A. Butler

Firework manufacture has a long history, but the development of the pyrotechnic art has been remarkably slow. The Chinese may have made fireworks of sorts over a thousand years ago; displays have been fired at public and private celebrations for five hundred years, and their popularity, now world-wide, seems undiminished. Nevertheless, basically, firework displays have changed little over the centuries, with rockets, shells and Roman candles, in various forms, remaining the main display components. Certainly the quality and range of colours have been improved, shells are more spectacular, rockets are propelled higher, the use of new materials has brought some original effects, and fashions in set pieces and in the style of displays have changed. Although modern technology, in the form of sophisticated electronic firing boards and musical accompaniments, now enhances the spectacle, the essential ingredients of the firework exhibition do not alter. The fireworker still strives to excite and delight with a combination of colour and noise. He creates patterns of beauty and brilliance using natural materials and employing a knowledge of chemical reaction, together with the benefits of experience, and often much patience, dedication and intuition. The invention of gunpowder heralded the beginning of the pyrotechnic art, and this dark mixture is still the firework maker's principal material. Thus, in this capacity as a bringer of pleasure and beauty, gunpowder makes some amends for its evil reputation as a source of death and destruction.

It is probable that the first gunpowder was formed when, quite by chance, charcoal, saltpetre and sulphur were brought together. The result of this accident must have been obvious if the mixture was exposed to some means of ignition, and the potential use of this new explosive material must soon have become apparent. Traditionally, the Chinese are credited with the discovery at a time well before historical records. Certainly the evidence suggests that gunpowder originated in the East, with China or India being the likely source, although the Arabs and Greeks have certain claims. Tradition too credits Roger Bacon, an English friar of the thirteenth century, with the invention of a gunpowder mixture. Michael Swisher, however, argues conclusively in *Pyrotechnica* (November 1997) that:

> 'Roger Bacon did not invent gunpowder. He knew of it, and described it in several of his works with varying degrees of detail. The only application he describes is in a firecracker, a child's toy made in diverse parts of the world.'

Swisher also explodes the popular myth that Marco Polo brought knowledge of fireworks back from China in 1295. Polo makes no mention of fireworks in his account of his exploits, and, anyway, the writings of Bacon and others show that gunpowder and fireworks were known in Europe well before that time.

As for the application of gunpowder, the invention of the gun is usually attributed to a Franciscan monk called Berthold Schwarz, and the town of Freiburg has erected a statue in the town square in his honour. Attractive as the image of the 'Powder Monk' might be, Professor J.R. Partington in his meticulously-researched *History of Greek Fire and Gunpowder* (1960) finds no evidence to suggest that Schwarz even existed. It is thought that the invention could well have had Asiatic origins, although it was over two centuries later that the first artillery was reported in China, and that was on Portuguese and Dutch ships.

The Chinese, however, had employed pyrotechnic mixtures long before this date. Ancient manuscripts describe explosive bombs, which were fired from giant catapults, and burst on landing or in the air. Similar missiles were merely dropped on the enemy from fortress walls. Firecrackers were used in early times, just as they are now, to scare away evil spirits from wedding and birth celebrations and from funerals, and they were also much in evidence at various religious festivals. These crackers were often made by packing gunpowder into bamboo cases or rolled paper tubes, so laying the foundations of modern firework manufacture. They exploded when thrown on to the fire, hence the origin of the name 'firecracker'.

An encyclopaedia by Fang I Chih, dated around 1630, refers to 'fire trees and silver trees' used in the Tang dynasty (7th to 10th centuries) in which gunpowder was thought by the author to have been used.

These fireworks may have been the forerunners of those used in big displays which were frequently put on in China in the seventeenth and eighteenth centuries, and which were described in various writings by travellers returning to Europe. Apparently the development of Chinese fireworks proceeded very slowly, and in 1821 Claude-Fortune Ruggiari, the French pyrotechnist, remarked that the 'Chinese fireworks.... were no different from what the Chinese have been making for three or four centuries; this convinced me that we in Europe are far superior to the Chinese'. But, of course, this could have been wishful thinking!

In India, too, progress appears to have been slow, for war rockets were in use at a very early time. Here, as in China, fireworks of sorts were frequently seen at celebrations and public festivals, and fifteenth and sixteenth century writings, such as the Marathi poem of Saint Ekanatha, describe displays, and mention rockets and fireworks producing garlands of flowers, a moonlight effect and hissing noises. By the eighteenth century, displays were organised on a lavish scale. The first English display in India was in 1790 near Lucknow, and was said to have taken six months to prepare.

In Europe, pyrotechnics for military purposes saw an early peak of achievement in the form of Greek fire. Highly combustible material, including sulphur, resin, camphor and pitch, was blown by a bellows device out of copper or iron tubes, or even hand pumps, and was almost inextinguishable. Old manuscripts suggest several ways of attempting to combat the fire, especially the application of wine, vinegar, sand, and even urine. For four hundred years, the Greeks guarded the secret of their devastating weapon, and used it with spectacular effect on land and sea; but by the tenth century, the Saracens had learned the formula, and used it against the Crusaders. By the fourteenth century gunpowder appear in European warfare, and made the short-ranged Greek fire powerless against far-flung missiles.

In the wake of gunpowder came the arrival of firework mixtures, both of them appearing in Europe, probably as a result of information on their manufacture being brought from the East. Italy seems to have been the first area in Europe to make fireworks, as opposed to military pyrotechnics, and put on displays. It is clear that before 1500 fireworks were employed extensively at religious festivals and public events, as frequent displays were becoming popular entertainments. Florence was probably the centre of an expanding manufacturing industry, as demand for the new spectacle increased. Before this period, fireworks had been used as scenic effects at theatrical productions. In fact, fiery torches and the like had been added embellishments in the amphitheatres of classical Roman times. Now the fireworks became the main concern, although elaborate scenic sets and buildings were to form backgrounds to displays for many years to come.

Firework displays were seldom seen in England before the end of the sixteenth century. Shakespeare refers to 'fireworks' on several occasions in his plays, suggesting that the term was in general usage in England in Tudor times. Other literature of the period often mentions the 'green man', whose function was to walk at the head of processions carrying 'fire clubs' and scattering 'fireworks' (in this case probably meaning sparks) to clear the way. The origin of this character and his title are a mystery, but we are told that he was usually made up to appear very ugly, and he certainly survived well into the following century.

The earliest record of a firework display in England was in 1572, when a large show was put on at Warwick Castle to mark the visit of Queen Elizabeth I. The Queen is said to have enjoyed the spectacle immensely, and this approval served to encourage the organization of many more displays, including two shows fire at Kenilworth Castle, Warwickshire, to entertain Her Majesty during a visit there in 1575. The first of the displays on the River Thames was in 1613 to celebrate the marriage of King James's daughter Elizabeth. The site has been used with great regularity ever since.

The early displays in England were mainly the work of firework makers from France and Italy, especially the latter, who seem to have been supreme in Europe until the end of the seventeenth century. It was not until considerably later that English pyrotechnists began to challenge the continental lead. Responsibility for the provision of fireworks and the organisation of displays was put in the hands of the military, and Ordnance officers, ranked Firemasters, were appointed to take charge.

While the English lagged behind, two distinct schools of firework making appeared in Europe. In the Northern area, such states as Poland, Sweden, Denmark and the German states were developing new methods of firework presentation, which differed markedly from the traditional style of the Mediterranean countries. Brock considers that the split was closely related to religious matters, and the intense feelings which the Reformation aroused found outlet in more sectarian spheres, including pyrotechnics. In fact, the fireworks made in the north and south remained very similar in effects; the divergence occurs more often in the presentation of displays.

The Italian style, illustrated especially by the Ruggieri brothers of

Bologna, and followed by the manufacturers of France (who were joined by the Ruggieri family at a later date), had grown from the early ceremonial displays in Florence at the Feast of Saint Peter and Saint Paul. Invariably, collections of small fireworks were arranged on, and in front of, huge, elaborate structures, built in the form of castles, temples and classical edifices, and known as 'machines' or 'temples'. The imposing frontages were lavishly adorned with rich decorations, and the whole was illuminated from within and without. The audience was thus entertained before the actual display began, and when the fireworks were lit they tended to heighten the general spectacle of the 'machine', rather than provide purely pyrotechnical amusement.

The breakaway Northern school took their lead from Nürnberg, where experts like Hoch, Muller, Clarmer and Miller, challenged the masters of Florence and Bologna. The displays in the North gave the fireworks the prime importance and diminished the role of the 'machine'. The fireworks were set out in neat rows on the ground for all to inspect before the display was fired. If the 'machine' was used, it was of a much less elaborate construction than in the South, although sometimes real buildings or landscapes were utilized to add atmosphere to the shows. The effect achieved by firing displays behind a foreground of water was realized in this period, and engravings of displays at Stockholm, Paris, Versailles and on the Thames, illustrate the early beginnings of this still popular practice.

Spectators accustomed to either Northern or Southern types of displays were scornful of the attempts of the rival school, as can be clearly discerned from contemporary publications. The most authoritative was *The Great Art Of Artillery*, (46) penned by Casimir Simienowicz, the Lieutenant General of the Ordnance to the King of Poland, in 1650. His displays, although following the techniques of the North, included some features of the South, so giving his shows decorative effect before firing time, yet concentrating on pure firework amusement during the performance. This kind of compromise display often included figures and architectural structures, smaller and less intricate than the 'machine', and made of a wooden frame, over which was papier-mache, which concealed fireworks. At a certain point in the show, sparks and stars would be seen to issue from the model with spectacular effect. Various figures made their appearance in the different shows, although the Cupid was perhaps the most popular, and the tall obelisk was a regular feature at displays for many decades.

In their various styles, displays increased enormously all over Europe. As far back as 1532, Charles V, the Holy Roman Emperor, celebrated his military victories with displays. In 1690, Peter the Great of Russia put on a five-hour display to celebrate the birth of his son, Alexis. Louis XIV and XV enjoyed numerous shows in Paris and at Versailles in celebration of royal births and weddings, state occasions and victory or peace festivals. In almost every European country, visiting royalty were treated to huge displays. Peace treaties, like that signed at Aix-la-Chapelle in 1742, were excuses for expensive performances in many European capitals. Unfortunately, according to reports at the time, the show staged in Paris resulted in 'forty killed and nearly three hundred wounded by a dispute between the French and the Italians, who, quarreling for precedence in lighting the fires, both lighted at once and blew up the whole'. Numerous prints and engravings of the time undoubtedly flatter many of these shows by depicting them always in full, extravagant splendour.

In fact, not all displays were the spectacular success their advance publicity proclaimed. The pyrotechnic celebration planned to take place in London's Green Park in 1742 was to have been the greatest display of all time. An official estimate of the cost was over £14,500, and Ruggieri and other notable Italian manufacturers were brought over especially for the occasion. Nearly six months were spent in erecting huge temples and various ornate machines of elaborate design. One machine, designed by Cavalieri Servadoni, was 410 feet long and 114 feet high. Eleven thousand fireworks were prepared to accompany the *Music for the Royal Fireworks*, which Handel had composed especially for the occasion.

At the appointed hour, King George II, accompanied by an impressive array of aristocracy, paraded to his seat past the huge, excited crowd. However, all was not well behind the scenes, for violent arguments had arisen between the English and Italian fireworkers. These disagreements were brought to a dramatic end as an explosion rent the North Pavilion, which burst into flames. The fire caused widespread confusion and alarm, but was eventually brought under control so that the planned fireworks could begin. Judging by eyewitness reports, however, the display was anything but the memorable spectacle which had been promised. Such descriptions as 'pitiful and ill-conducted', 'the Grand Whim for posterity to laugh at' and 'the machine was very beautiful and was all that was worth seeing' were just some of the less abusive comments. Certainly it was the last big display London was to see for many years.

Private firework companies had long been operating on the continent of Europe, but in England artillery officers were still in charge of displays, although the actual arrangements were probably under the control of civilians. No doubt small English companies made fireworks for the shows, and large quantities were regularly imported from France and Italy. It is recorded that a Swede, Martin Beckman, made fireworks for the celebrations which marked the coronations of Charles II (1660) and James II (1685), both on the Thames, and also that of William of Orange (1689). The eighteenth century, the 'Age of Elegance', gave the English manufacturers the opportunity to show their skills and to increase their sales and production.

It was during this period that the 'Pleasure Garden' became, for the respectable townsmen and their ladies, the fashionable place at which to be seen. Taking a lead from London, most towns of note established these exclusive resorts, with their concerts and tea parties, opportunities to exchange gossip and to be sociable, not to mention the availability of medicinal waters in such towns as Bath, Harrogate and Leamington Spa. Soon other entertainments were added to amuse and excite the clientele. Male and female bare-knuckle fights, dog and cock fights, bear- and bull-baiting were all popular attractions, and eventually firework displays became regular items on the programmes. Many small manufacturers found this new and expanding market just the incentive they needed to develop their businesses and make their reputations. The Brock family business, in particular, made great strides during this period, with impressive displays at the famous Marylebone Gardens, and later at Ranelagh, Vauxhall and the Spa Gardens, Bermondsey. London boasted scores of resorts, ranging from the most fashionable and exclusive, to others which were rather less salubrious and often short-lived.

Outside London, the most outstanding resort was The Belle Vue Gardens in Manchester. It started as an extension of a public house which exhibited a few animals for the amusement of customers, and developed into a sporting and amusement centre, a zoological garden and, after 1852, a site for regular firework displays. Spectacular recreations of famous battles using pyrotechnic effects were a speciality, and these continued until 1939. The fireworks were provided by the Belle Vue Fireworks Company until 1926 when Brock took over. Immediately after the Second World War, shows were fired every night throughout the autumn, with a huge display on November 5th as a finale. Rising costs later necessitated the reduction of the number of shows and the budgets, until the Gardens closed in the 1970s.

The other English pleasure gardens had long since disappeared, victims of the vast and rapid expansion of London and other cities during the nineteenth century, although some of them were converted into public houses and still serve, if for a wider clientele. The Tivoli Gardens in Copenhagen remains, complete with regular firework displays. The numerous 'theme parks', epitomised by the Disney enterprises, are modern equivalents of 'pleasure gardens' of the past.

Events of national importance continued to provide income for the companies through the nineteenth century. Notable among these were the Peace Treaty of 1814, the Jubilee of George III and the coronations of George IV in 1821 and Victoria in 1838. The expensive Hyde Park displays which marked these occasions rivalled in effect the many held in France at that time. (Napoleon, in particular, was a great firework enthusiast and had much to celebrate before his ultimate defeat.)

As the nineteenth century wore on, the techniques of firework-making, a process which mirrored the vast development which was proceeding in all fields of scientific research and means of communication in Europe took a dramatic leap forward. In time, the better understanding of chemical reactions produced new pyrotechnic effects and especially a wider range and greater intensity of colours. A better use of propellants and more efficient methods of firing led to ever-improving pieces and consequently to better displays. Newly-discovered knowledge was circulated by the numerous scientific books which were being published, encouraging a large and new generation of amateur pyrotechnists. The expanding sales of newspapers and journals like *The Illustrated London Times'* and *The Illustrated News of the World* publicised and popularised displays with frequent and large illustrations. Better means of transport enabled manufacturers to put on displays in areas which had previously been regarded as inaccessible, and allowed people from increasingly wide circles to travel to watch the exhibitions. Moreover, all over Europe, Royalty and other dignitaries, were able to move around with much greater facility and were often treated to a spectacular firework display in each city they visited. In this way Victoria and Albert were entertained during their tour of 1845; and in 1871 sixty thousand people assembled in the Crystal Palace grounds to enjoy the display given in honour of the visit of the Grand Duke Vladimir of Russia to London.

There was, of course, an ever-increasing number of small and public displays, but the contracts for the huge and expensive shows to celebrate national events were heaven-sent opportunities to the manufacturers, not only to increase their profits considerably, but also to publicise their wares - as indeed, such events are today. Hence they greeted the victories during the Crimean War with much enthusiasm, and the Peace

Treaty of 1856 was the signal for a glut of displays in every sizeable town in Britain, including no less than four in London, as well as in most French cities. For English manufacturers, Queen Victoria proved an even greater asset, since the celebrations which accompanied Her Majesty's Silver and Golden Jubilees required numerous and lavish displays, not only in Great Britain, but also throughout the Empire.

Apart from the occasional spectacles marking national events, the most important displays in Britain were certainly those put on at the Crystal Palace by the Brock company. Charles T. Brock inaugurated the series at the new and popular resort at Sydenham, London, in 1865. The idea was such a success that the company gave regular displays every year until 1910, and then again after the First World War from 1920 to 1936, when fire destroyed the building. Thus a series of nearly two thousand displays was brought to an end. They had come to be known as 'Brock's Benefits', after an explosion nearly ruined Brock's business in the 1820's and, as we are told on a contemporary poster, a sympathiser gave Brock 'the gratuitous use of his commodious Ground (in the City Road) to display an exhibition of fireworks for his benefit'. In an effort to popularise the newly-opened Alexandra Palace, a firework competition was held at the resort in 1876. Among the prize-winners were Pain's, Wells and Wilder, as well as Brock's, company names still familiar up to a few years ago.

The displays of the period, as typified by the early 'Benefits' at the Crystal Palace, bore a significant resemblance to the modern displays in respect of type of firework and general display programmed, and underlined the changes and improvements made in the previous years. Gone were the elaborate scenery and decorated buildings, and gone too was the obelisk or similar central model. Instead, the spectacle was provided by a greater effectiveness from the fireworks displayed and an altogether wider range of items. The discovery of potassium chlorate by Berthollet at the end of the eighteenth century allowed the firework industry to produce colours which had never been seen before. The addition of metals like aluminum and magnesium, the latter in about 1865 and former in about 1894, gave fireworks an increased brilliance. Rockets of ½ pound and 1 pound calibre soared higher, shells increased in diameter to 200, 300 and 400 mm. (It was Ruggieri who first wrote of a shell with lifting charge and projectile contained in one unit in 1812.) The potassium picrate 'whistlers' made their first appearance at the Palace.

Yet it was the set pieces which were the main attractions of the time. The Crystal Palace with its shrubberies and fountains presented a splendid backdrop for a firework display, but the sheer size and magnificence of the setting demanded a performance on the same grand scale, hence Brock's introduction of the huge pictorial set piece. Using thousands of coloured lances on frames, and over seven miles of quickmatch, 'fire pictures' up to eight hundred feet long and ninety feet high were produced, depicting such epic events as the Battle of Trafalgar, the Siege of Gibraltar and the Eruption of Vesuvius. After 1897, portraits in fire of royal personages, visiting dignitaries, politicians and, later, even film personalities became popular. A spectacular variation was the transformation set piece in which a design made up of quick-burning coloured lances gave way to a picture of slow-burning white lances, the white having been obscured by the brighter colours until that point. By very careful choice of compositions and using lances of different lengths, a transformation piece could be presented in which a rural scene changed from spring to summer, then autumn and finally winter. The largest set piece ever constructed was Brock's spectacular depiction in 1898 of the destruction of the Spanish fleet in Manila Bay in the same year. The structure covered sixty thousand square feet.

Various other set pieces like fire-wheels up to a hundred feet in diameter, lattice poles, flights of 5,000 or more rockets, bouquets, and the famous Niagara of fire, a magnificent cascade which covered an area of 25,000 square feet and burned a ton of iron filings, became regular items. So too did humourous lancework pieces, like the seal which seemed to balance a ball on its nose, donkeys which threw off their riders, elephants which blew showers of sparks from their trunks and the British lion which lashed its tail and winked at the delighted crowd. Innovations at the 'Benefits', which have disappeared with the very large set pieces, were the 'living fireworks', so popular at the time. In these, live actors, dressed in asbestos and outlined in lancework, wrestled, boxed, enacted scenes and even walked the tightrope. On one famous occasion an actor named Bill Gregory, who was listed in the programme as Signor Gregorini, was to slide down a wire from the tower to the terrace. At his first attempt he stuck half way down, and had to remain there suspended for the remainder of the display. As Brock notes in his book, 'his remarks left no doubt as to the country of *his* origin. It is interesting to find that a member of the Gregory family was still working for the Brock Company in the 1960's (Figs. 1.1 and 1.2).

While Brock's gained remarkable publicity and deserved acclaim for their big displays at Crystal Palace and elsewhere, other companies in England were also extending their business and influence. Wells

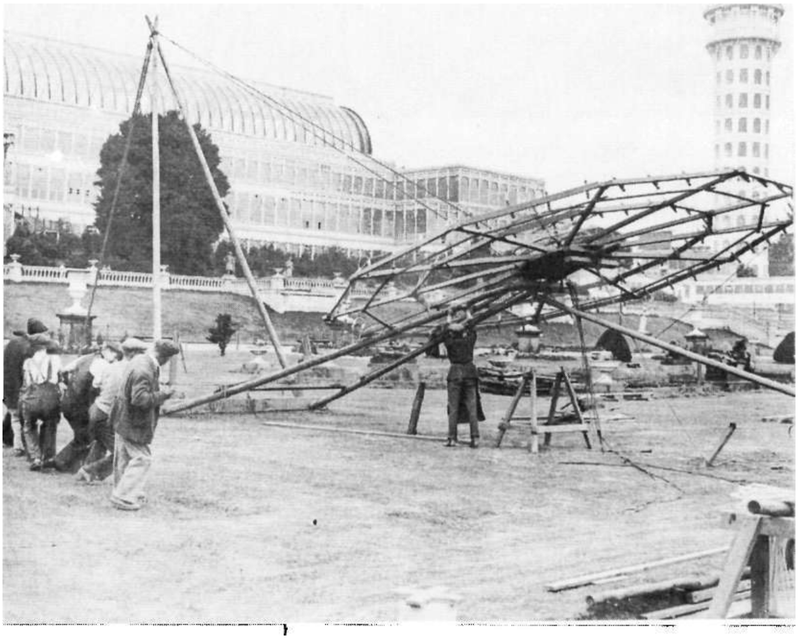

Fig. 1.1 Brock's Firework Displays at the Crystal Palace, London. Early 20th Century. Brock's Fireworks

(established 1837), Pain's (1860s) and Wilder's (1876) were among firms sharing an expanding market in this country and the Empire. On the continent of Europe, many of the famous companies were well established by the turn of the century, and were rapidly extending their arts, techniques and businesses. For instance, the Lacroix company was established in 1848 to rival Ruggieri in France and Hansson of Gothenberg dates back to 1888.

In this century the number of displays has not decreased, and the big national event, such as the Peace Celebrations of 1946, the Coronation of Queen Elizabeth in 1953, various Independence Celebrations around the Commonwealth, the Silver Jubilee of H.M. Queen Elizabeth in 1977, the marriage of the Prince of Wales and Lady Diana Spencer, and the fiftieth anniversary of VE Day, still demands a pyrotechnic show. The companies are anticipating the Millennium with considerable relish. Moreover, displays are becoming increasingly popular at carnivals, regattas and fund-raising events, and as accompaniments to outdoor concerts. Traditional English occasions such as the Henley and

Fig. 1.2 Brock's Fireworks at the Crystal Palace, London. Early 20th Century. Brock's Fireworks

Cowes Regattas, or Shrewsbury Flower Show, would be incomplete without their displays, and fireworks are regular items on the programmes of County Shows and Town Carnivals throughout the summer. In the U.S.A., the State Fairs usually boast expensive shows; the spectacular 'Setting the Rhine on Fire' shows are frequent entries in the calendars of Moog and other German manufacturers; the French resorts regularly entertain their visitors with displays; and in Italy and

Spain numerous religious festivals have been celebrated with fireworks for centuries.

Twenty years ago it could have been said that, as exciting and spectacular as the big displays undoubtedly were for the spectators, to the manufacturers they were often more useful as means of publicity than great profit-making items. At that time, most firms depended on sales of small fireworks through retail shops to accrue their main profits, and their factories were mainly engaged in making fountains, small rockets and candles, 'volcanoes' and 'bangers' for the general public, rather than large shells and set pieces for exhibition purposes. In Britain over ninety per cent of all fireworks were sold within six weeks before Guy Fawkes Day on November 5th. Similarly the peak sales period in the U.S.A. was just before the July 4th Independence Day festivities. In France, the main demand comes prior to July 14th, Bastille Day, and in most European countries firework parties on New Year's Eve are an old-established tradition. A combination of ever-stricter regulations governing the sale of many types of shop goods, higher production costs and the increasing importation of cheap Chinese fireworks, has led to a ravaging of firework manufacture in many countries. Factories have been forced to close down, turn to military pyrotechnics for survival or rely on importation to furnish their display needs. If family firework parties are less popular than in the past, the number of organised displays fired by enthusiastic amateurs has proliferated. There is now a large, and growing, market for 'do-it-yourself display packs. A further result of the changes is that the old established companies are having to compete with a rash of small businesses, which can buy goods from home or foreign producers, for displays or the 'packs' trade, without needing to have the expertise or the plant and machinery for manufacturing.

These trends are unlikely to change in the near future. Fireworks are potentially dangerous objects if they are negligently handled. When the instructions are not followed accidents inevitably happen and lead to much negative publicity. Considerable opposition has been directed against the sale of fireworks, or even their manufacture, in almost every country where they are made. Certainly in the U.S.A. and the European Union, governments have often reacted vigorously, and sometimes with almost hysterical haste, in response to campaigns for greater control. In the United States, different legislation applies in the separate states. Some administrations ban the sale of all types of firework, while others allow only 'safe and sane' types, which include flares, candles, fountains, wheels, sparklers, etc., but not those with explosive elements.

In Britain, ever-stricter laws have been imposed in recent years. The sale of shells to the public was banned in 1996, and 'bangers' in 1997, when it also became unlawful for those under eighteen to purchase any sort of firework. There are rigid laws governing the transportation of explosive materials, regulations concerning the amount of fireworks which retailers may store, the storage conditions and the manner in which pieces may be displayed in shops. The controls within which firework factories must operate are very severe, as are those covering importation. The current regulations in Britain have come about after many centuries of change. As has already been seen, there were scores of small factories established by the eighteenth century, ready to supply the needs of the Pleasure Gardens as well as a growing clientele elsewhere. Long before that time squibs and crackers had been made in considerable quantities for the local general public to celebrate the traditional festivals, such as Guy Fawkes Day, Queen Elizabeth Day or Saint John's Eve. The diarist Samuel Pepys mentions a firework party attended with his family after the victory over the Dutch in 1666. Many of the manufacturers came from the continent as religious refugees, although the making of fireworks was usually a spare-time occupation, carried out in their homes after a day's work in the silk or woollen industries. It was in these conditions of manufacture where the main dangers of explosions lay.

The situation was made worse after 1695, when the making of fireworks was completely banned following the anti-government riots, which flared up during the November 5th celebrations of that year. In fact, the Act made clear that 'if any Person shall make or cause to be made, or sell, give, or offer, or expose to sale any Squibs, Rockets, Serpents, or other Fireworks, he shall forfeit Five Pounds'. Unfortunately, the legislation was not, nor could be, adequately enforced and only served to drive manufacturers to work in more and more dangerous conditions in back kitchens, with no opportunity to extend and improve their technically illegal businesses. There was no diminution in the supply of fireworks for Guy Fawkes Night or Pleasure Gardens requirements. Gun-powder, compositions and stars were stored around kitchens near open fires. There was no official control or inspection, since theoretically no fireworks were being made. The ludicrousness of the situation was high-lighted when the authorities engaged persons to break the law if fireworks were needed for public displays. The addition of potassium chlorate to the list of ingredients in firework mixtures added greatly to the potential risks involved.

Inevitably, many accidents occurred. In 1839, three people were lucky to escape death when a spark from an open fire fell on a pile of gunpowder lying on the table, and this in turn set off a barrel of powder nearby. It was recorded that an explosion shook the premises of Mr Mortram, when some rocket stars, which were drying in front of an open fire, burst into flame and exploded. The *Weekly Messenger* of September 4th, 1825, vividly describes the 'dreadful explosion' in Brock's own factory in Whitechapel, London, when 'ten houses were seriously damaged, and over sixty had their windows broken from top to bottom', and 'one poor woman. . . was so dreadfully injured by the broken glass that she lies in London Hospital without hopes of recovery'. Apparently two boys had been ramming rockets, when the ramrod struck against the funnel. The friction caused a spark, which fired some nearby gunpowder. Other fireworks were set off, and eventually the fire reached the gunpowder magazines. This caused the real disaster, and for a considerable distance was heard 'a sort of rumbling noise as if of distant thunder, and the next moment a tremendous and deafening explosion followed, and the air was illuminated with lights of various descriptions, and accompanied by continued reports'.

Firework accidents occurred with frightening regularity, and the damage to property was great. Moreover, the lists of persons badly injured and killed increased continually, and these included 'third parties' who were unconnected with firework manufacture. At last the authorities decided to act. To try to implement the old legislation would have been very difficult and undesirable, since many people were employed in the industry and fireworks were in great demand. So the 'Gun-powder Act of 1860' was enforced after a hundred and sixty-five years of illegal manufacture. The new law sensibly laid down regulations concerning the making and storing of fireworks, and the preparation of compositions. Justices of the Peace were empowered to grant licences to those who wished to make or sell fireworks, and inspectors were appointed to make regular visits to ensure that the new laws were kept. The Act was not perfect, but did encourage many manufacturers to move their businesses out of the back streets, and to set up bigger and safer factories.

C.T. Brock, who started his Crystal Palace displays in 1866, found that the large quantities of fireworks that he now required, necessitated the building of a large new factory at Nunhead. This was built with special regard to safety, and over the next few years Brock carried out a series of experiments concerning this subject. Many basic conclusions were arrived at, including findings on such important issues as 'the liability of fireworks to ignite by concussion or friction', 'whether twenty yards is ample distance to prevent an explosion in one shed communicating to other sheds situated at the statuary distance', or 'the liability of fireworks to explode en masse if from any cause they should be accidentally ignited'. The experiments were witnessed by a Royal Commission with great interest, and the results formed the basis for the Explosives Act of 1875, in so far as it relates to fireworks.

The results of the Act were immediately seen, as the number of fireworks accidents decreased dramatically. Yet, one important clause had been omitted from the regulations, and this concerned potassium chlorate and sulphur mixtures. Sulphur by itself is not very reactive, and even in a finely divided state is difficult to ignite. Similarly, potassium chlorate is a relatively stable compound at ordinary temperature, and only decomposes when heated almost to its melting point of 368°C. Yet, when mixed together, sulphur-potassium chlorate is unstable and is liable to ignite spontaneously or to detonate at the slightest frictional provocation. Accidents from these causes had been prevalent before the 1875 Act and continued to spoil the new safety records thereafter. No less than twenty-eight accidents and eleven deaths due to these causes occurred in the twenty-eight years after 1875. Ironically, the last of these accidents was recorded in Brock's factory, when a man emptying crimson stars from a canvas tray into an earthenware jar, suddenly found that the slight friction involved had been enough to cause ignition. Soon, the whole building was alight, and the man suffered severe burning from which he subsequently died. The authorities at last saw the necessity for a complete ban on all sulphur-chlorate mixtures. Consequently legislation to this effect was introduced by an Order of Council in April 1894.

The Acts of 1860, 1875 and 1894 were so successful in reducing accidents that they still form the basis of the laws relating to the manufacture, storing and selling of fireworks in Britain. Other countries have, of course, made their own laws and in general most have regulations similar to those in Britain as far as the more vital issues are concerned. In spite of the obvious potential danger in working with explosives, the firework industry is now a remarkably safe one, in most countries. Accidents do inevitably occur from time to time, and when they do they tend to be rather spectacular ones, especially when in the form of explosions, sometimes with loss of life. In the East, of where regulations are sometimes lax, until recent times explosions were a frequent occurrence, often with tragic consequences. The Madras accident of 1936 accounted for the lives of thirty-nine people, and the explosions in Macao in the same year claimed twenty-three more. Italy, Spain and

Portugal are now tightening up on their precautionary measures after a bad history of accidents. In Northern Europe the record has been good, with little loss of life. The United States, in spite of all its precautions where the public are concerned, until recently had a factory explosion rate which was much higher than average, although certainly not as high as Latin America, where regulations still seem to be liberal or flouted by manufacturers.

Firework manufacture is an art, but for the manufacturing companies it is also a business. As such, it faces the multitude of problems which confront all other businesses in the modern, competitive commercial world. Above all, the work must show a profit, and with rising costs of materials and transport, increasing wage bills, higher insurance premiums, the escalating costs, expenses of various overheads, the expensive safety regulations imposed by the authorities and the invasion of cheap competition from the Far East, the fireworks business in many countries is facing difficult times. In recent years many countries, small and large firms have been finding it increasingly difficult to fight against mounting economic pressures and cut-throat competition. Takeovers and mergers have often been answers to problems in an age when the big combine can find the capital necessary for mechanisation and organisation in order to hold prices down to competitive levels. Sadly, many of the great pioneering companies no longer manufacture; even Brock's is gone Fig. 1.3.

Brock's Fireworks was founded in about 1700 by John Brock in the Islington Road, London. Ironically, but appropriately, he was buried on November 5th, 1720, but not before he had established the reputation of his company with major displays at the fashionable Pleasure Gardens at Vauxhall and Bermondsey. Later regular shows at the Ranelagh Gardens further enhanced the firm's stature, and the 'Brock's Benefits' and Crystal Palace displays after 1865 already referred to, continued its rise to prominence. 'Crystal Palace', as they became known, moved to new premises in South Norwood in 1877 and such was the need for bigger and better works, that they moved again in 1901 to Sutton, Surrey. Brock's fireworks were constantly in great demand for public and private shows. Their archive records, dating back to the Aix-la-Chapelle Peace display at Kenwood in 1749, list an illumination of the Taj Mahal during the visit of the Prince of Wales in 1875, gold and silver medals won at firework festivals in Cape Town, Brussels and Barcelona in the 1880's, and a display from the Brooklyn Bridge in New York in 1892 to celebrate the four hundredth anniversary of arrival in the Americas. The catalogue is long and varied and includes the Dusseldorf Exhibition display on the Rhine

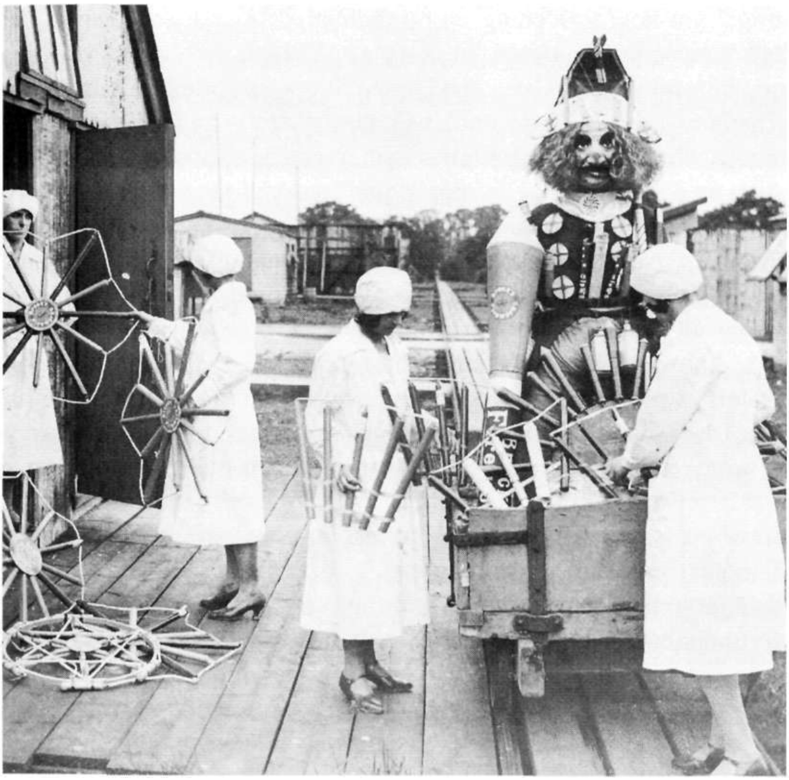

Fig. 1.3 Display Goods and Guy Fawkes Effigy. Early 20th Century. Brock's Fireworks

in 1906, Stockholm Olympics in 1912 and the Peace Celebrations in 1919 in all parts of the Empire. The success had again necessitated a need to expand, and a new factory was built at Hemel Hempstead in Hertfordshire in 1933. This was said to be the largest fireworks factory in the world, covering 207 acres, with 200 buildings, sixty storage magazines, housing, a social club, and playing fields. The Jubilee of King George V was celebrated with huge displays in all the colonies and this highly profitable event was quickly followed in 1937 by the need for scores of shows for King George VI's Coronation. After the Second World War ended, the list continues with Peace Celebrations (1946), the Festival of Britain (1951), the Empire Games at Cardiff (1951), the Prince of Wales's 21st Birthday (1969) and numerous independence celebrations around the

Fig. 1.4 Large Rockets as sold before 1939. Brock's Fireworks

Commonwealth. Meanwhile Brock's continued to benefit from a substantial share of Britain's 'shop goods' market Fig. 1.4 and Fig. 1.5.

In 1956, a subsidiary factory was built at Swaffham in Norfolk, another was later developed at Skelmersdale, near Liverpool, and Wilder's Fireworks were taken over in 1971. But, the great company was feeling the effects of economic pressures and foreign competition, and it must be said, a decline in quality. Brock's was obliged to import fireworks from China and Malaysia; their display business declined. The Hemel Hempstead factory was closed in 1973, and a new one built at Sanquhar in Scotland. By 1987, both Swaffham and Skelmersdale had gone, and Brock's was depending on the manufacture of commercial explosives, especially signals for the army, in order to remain solvent. In 1987 Brock's merged with Standard Fireworks to end an era in fireworks history and share a fate suffered by other celebrated British firms such as Pain, Wells and Wilder.

James Pain founded his company in the 1860's, assisted by the advice

Fig. 1.5 Large shell. Early 20th Century. Brock's Fireworks

and experience of his uncle, a member of a well-known family of pyrotechnists call Mortram. After manufacturing on a limited scale (and suffering several accidents), at Walworth in London, near to the Surrey Gardens, where regular shows boosted their reputation, they soon moved to Brixton and in 1876 were winners of a prestigious prize for manufacturers at the Alexander Palace. The requirements of the 1875 Explosives Act caused a move to large and modern premises at Mitcham in 1877. At about this time Pains also built a factory at Parkville, Long Island, New York, and competed successfully in the American market, producing much appreciated displays at such venues as Manhattan Beach and the Chicago World's Fair. Like Brock's, Pains travelled the world with their typically-British, part-scenic, part-fireworks displays, especially for Royal visits to various countries of the Empire and eventually for Independence celebrations. In 1898 Pains had fired a display in Lisbon to commemorate the four-hundredth anniversary of Vasco da Gama' s voyage to India. Long-standing shows in England included those for the Cowes Regatta and the Alexandra Palace, while smaller displays at various seaside resorts were regular dates for decades.

The progress of the company, however, was not without its financial and organisational problems. During the First World War, the manufacture of military and naval pyrotechnics and Very lights acted as a stimulus to growth, but the twenties and thirties were lean years with only the Coronation of King George VI to provide substantial earnings. The last of the Pain family died in 1926, and his nephews, Philip and Arthur Milholland, took over to steer the business through those difficult times. The Second World War again saw Pains helping the war effort with the production of Very cartridges and wing-tip flares. Peace time brought a return to normal firework production and increased prosperity for the firm. But this was not to last, and in 1963 Pains were amalgamated with WAECO under the direction of the Bryant and May's British Match Company. The take-over meant the closure of the Mitcham plant in 1965 and the transference of manufacture to a new extensive and modern factory at High Post near Salisbury.

WAECO (Wessex Aircraft Engineering Company Limited) was founded in 1933 to make wind direction smoke generators for use in civil light aircraft. As a result of the trade depression, the firm took up experimental pyrotechnic work with the encouragement of the nearby Porton Governmental Experimental Establishment. The company prospered, especially under the direction of Mr E.H. Wheelwright, after 1937. During the War, smokes and other items were made for the Government, but later pesticidal smokes (known as Fumite) and fuses for stage and film effects were added to the list of products. In 1947, Wheelwright launched into fireworks under the Wessex brand name, and with new buildings and modern equipment made large strides. The range of products was completed in 1952 when the Wessex marine signal made its appearance.

Unfortunately, the British Match Company was more interested in military pyrotechnics than the seasonal fireworks trade, and Pains-Wessex ceased to retail fireworks in 1979. Under new owners called Chemring, and incorporating the firm of Schermuly, which had already taken over Wells's Fireworks, the business continues to manufacture signals. In 1980, John Deeker, an ex-director of Pains-Wessex re-established the old name of 'Pains Fireworks' at a site in Whiteparish, near Salisbury, and produces displays using material purchased from other sources in England and abroad.

A third long-established English firework firm was Joseph Wells and Sons Limited. The original company was established in 1837 at Earlsfield and Camberwell in the City of London. Prior to this Joseph Wells carried on the business of Public Decorators and Limelight Contractors. This consisted of decorating the streets, houses and gardens with flags, festoons of bunting, ornamental shields and designs, and little candle bucket lamps and Japanese lanterns. Such service was in great demand for the celebration of weddings and births, and at religious festivals, or for the passage of royalty or other dignitaries through towns. Before the introduction of electric lamps, gas limelights were in constant demand in theatres and concert halls, and also for outside floodlighting and illuminations. Early in the nineteenth century, fireworks became allied to the decoration business, as they were needed to give realistic representation in mystery plays, and were employed in pageants and processions held to celebrate great occasions. The invention of coloured fireworks widened the possibilities of the pyrotechnic art and thus increased its popularity.

The company's expertise in firework manufacture increased rapidly, so that by 1873 Wells won the gold medal for 'the superiority of signal rockets' at the Hyde Park International Expedition. In 1875 they were awarded first place for Roman Candles at the international competition at Alexandra Palace. At this time they were supplying regular displays at both the Cremorne and North Woolwich Gardens. To meet the increasing demand and to comply with the requirements of the 1875 Explosives Act, a new factory was opened at Honor Oak Park in 1878. By 1883 these premises rivalled those of Brock and Pain in their modernity. Such was the reputation of the Wells Company under the direction of Joseph Richard in the years leading up to the First World War that they were known in the trade as the 'Rolls Royce' of fireworks. A huge overseas business had been built up in Australia, South Africa, New Zealand and other countries of the Empire. Wells fired many shows in Europe, and only Brock and Pain exceeded their sales in Britain.

Delight after a series of fine displays for the Earls Court Exposition in 1913 turned to dismay in the following year when war broke out and all firework manufacturers were ordered to cease sales. Fortunately, Wells was able to remain profitable through government contracts for signal cartridges, parachute rockets and smoke flares for the navy. The Peace Day celebrations in Hyde Park featured a huge display to which all the British companies contributed. After a few good years, during which the new factory at Colchester (opened in 1915) supplemented the Honor Oak production, the business suffered during the years of the Depression, along with the whole of British industry. The Jubilee of King George V in 1935, and the accession of Edward VIII, to be quickly followed by the coronation of George VI in 1937, were a 'god-send' to the firework companies. In 1938 a new factory was built at Dartford, Kent, and the Colchester works was closed. Incidentally, at this time, Wells signed a deal with the Disney organisation to produce a special box of fireworks with Disney characters depicted on the labels. These Mickey Mouse fireworks proved popular, but they, and all fireworks, disappeared for several years when World War II broke out. Again the firm turned to the manufacture of military signals. (The Honor Oak works closed in 1947.)

The post war years were boom times for the firework trade and 1953 was all set to be the best of all, with the prospect of a host of lucrative public and private shows during Queen Elizabeth II's Coronation year. But, for Wells, tragedy struck in the form of coastal floods, which swept through the Dartford factory. The firework stocks, which were not insured, materials, chemicals and paper were all destroyed. The other firework companies assisted as best they could with stock, materials and machinery, and Wells were back in business before the end of the year. But the company never really recovered. In 1968 Joseph Wells and Sons were bought out by Schermuly of Dorking; the manufacture of fireworks ceased in 1971. In 1973 Schermuly was taken over by British Match, which already owned Pains-Wessex.

The Dartford factory was bought by John Decker, who, in association with Unwin Pyrotechnics, manufactured display fireworks under the old Pains name. When he, and Wilf Wells, the last Wells director, moved to Hampshire, the old buildings were used by Unwin's, and finally, Astra Fireworks. Thus, sadly, ended another era in the fireworks story.

Besides Brock's, Pains-Wessex and Wells, several other companies were established rather later in Britain, the best known being Standard Fireworks and Lion Fireworks, both based in Huddersfield, Yorkshire. It is said that the Huddersfield trade came about through the use of blackpowder by coal miners in the last century. Certainly where the Yorkshire fireworks industry was concerned, the town of Lepton played a vital part. It was there that Allen Jessop, as early as 1847, enjoyed a hobby of making squibs in his cellar to sell locally for the November 5th celebrations. After the 1875 Explosives Act, records refer to the factory as No. 55. After the death of Allen Jessop in 1880, it appears that the family business was continued under his son, Elliott, until taken over by the Parrett family, who in turn sold out to Standard Fireworks in the 1930s. Two other sons, Humphrey and Eli, started a new business close by, and yet another son, Ben, went into partnership with Harry Kilner, a member of another local firework family, and whose mother was, in fact, the daughter of Allen Jessop. The records show that they were taken over by Standard in 1917. The Kilners probably made the greatest contribution to the development of the industry in Lepton. Originally called the Yorkshire Fireworks Company, they became Lion Fireworks in the 1930s, folding in about 1970. The Shaws were another family manufacturing fireworks in 1865 in the area. They were listed as factory No 32 in 1876 and traded as Globe Fireworks until the 1940s. It is unfortunate that so many of the records of these companies have been lost. The story evolves like a jigsaw with many pieces missing. Yet the scraps of information culled from existing documents and the memories of the decreasing number of people who were directly involved, provide an insight into the beginnings of the firework industry in Britain. Probably several areas spawned similar groups of families involved in firework making, but those of London and Yorkshire seem to have enjoyed greater long-term success.

The one Yorkshire company which earned the greatest acclaim, and which we have yet to discuss, is Standard Fireworks. In 1891; James Greenhalgh started selling fireworks in his drapery business in Huddersfield, obtaining the goods from the Shaw, Jessop and Kilner factories, and having some of these made up with his own labels. He also imported fireworks from China, transporting them to Huddersfield on barges. Almost inevitably, manufacturing began around 1910, when a factory was built in an old stone quarry at Grassland Hill, on the outskirts of the town. Edward and Richard Greenhalgh, together with their sister Kate, were the driving force of the business, which became the largest manufacturer in Europe, employing over 600 people. The Greenhalgh brothers were dedicated pyrotechnists who knew what they wanted and, like all the pioneers, were not afraid to get their hands dirty. Standard competed well with the other main companies for big and small display business, but were probably more renowned for their 'shop goods'. Until the 1980s, Standard dominated the sales of small fireworks, especially for the November 5th celebrations. Ironically, Chinese fireworks, which had helped the business to become established in the beginning, were a major factor in its decline. Cheap imports swamped the market and sales slumped. Standard became a wholly owned subsidiary of the Yorkshire-based industrial and property group Scottish Heritable Trust in 1986. A year later, Standard merged with Brocks. Mr Mel Barker bought the management in 1992, but manufacture ceased in 1998.

Alongside the 'main players', many small companies appear in British pyrotechnic history. We know that Frederick Copley, proprietor of a hairdressing business, was manufacturing in Sheffield in 1841. In 1881, a separate factory was built, and his advertisements included the boast that he was 'pyrotechnist to their Royal Highnesses the Prince and Princess of Wales'.

In the 1790s, Michael and Sarah Hengler were making fireworks to give more dramatic effect to circus acts. Soon they were supplying shows for several London pleasure gardens, including Ranelagh and Vauxhall. After Michael's death, 'Signora' Hengler continued to manufacture, as well as perform on the tight-rope 'amidst a shower of fire', and died dramatically in a fire at her factory in 1845.

Hammond's Fireworks, founded by Thomas Hammond, are known to have existed between 1873 and 1974. In 1890 the company prided itself on being 'the cheapest house for good fireworks', and was advertising packs at various prices from 10s 6d to £20, which were 'ideal for garden parties and children's fetes'.

Michael Riley established Riley's Fireworks in 1844 at Ossett, Yorkshire. The business flourished, and the name became well-known in the North of England, to both retail buyers, to whom they offered 'between 250 and 300 different kinds of fireworks', and the display business. Many northern towns were thrilled by regular displays at galas and seaside resorts, like Bridlington, and for special events like the 1918 Peace Celebrations and the Coronation of George V. It seems that the company did not survive the economic depressions of the interwar years.

Wilder's Fireworks was a well-recognized label before being bought up by Brock's in 1971, after over a hundred years of production in Birmingham. Excelsior Fireworks was founded by Oswald Bradley near Ripon in Yorkshire at the turn of the century, but moved to Southport in Lancashire in 1911. The company ceased trading in 1971. Guy's Fireworks began life as Comet Fireworks at Calverly near Leeds in 1946, the brain-child of a chemistry teacher, Hugh Allen. It changed its name in 1948 and was dissolved in 1957. Wizard was founded by Philip Rose, previously of Phoenix Fireworks, on the disused aerodrome at Chedburgh, near Bury St. Edmunds in Suffolk. It prospered with the sale of a broad range of popular retail fireworks, but also branched out into agricultural devices and distress flares. Wizard special effects were used in major films including *Cleopatra, Bridge on the River Kwai, Battle of the River Plate* and *The Yangtze Incident.* Financial difficulties, particularly affecting their backers, Coopal of Belgium, caused the last Wizard fireworks to be sold in 1962, the factory being taken over by Haley and Weller for the manufacture of Benwell fireworks.

This label made its appearance in 1949, when Ben Weller of the Haley and Weller toy-making company set up a firework factory at Wilne, near Draycott, in Derbyshire. In 1952, the manufacture of signals, flares and smokes was added to the fireworks production. The transfer of the fireworks division from Draycott to Chedburgh in 1965, was followed in 1970 by Haley and Weller becoming part of MY Dart plc, which in 1987 became MY Holdings. A decision was made to cease fireworks production, but signals and other military pyrotechnics are still being made as part of the Chemring Group.

Astra Fireworks was another company which was born and thrived in the boom period for fireworks immediately after the Second World War. Established in 1947 at Bromley in Kent to make sparklers, it quickly gained a reputation and supplied fireworks to both Guy's and Benwells. By the 1970s, Astra had taken over Rainbow Fireworks, which had been established in Berkshire in 1949, and acquired a bigger factory at Sandwich. The company was purchased from its founders in 1980, and experienced personnel from Brock's were brought in. Yet, in spite of improved production methods, bright new label designs and attractive packaging, firework sales dropped and Astra moved into military pyrotechnics. All production ceased in 1992, and the factory was demolished. Astra continued as a trading name selling imported material until 1996.

These brief histories have many common threads. The old pioneering companies, established by families of enthusiasts, have all suffered and died in the modern era of high overhead costs, 'big business' and cheap foreign competition. Moreover, the industry now lacks the 'characters', like Willy Stott of Standard and Jack Lineham of Pains, who learned their trade through years of experience at the mixing bench, in the filling sheds and on the display sites. An example of those who have spent a lifetime in the business is Malcolm Armstrong. He learned his trade under Edward Greenhalgh at Standard. Starting in 1946 by doing jobs around the factory on Saturday mornings, he was put on the payroll in 1950. In 1956 he became factory manager at Guy's Fireworks at the age of twenty-one, and when that company failed he moved to Haley and Weller's Benwell factory, eventually becoming works manager. By the time Malcolm was twenty-six he had moved to Astra where, as general manager, he modernised the company and made it competitive. In the 1970s he became interested in theatrical pyrotechnics and realized that there was a growing market in this field. With Reg Harden, an ex-Brock employee, he set up Theatrical Pyrotechnics Limited, at first in Astra sheds, and later in a new factory at Mansion Airport in 1984. The company is now internationally renowned and has provided material for countless stage productions and a formidable list of epic films, including several James Bond spectaculars, the *Star War Trilogy, Alien and Judge Dredd.* (TPL's main rival in manufacturing effects for the entertainments industry is LeMaitre Fireworks.)

During a period when so many British companies have been forced into mergers, take-overs or extinction, one shining success story is that of Kimbolton Fireworks. The Reverend Ron Lancaster developed his interest in fireworks while a schoolboy in Huddersfield in the 1940s, and gained early experience at the local factories. After originally intending to read medicine, he was ordained into the Anglican Church and, after six years serving as a parish priest, he spent the rest of his career teaching divinity and chemistry as a Chaplain at Kimbolton School in Huntingdonshire (now Cambridgeshire). In 1964 he set up a couple of workshops in his back garden in which to pursue consultancy research for Pains, and in order to finance his fascination for fireworks he started to put on displays at local fetes and carnivals. The business grew quickly and soon scores of displays were being fired all over the country, including prestige shows for the Henley Regatta, Shrewsbury Flower Show, National Trust and English Heritage Events, and for Royal Functions. Ron Lancaster was the firework advisor to the London Celebrations Committee, which organized the Silver Jubilee celebrations in 1977. In 1978, Kimbolton Fireworks put on the display outside Buckingham Palace to mark the twenty-fifth anniversary of the Coronation of Queen Elizabeth II.

In 1988, Ron Lancaster retired from teaching but did not cease his involvement in the fireworks business. A new factory, with modern technology, was built, and the workforce increased. All types of fireworks are manufactured (except rockets), and candles and shells are, as always, Kimbolton's specialities. Taking pride of place among the many awards in the trophy cabinet is the Silver Jupiter won at the Montreal International Competition in 1993. In 1995, the company staged the massive VJ 50th Anniversary display on the River Thames, when 18 tonnes of explosives were fired from five barges, synchronised to the same music over a distance of two miles. To add spectacle to the Handover Ceremony in Hong Kong in 1997, Kimbolton Fireworks fired a huge display over Victoria Harbour. Ron Lancaster was made a Member of The Most Excellent Order of the British Empire in 1992 for his services to the fireworks industry. He still keeps a vigilant eye over the progress of the com-

Fig. 1.6 Two barges being towed up the R. Thames. 50th Anniversary of the End of the War in the Far East, Courtesy Leo Kennedy

pany, but the day-to-day running of the business is mainly in the hands of his son, Mark, while father attends to production and development, and display manager, Dr. Tom Smith. (Fig. 1.6).

Before we leave this survey of British pyrotechnic companies, mention must be made of Octavius Hunt. He lived in a cottage at the end of Dove Lane at Redfield, Bristol. His original occupation is not known, but as early as 1851 he had experimented with the manufacture of matches to the extent that he was able to tour the local area selling them from a barrow. The business thrived, and gradually he bought up the other properties in Dove Lane so that a factory could be built. In 1912 the business became a subsidiary of the Bryant and May Match Company and turned to producing special, hand-made matches, including wind-proof 'survival' matches for the forces, fusees and Bengal matches. The latter, often sold under the brand name of Bronco, were supplied in quantity to the firework companies, since they remain alight in windy or damp weather. In 1936, Octavius Hunt Ltd. started making sparklers, which were sold under the Stella brand name. In 1991, the company was taken over by the Chemring Group. Besides special matches-in fact, it is the only match factory remaining in England- and sparklers, military and pesticidal smokes are the main business. 1998 saw a management purchase by its managing director, Jan Reynolds.

The Italians rightly take a great deal of the credit for pioneering the pyrotechnic art in Europe. One of the first books on fireworks was 'De Pirotecnia' written by Vannuccio Biringuccio in 1540. He describes the huge Renaissance feasts at the courts of popes and princes in the rich cities of Rome, Florence, Naples and Venice and the enormous 'machines', ornamented with a variety of fireworks, which have already been referred to. During the seventeenth century famous architects like Bernini and Buontalenti designed 'machines' representing palaces, gardens and mythical scenes as the bases for pyrotechnic displays. Few names of the fireworkers have been handed down, but in the early 1700s the five Ruggieri brothers became famous for their shows in many European cities, and began a tradition continued in France today. By the end of the eighteenth century, fireworks were being made by hundreds of small groups of workers in villages and towns all over Italy in preparation for a few displays on saints' days and other religious feasts throughout the year. In the 1861 celebrations to mark the end of wars which preceded the Unification of Italy, aerial shells were used. These became the speciality of Italian manufacturers. Some of the families of artisans developed into bigger commercial concerns and remain to this day. Viola of Sicily, Pagano of Naples, Parente and Martarello of Rovigo, Panzera of Turin and Soldi of Florence all derived from a family tradition and represent scores of others. In the south, in Sicily or Naples for example, there may be as many as two hundred tiny enterprises. In the north are now the larger, better organised, capital-intensive factories. Most converted temporarily to military pyrotechnics during World War II, and some, like Coccia of Rome, continue in that field. Because of the strong local traditions, the displays differ widely in their contents and style in different parts of the country. In the north, the wide-fronted, electrically-fired shows are popular, while in the south leisurely, but rhythmical and very noisy, daylight shows are traditional. Many small businesses are under increasing pressure. They lack the finances and technical ability to comply with the stricter laws being introduced, especially by the European Union, to reduce the frequent accidents, both in manufacturing and at public displays. Moreover, it is an increasing trend for young people to seek better-paid, cleaner and safer employment.

A large number of well-established firework companies operate in Germany, many of them making military pyrotechnics as well as display and retail fireworks. As has already been seen, the German states were among the leaders of the Northern tradition as early as the sixteenth century. No doubt scores of small concerns thrived in the nineteenth century, some of them surviving to become the large commercial companies of today. Wolfgang Buchwald, in his superb publication *Feuerzauber* (1996) (41) comments that there were 54 companies in existence in Germany in 1934. Inevitably, World War II, and the subsequent partition of the country, resulted in the demise of several of these, together with the movement of key technicians from one firm to another. Certain areas of the country stand out as important, and it is interesting to note how the availability of the raw materials, such as charcoal and potassium nitrate, had a profound effect on the original location of many companies.

The Hamburg area is a prolific pyrotechnics quarter. The firm of J.G.W. Berckholtz was established there in 1838 and was fortunate to survive wartime bombing. After the War, Wilhelm Berkholtz still owned the company, but it was leased to a Czech technician, Dr. Kustynowitsch, who was able to secure business putting on displays for the British army. Gunpowder was even brought from England for the purpose. The doctor was ambitious and rented factory space with the Burmester company in Trittau and Moog at Wuppertal. Financial troubles led to an amalgamation with Moog-Nicholaus in 1949, and by 1964 a new plant had been built at Quickborn. Unfortunately Wilhelm and his son, Horst, were to become bankrupt in 1975, thus ending a long company history.

The Carl Flemming firm was founded in 1910 as a fireworks company. During wartime it turned to signals manufacture and has continued in that line since, now at a factory at Hornbek. Nico Pyrotechnik was founded by Hanns-Jurgen Diederichs, formerly a colleague of Moog and Nicholaus, in 1949, on the site of the Burmester factory at Trittau. The company has flourished, with the purchase of the old Lünig firm and the securing of a major shareholding in Pyrotechnik Silberhütte. Comet Fireworks of Bremerhaven began in 1953, and now specialises in signals as well as fireworks. It absorbed Rudolf Brandt's Gebrüder Bock company at Trappenkamp.

Further south, in the Rhine Valley, perhaps the best-known German company, Moog, has been in business at Wuppertal since 1916. The present plant was established in 1924 by Wilhelm Moog, in collaboration with his stepson, Dr Fritz Feistel, who later set up laboratories in Berlin, which grew to become the Deutsche Leucht und Signalmittelwerk Berlin. After the War, business gradually recovered, and, after the brief liaison with Berckholtz mentioned above, Moog displays were soon being acclaimed all over the world. In 1949, Moog was joined by Heinrich Nicholaus and Dr Feistel. The latter also helped the Meissner company to found Standard Pyrotechnik Mannheim, which later moved into a new factory at Schwegenheim, with Wilhelm Schübel as manager. The factory closed in 1982. (Incidentally, Dr Feistel's son, Fritz, who was also a chemist, set up the Feistel factory at Göllheim in 1960, producing all types of fireworks and signals.)

Heinrich Nicholaus was the son of Adolf Nicholaus whose firm, founded in 1921, had made toy fireworks and sparklers at Meiningen. During the war they manufactured signals and with the departure of the Americans from Türingen in 1945, the family had moved to a refugee camp at Aalen. When Adolf died in 1949, Heinrich transferred to Moog, but the Nicholaus logo, a red cockerel, Nico-Hahn, became a part of the new firm Pyrotechnische Fabrik Hans Moog-H. Nicolaus.

The great annual pyrotechnical event in Germany is known as the 'Rhine in Flames'. Since 1955 a series of displays and other events has taken place along the river near Koblenz in August, in front of huge crowds. As the country's leading fireworks manufacturer, Moog invariably fire these shows. Klaus Moog took over the company in 1971, but financial worries forced him to sell out to the Piepenbrock Group of Osnabruck in 1981. The latter also absorbed the Feisel concern at the same time.

The Weco company, in Eitorf, prospered under the ambitious policies of their leaders, and Hermann Weber originally from Nicolaus of Meiningen was honoured by the State for his contribution to post-war industry. He died in 1993, but with Frank Weber-Pickard at the helm the firm is buoyant. It was an early importer of Chinese fireworks, has interests in the UK and in 1989 bought the firm of Wicke of Hattingen, which had manufactured since 1866. In 1990, with the cooperation of Zink Fireworks, Weco secured a major investment in Sachsenfeuerwerk, located near Freiberg in Saxony.

The Harz area has for long been associated with black powder and fireworks. Gunpowder was made in the area in the eighteenth century, and the firm of Eisfeld was established near Harzgerode by 1855. Fireworks of all sorts were made over the years and great efforts were made between the two World Wars to improve the technical ability of the manufacturers. The company became famous for its fine displays at Nürnberg. As many as 700 workers were said to have been employed in military pyrotechnic manufacture during World War II. By 1973, fireworks were again in production under the name of VEB Pyrotechnische Fabrik Silberhütte.

Sometime in the middle of the nineteenth century, a firework business was set up at Cleebronn in Wurtemburg. It seems that one Oscar

Fischer, who kept an inn and a grocery store, bought the factory in 1883. Financial problems caused Fischer's son to set up his own factory on Lake Constance. Certainly at one stage early this century money was injected by the Eisfeld company, and in 1929 it became part of a group which changed its name to 'Depyfag-Deutschen Pyrotechnische Fabriken'. The factory at Cleebronn must be one of the most picturesque anywhere. Situated on a hillside among vineyards, it was greatly extended during World War II, and over 600 workers were employed. Special lifts and conveyors had to be installed because of the steepness of the slope. After the war it was purchased first by Dynamit Nobel AG and later by Buck Werke in 1992, the manufacturing being transferred to Uftrungen.

This was not the end of the fireworks story in Cleebronn, for a new company had been created in 1949 by Paul Zink, who had been a foreman with the Fischer concern at Lake Constance. Walter Zink, the son of Paul, now runs the company, and is a very practical man, with a high reputation for making high quality fireworks, especially rockets. He also has a financial interest in Sachsenfeuerwerk of Freiberg.

The Lünig family were making fireworks at Stuttgart at the beginning of this century. Artur Lünig founded the firm, which has built up an international reputation for big, spectacular displays, the most recent of which was designed by Matthias, a member of the fourth generation of the family. The firm went into partnership with Nico Pyrotechnik in 1992.

Clearly, as in all countries, in Germany the old family firms have often been forced by financial circumstances to close or to surrender their independence to survive. It is therefore refreshing to record the firm of Fritz Sauer of Gersthofen, north of Augsburg. Founded in 1854, the firm has seen good and bad times, but is still under the direction of the original family.

The history of fireworks in Spain and Portugal is still largely unexplored. It appears that, as in so many other aspects of technology and philosophy, Iberia benefited from both the Christian and Muslim traditions during the Middle Ages and the Renaissance. Gunpowder and its uses were introduced by the Arabs at an early date, but fireworks as we know them probably arrived from Italy in the sixteenth century, and were used extensively for civic and religious ceremonies. At that time, guilds of coheteros (rocket makers) are often referred to and there are records of examinations to become a Master of the trade.

Today, three firework traditions can be recognised. In the Galicia Province of North-West Spain and Northern Portugal, pyrotechnists have developed rocket-making to perfection. The large examples (cohetones in Spanish, foguetões in Portuguese) are propelled by two motors tied to a four-metre long bamboo cane, and can lift a kilogram of stars to an enormous height. They are fired singly with flights of several dozen smaller rockets interspersed. The almost silent launching of the rockets, and the release of shooting stars covering the sky, give a unique effect. Unfortunately, the rising cost of skilled labour, more stringent safety regulations and the availability of shells from other parts of Spain and abroad, has caused a dilution of the foguetão tradition, and many factories in the area are now manufacturing a range of fireworks. Gabriel Rocha, the leading Galician pyrotechnist, still sells large quantities of his famous big rockets, including some with parachute effects, to other Spanish companies. In Portugal, the Silvas at Viana do Castelo and the Fernandes at Lanhelas, Minho, were the leading manufacturers. The former company is no longer in business, but the Fernandes are thriving and are famous for their intricate set-pieces.

On the Mediterranean coast, in Valencia and Catalonia, a large number of companies produce very spectacular shows using the whole range of firework types and effects. The displays are called castells, or castles, perhaps as a relic of the 'machines' of the past. Igual is the foremost Catalonian firm and won the contract to fire the display which opened the 1992 Olympic Games in Barcelona. In Valencia, the Caballer family, whose members run three competing firms (Pirotechnia Caballer, Ricardo Caballer and Miguel Zamorano Caballer), and the Brunchu concern, founded in 1809, are leading companies. 'Pirofantasia', recently formed by Bernado Sanchiz and Miguel Gonzalez, presents displays in a modern, innovative style. Also in Valencia, the Jurado family companies (Garuda and Pirotechnia Arnal) and Pirotechnia Turis, under the direction of Caspar Lopez and Vincente Domingo, are thriving concerns.

In Central Spain displays show elements derived from both the Western and Eastern traditions. Pirotechnia Zaragozana from Saragossa, run by the Perez Sanz family, had early beginnings and is a major exporter.

The regular international competitions are important to the progress of Iberian companies, since they introduce new ideas to the industry. The San Sebastian contest, started in 1964, is the most prestigious, but others are staged at Alicante, Blanes and Bilbao, while the more local competition at the Valencia Fair in July has been an attraction for over a century.

France has a very long fireworks tradition. The Ruggieri family emigrated from Italy in the seventeenth century, and the company now known as Ruggieri Artificier, manufacture in Monteux. They, together with Lacroix of St. Etienne, established 1848, still dominate the industry in France. Other French firms are Berastegui and Rollet of Angouleme, Davey Bickford of Rouen, Guerard Pyrotechnic of Saint Laurent Brevedent, Legoux Artifices of Tourville-en-Auge, Maurel Pyrotechnie in Pertuis, and Marmajou, who have been manufacturing at Dax since 1889. But many of the smaller firms are disappearing fast in response to foreign imports. 70% of sales are made for Bastille Day on July 14th, the biggest displays being at Paris and Carcassonne. 15 to 20% are fired at the tourist resorts in the summer and about 10% for New Year's Eve. As in most advanced countries, shows are increasingly accompanied by music, lasers and water fountains, and electronic firing devices aid synchronization.

In 1895, legislation was passed in Sweden to make the manufacture and displaying of fireworks safer. This effectively eliminated the long-standing and widespread practice of casual firework-making in kitchens and sheds around the country. So, at the end of the nineteenth century, there were six firework factories in Sweden, all of them small family concerns. C.R. Hansson had been making fireworks for a couple of years when, after three months experience at the Pains factory at London, he started his own factory at Gothenburg in 1888. Hansson's displays were famous around Scandinavia until they were forced to cease fireworks production in 1983. The company still makes distress flares under the name of Norabel Hansson.

The Hammargrens, starting as tobacconists in Gothenburg in 1879, began to import German and Italian fireworks at the beginning of the twentieth century. The business expanded, and they started their own fireworks factory in the 1920s. Financial problems caused it to close down in 1992, but the company survives as an importer and wholesale dealer of 'shop' goods.

Sadly, the third major Swedish company, Tomer's, which was started in Stockholm by A.R. Torner, an officer and teacher at the artillery fireworks corps, in 1880, was forced to close in 1972. Thus, the recurring theme seen throughout Europe is suffered in Sweden. After the lucrative, palmy days of the fifties and sixties, craftmanship and skill have given way to mass, cheap imports and commercialism.

Gunpowder came to Denmark in the middle of the fourteenth century. The first recorded display took place in 1559 for the coronation of King Frederick II. He was so much a fireworks enthusiast that he had a book on the subject printed especially, and exclusively, for his son, who became Christian IV, at the age of eleven, when his father died in 1588.

The book remains at the Royal Museum in Copenhagen, complete with notes in the margin written by Christian himself. Under the building which now houses the Library, is a building called the 'Svovlhuset' (Sulphur House) where Christian often made fireworks himself, a hobby which was referred to in his funeral address. For his coronation, Christian had a massive display at Castle Kronborg, Elsinore, consisting of 80,000 pieces, and for the wedding of his son in 1634, another huge show was arranged.

On August 15th, 1843, a fireworks display helped to open the famous Tivoli Gardens in Copenhagen, and regular shows have been fired ever since. At present there are two each week, with a special celebration on the opening night anniversary. The first Tivoli pyrotechnist was C. Hoegh-Guldberg, an amateur craftsman who later, in 1865 and 1867, recorded his skills and experience in a two-volume publication. The Hoffman-Barfod family had learned their fireworks skills in Austria, around 1800, before moving to Denmark. They started producing the Tivoli displays in 1938 and still make all the fireworks at their factory near Roskilde. Happily, because of the regular business, Lars Hoffman Barfod, has been able to withstand the competition from the East, which has ruined other Danish firms. Verner Poulsen, a former employee of the Hoffmann-Barfod company, has founded a successful factory near Ringsted to manufacture indoor fireworks.

In the eighteenth and early nineteenth centuries, chemists and pharmacists in the Netherlands earned themselves extra income by using their knowledge to make and display fireworks, in spite of frequent accidents. Among them were the founders of companies still operating today: Schuurmans of Leeuwarden, founded in 1821, 'Kat' of Leiden (1823), and Ruysch of Utrecht.

Early in the nineteenth century, Mr Schuurmans kept a small general stores and made squibs, fountains and firecrackers for local sales. His son set up a small fireworks factory in 1821 and supplied the neighbourhood with material for celebrations on New Year's Eve and for private weddings and parties. The reputation of the business grew, so that in 1896 Schuurmans obtained the right to supply fireworks to Queen Mother Emma and later Queen Wilhelmina. In spite of several factory explosions and fatalities, and the problems posed by two World Wars, the company survived until the boom years after 1946, although the Schuurmans family had given up the management of the firm. (Mr P.A. de Bruin took control between 1937 and 1998.) Following a familiar pattern, signal cartridges for the Ministry of Defence became important in the 1940s, and in the 1960s large-scale importation from China became more profitable than manufacturing in the Netherlands. The business is now a public liability company, a section of which, called JNS Pyrotechniek, directed by Hein Hofmeester, has recently set off many spectacular displays, with musical accompaniment, including the show for the fifth anniversary of the European Technology Programme in Rotterdam in 1991, and award-winning spectacles in Canada in 1991 and 1995.

The Hendrickx brothers have, for long, dominated the fireworks trade in Belgium, although the spread of Antwerp is threatening their factory site. Van Cleemput of Brussels has ceased to manufacture. In Switzerland, Hamberger of Oberried, Bugano of Neudorf and Muller of Kreuzlingen are well-respected names, as are Leibenwein and Pokorny in Austria. Jakob Hatteland operates in Norway.

Details on fireworks history in Eastern Europe are hard to come by. Certainly black powder was known in Russia in the fifteenth century, and in 1674 rockets and firecrackers were used in a display at Ustyug. Peter the Great was an enthusiast and displays were made obligatory at every state occasion and festival during his reign. His fascination led him to set up his own workshop to make pin-wheels, rockets and lancework. In 1693, introduced by a fifty-six-cannon salute, he is said to have put on a huge display which included a portrait of Hercules prising open the jaws of a lion, all in lancework. Much is written about the advances in firework technology brought about by Professor Lomonosov in the 1750s, including the means of making green stars. This period saw great advances in Russian pyrotechnics. Set pieces on the vintage Brock scale, measuring 300 feet long by 150 feet high are described. In 1855, the Mikhaylovskaya Artillery Academy was founded as a scientific centre for research into military technology, and pyrotechnic research was also performed there. Fireworks manufacture and firing was under the control of the military authorities until the Communist regime, when the fireworks detachment of the Ministry of Internal Affairs took over. Spectacular displays regularly celebrated national days in all the main cities, and there were impressive shows for the 1980 Moscow Olympics. Since the demise of communism, the situation regarding fireworks manufacture is unclear. Russian Joint Stock Company, directed by Vladimir Popov, manufacture in Moscow.

Fireworks are known to be freely available again in the shops of the Czech Republic, especially for 'Silvestr'—New Year's Eve—celebrations. This tradition was suppressed during the communist regime, when shows were allowed only to commemorate socialist anniversaries. The state-operated Zeveta Bojkovice concern had the monopoly of sales. This business now trades as an independent company known as Pyros Zeveta Bojkovice, along-side others like Konstructa Trencin and ZVS Dubnica. The companies have invested in publicity campaigns inviting people to buy fireworks throughout the year to celebrate festivals and personal anniversaries in an attempt to boost sales, and to meet the competition from the familiar Chinese imports.

Pyros Praha was, until 1975, part of Konstrukta Trencin and specialised in research and production for the army. It was then created into a separate state-run enterprise and branched out into manufacturing special explosive effects for films and television. With the removal of communist control, Pyros Praha, like other former army products manufacturers, including Explosia semtin, Policske Strojirny Policka and Zbrojovka Jablunka, had to solve the problems involved in the transition from military products to civil ones, and to secure markets in a competitive commercial world. Pyros Praha started to manufacture fireworks. Sadly they were forced into liquidation, but the staff have high hopes of creating a new company.

Fireworks were introduced to the United States by immigrants. As early as 1608, Captain John Smith remarked in his history of Virginia that rockets had been let off, terrifying the Indians. In 1731, regulations to restrict their use in Rhode Island were imposed after one, Benjamin Thompson, was injured making fireworks to mark the repeal of the Stamp Act. In 1783, a large display in New York, viewed by George Washington, celebrated independence from Britain. The Fourth of July became, of course, the country's chief firework day. The first American book on fireworks, 'A System of Pyrotechny', by Professor James Cutbush of the West Point Military Academy, was much influenced by the British army officer, Captain Robert Jones, who master-minded many early displays, and French experts like Ruggieri. The earliest known manufacturer of fireworks for pleasure in the USA was the Du Pont family near Wilmington, Delaware in 1809. The business thrived until the 1940s and continued to supply powder for the industry until the 1970s.

In the nineteenth century, many American manufacturers were branches of European companies. Masten and Wells of Boston and Manhattan Beach Fireworks were established by the English firms Wells and Pain respectively. Later in the century, H.P. Diehl and A.L. Due thrived close to the King Powder mills in Cincinnati. At this time Italian immigrants brought new technology, especially for the making of multi-break shells. The Gruccis from Bari based in New York, and the Zambellis (now in New Castle, Pennsylvania) and Rozzis (now in

Loveland, Ohio) both from Caserta, are still major companies. Chinese immigrants organised imports from China, especially fire-crackers, at an early date. The Communist authorities broke off trade in 1948, but fireworks continued to move through Hong Kong and Macao, and from firms in Taiwan. In 1972, new trade links were established between the USA and the People's Republic of China and vast quantities of fireworks, of low price, but often dubious quality, began to flood the market. Zambelli Internationale claims to fire nearly 1500 shows around the country on each July 4th. Almost every major city puts on a spectacular show on that day, the most notable being around the Washington Memorial in Washington D.C., off the Esplanade at Boston, on the lakefront at Milwaukee and the Macy's show in New York. New Year's Eve is the second most popular time for displays, and then there are innumerable shows for state fairs, feast days, and regular or one-off local celebrations. The Venetian Night at Chicago, the Cincinnati 'Riverfest', and the 'Harborfest' at Newport, Virginia are notable displays.

Regulations have inhibited the US fireworks industry since the beginning of the twentieth century when, after a series of accidents, some of them fatal and some concerning children, vigorous anti-fireworks campaigns ensued. A combination of restrictive legislation and economic depression in the 1930s caused many firework companies to close. Some turned to making military pyrotechnics during World War II, but afterwards even more restrictive laws destroyed much of the market. Moreover, the regulations differ from state to state. Added to this burden is the increasing amount of litigation when accidents occur. Ridiculously high monetary awards are made to successful claimants, no award of costs is made against unsuccessful plaintiffs, attorneys' fees are huge, and liability insurance premiums have escalated, and are sometimes unobtainable. The manufacturers' plight is deepened by the increasing invasion of both 'shop' goods and display fireworks from China, Taiwan and Japan. Probably as much as 85% of fireworks fired in the US comes from the Orient.

As one would expect, displays have benefited from innovative technology. Music has become a familiar part of shows, with companies such as Austin Fireworks becoming famous for its 'Concert in the Sky' performances. Computerised multi-switch firing boards are commonplace. The 2 million dollar 1986 Statue of Liberty display in New York used 40,000 shells fired electronically from barges. The Disney theme parks, in Los Angeles and Florida, are probably the largest users of fireworks in the US, and have invested in equipment which propels shells by compressed air rather than gunpowder.

There is increasing demand for fireworks in the USA, but high production costs, together with the problems outlined above, have caused many firms to go bankrupt and others to cease manufacturing in order to organize shows using imported materials. Some of the best known companies, apart from those mentioned above, are Precocious Pyrotechnics of Belgrade, Minnesota, directed by Garry Hanson, and the Rozzi family business in Lowland, Ohio.

Hands Fireworks are the leading manufacturers and display company in Canada. In 1873, William Hand emigrated from England, with pyrotechnic knowledge acquired in employment at Woolwich Arsenal, and set up a firework factory in Thorold, Ontario. His first public show was for the 'Whit Monday' public holiday at St Catherines, on May 25, 1874. This was the beginning of a catalogue of Tyro-Spectaculars' which were produced almost every year for half a century. The shows were massive, involving not only fireworks on a grand scale, but large casts of actors, acrobats, jugglers and marching bands, performing in front of colossal sets over 500 feet long and 50 feet high. The epic themes included 'The Siege of Sebastopol', 'The Last Days of Pompeii', 'The Taking of the Bastille', 'Cleopatra' and many commemorating events in Canadian and world history. The final items included a barrage of high level fireworks and huge lancework set-pieces depicting The Mapleleaf and 'God Save The King'. The displays took place regularly at Toronto, where over 120,000 would watch the ten or twelve sell-out performances in any one year, but also at large festivals in the USA and other main Canadian cities, including Montreal, Quebec, Hamilton, Winnipeg, Ottawa and Halifax.

In 1875, Hand moved from Thorold to Hamilton to satisfy the need for larger premises. A partner, Walter Teale, died from a fatal explosion in 1900, and a year later William Hand failed to recover from burns in another factory accident. His son, known as TW, took over the running of the business. In 1919 the company bought up a small concern called Great West Fireworks in Brandon. By 1930, the Hamilton urban area had grown so much that the fireworks factory had to move. By purchasing the small Dominion company in Cooksville, Hands acquired a large rural site for a new factory and the considerable technical experience of Dominion's former owner, Dominic Carson. TW died in 1931 and his sons, Hugh and Bill, guided the firm through the War years, when military pyrotechnics were manufactured, and into the boom time afterwards. Urban sprawl caused yet another move in 1963, this time to Papineauville. Although the Hand family sold the business in 1977, the company is still called Hands Fireworks Inc. Under the leadership of Richard Brown, the firm makes military pyrotechnics, smoke signals and rescue flares, theatre maroons and unique 'polar bear scaring devices', as well as a large range of fireworks. Government legislation, which has virtually prohibited the importation of Chinese material, has helped Hands and other Canadian companies to maintain sales and quality.

Other Canadian manufacturers include: Ampleman Pyrotechnics of Montreal; Blue Smoke Fireworks of Calgary; GSH Pyrotechnics; and Specialised Pyrotechnics; which acquired the factory at Kenilworth when Canadian Fireworks expired in 1997. The Butchart Gardens in Victoria are now famous for their use of fireworks and the prestigious international competition is organised by La Ronde in Montreal each year.

There must be hundreds of fireworks factories in Latin America. Certainly Mexico has a strong fireworks tradition. It is estimated that more than three thousand festivals each year use fireworks there, many of them featuring the 'castells' of Eastern Spain. Besides the innumerable local fiestas, the two national festivals—Independence Day in September and the day of the Virgin of Guadalupe in December—are celebrated across Mexico. Articulos Pirotécnicos Mexicanos of Mexico City, Fuegos Artificiales La Union/Azteca Fireworks of Guadalajara and Lux Pirotecnia are well-known company names. In Brazil, Caramuru of Sao Paulo are the only manufacturers left after the effects of the Chinese 'invasion', both in Brazil and in terms of reduced exports to Canada and other South American countries.

The best-known name in fireworks in Australia is Howard's. Sydney Howard experimented with compositions in his spare time and, after firing small shows for the local community, set up a factory at Eastwood, New South Wales, in 1922. Five years later they moved to bigger premises at Waterloo Road, Epping, NSW. Son Harry joined the business and soon the company earned a high reputation all around Australia, displaying at agricultural shows and in the big cities for major celebrations. Following the usual practice they made military pyrotechnics during the Second World War, after which they returned to the manufacture of commercial fireworks, with Harry's sons, Leslie and Sydney, joining the firm. In 1965, a modern factory was built at Box Hill, NSW, and this site had doubled in size by 1980. A successful excursion by Leslie and his wife into the importation and sale of Chinese 'shop' goods was thwarted by government regulations banning the sale of 'shop' goods in Victoria in 1982 and in New South Wales five years later. This legislation also put an end to that area of Howard's business.

In 1985, Sydney left the company to set up his own firework business called Syd Howard Fireworks International, in competition with the established company which then became known as The Original Howard and Sons Pyrotechnics. The latter has enhanced its reputation with displays for independence celebrations of Nauru, Fiji, Soloman Islands, Vanuatu and Papua New Guinea. Scores of displays marked the bicentennial of European Settlement in Australia. Prestigious awards were won at the international competitions in Toronto and Vancouver in 1991 and 1992. Howard's fireworks are sold widely in the USA and used extensively at the Disneyland theme-parks, and the firm is rightly proud of its traditions. Also in New South Wales, Foti's International Fireworks of Leppington, are successful manufacturers and displayers.

The first firework manufacturing in Japan was probably about 1620, although displays were performed there before that date. It is said that the word 'Hanabi', the Japanese for firework, was used in 1585 for the first time. 'Hana' means 'flowers' and 'Bi' is a softened sound for 'Hi' which means 'fire', and 'Flower of Fire' is the Japanese name which corresponds to the word 'Fireworks'. It is recorded that in 1613 a messenger from James I of England put on a fireworks display for Ieyasu Tokugawa, the founder of the Tokugawa government, although it is uncertain whether the fireworks were introduced into Japan by the Dutch or the Portuguese, together with fire-arms, at about this time.

In 1659, Kagiya, the famous fireworker, began his work in Edo (now Tokyo). In 1733, the renowned displays on the River Ryogoku in Edo were originated in commemoration of a Buddhist service for the many victims of a cholera epidemic in 1732. The fireworks were fired from ships, and the displays took place more or less annually until 1963.

In 1810, another famous fireworker, Tamaya, left the Kagiya concern and set up his own factory. However, in 1843, the Tokugawa government ordered him to remove his factory from Edo, after the outbreak of fire, for which he was responsible. Firework factories developed in many other parts of Japan, under the patronage of feudal lords.

For a long time Japanese fireworks were made only from black powder, but in about 1880 the introduction of potassium chlorate from Europe allowed coloured flame compositions to be used. Another milestone in Japanese firework history came when Gisaku Aoki introduced the double-petalled Chrysanthemum in 1926, and two years later, in the fireworks display to celebrate the enthronement of the Emperor, Aoki displayed a triple-petalled Chrysanthemum, with the centre of the flower in red, the inner petals in blue, and amber round the edge. After this, multipetalled Chrysanthemums were widely developed, and became the country's most representative firework. Japanese manufacturers are also noted for the very large shells they produce. A thirty-six inch diameter shell takes many weeks to make and may contain several layers of stars and smaller shells.

A large percentage of the fireworks produced in Japan used to be exported, but this is no longer the case; the bulk of them are used internally. This is because they require so much expensive hand labour that the finished products are very costly. There are many small manufacturers of shells which sell their products to the larger companies or to exporters. Marutamaya Ogatsu is possibly the largest company with an international reputation for exporting and displays. The original factory at Fuchu near Tokyo may date from the seventeenth century, but the present site is in the Yamanashi prefecture.

Hosoya used to be a name respected for shell production, but the company now concentrates on signals and commercial items like golf balls which issue a stream of smoke when struck. The Koa company is another well-known signals manufacturer, having dropped its fireworks division. As with Europe and America, Japan imports considerably from China and Taiwan, but unlike Europe, there are still over a hundred large and small companies, such as Koa, Sunaga, Mantsuma, and Aoki. Fig. 1.7.

China is usually considered the birthplace of black powder and firework making. Hundreds of factories supplied material for displays celebrating religious festivals and public events, and fire-crackers, fountains and candles marked family births, marriages and funerals. Ironically, all large displays were banned during the years of communist austerity, although exports were encouraged, especially through Hong Kong. Recent political changes in China have meant that many manufacturers are now allowed to invest private capital and trade unhindered across the world. Certainly, China leads the world in the volume of production and export. A large number of small companies, especially in the Guangdong, Guanxi, Hunan, Jiangxi and Hebei Provinces, feed the large exporters and display companies, which operate under such group titles as Temple of Heaven of Beijing or Red Lantern, and brand names like Sunny, Vulcan and An Ping. As has been made clear, the invasion of cheap Chinese fireworks into almost every firework manufacturing country, has had profound effects on domestic production, often to the extent that little remains of the list of original companies.

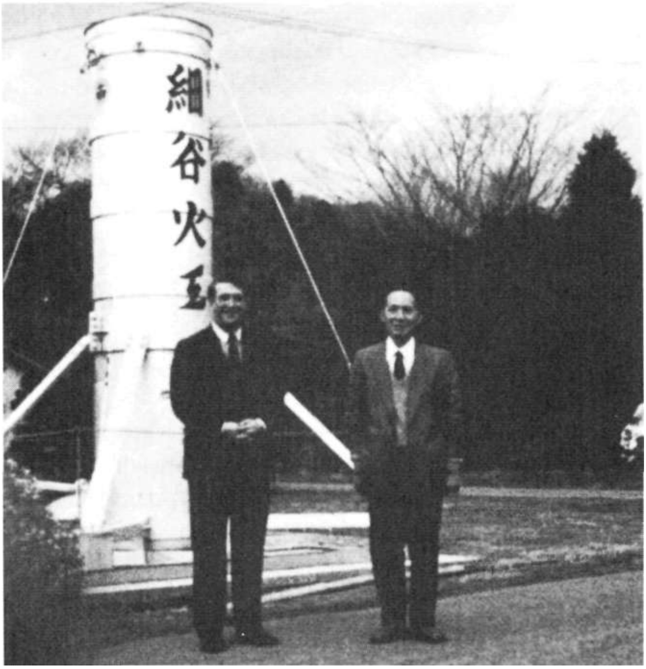

Fig. 1.7 Ron Lancaster and Takeo Shimizu at the Hozoya factory in Tokyo.

Taiwanese shells are now respected and are familiar additions to many displays. San Tai Fireworks, Mantsuna and Wan Dar supply many of them. Displays take place during the Moon Festival in August, during the Chinese New Year in February and for the birthday of a Buddhist deity called Ma Cha in May.

Early records in India refer to a display in 1443 in the Mahanavami Festival. Today, fireworks feature in the numerous Hindu ceremonials, especially The Festival of Lights in October, and at Hindu weddings. There are scores of small producers across the country and a few large factories, like Standard Fireworks, Sri Kaliswari Fireworks, Ravindra Fireworks and The Arasan Fireworks Factory, which was established in 1937 and boasts that it is 'one of the leading manufacturers and exporters of KUIL Brand Fireworks Varieties to South Africa, Finland, Italy, etc'.

There are a multitude of small differences between the products of manufacturers in different countries, and indeed within the same country, which probably few but the experts would notice. The vast majority of spectators at displays will be thrilled by certain effects and take away a general impression of the presentation as a whole. The expert will see much more. He will know through experience what the manufacturer was attempting to achieve with a particular firework, what some of the problems would be and to what extent success has been achieved. The experienced worker would be able to compare objectively the quality of the colours of stars, the efficiency of the rockets, or the spread of a shell burst. He would notice whether rockets and shells had burst before the zenith had been reached or after, and whether candle stars had been blown high enough or landed burning on the floor. Pyrotechny is obviously a potentially dangerous pursuit in which, unlike most other hobbies, few can 'dabble'. Hence the number of enthusiasts and experts must be small. Better communications have led to an easier exchange of ideas and information between them, and international festivals and competitions, like those at Montreal, Bilbao, Cannes, San Sebastian and Hanover, encourage this interchange. Where insularity may have perpetuated localised characteristic effects and styles of presentation in the past, intercommunication tends to diminish this tendency.

Sadly, the number of true experts and enthusiasts has been eroded dramatically over the last few decades. In these pages we have traced the demise of the bulk of the old-established companies in almost every country. The effects of mounting production costs, government safety regulations and especially the relentless 'invasion' of cheap goods from China and Taiwan, have caused business after business to turn to military pyrotechnics for economic salvation or to become importers and distributors of material from the Orient. Moreover, scores of concerns, often run by individuals who have no expertise or background in firework manufacture, have sprung up to share in the increasing market for 'do-it-yourself packs and organised displays. Indeed, the escalating cost of fireworks and deeper concern over safety, have brought greater demand for large shows.

In fireworking, progress used to be thought of in terms of creating new effects. By experimentation, a new chemical composition might produce an original star colour or noise effect, or a new shell burst or set-piece pattern might be achieved. Today, progress is measured mainly in terms of the spectacle that can be accomplished with the use of vast quantities of fireworks, sophisticated electronic firing devices and the enhancement that musical accompaniment and lasers can give to a show. With so few manufacturers left in many countries, fewer young people are learning the skills of a successful pyrotechnist. There are, therefore, many question marks over the future of the industry, but, without doubt, while fireworks remain so popular as the perfect spectacle for celebration, all over the world, displays will continue to be fired.

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2

FIREWORKS DISPLAYS EARLY EVOLUTION TO THE MODERN APPROACH

A PERSONAL VIEW

Mark Lancaster

Much of this book is dedicated to the principle and practice of the manufacture of fireworks, which in general remains much as it was 50 years ago. Perhaps the only exceptions to this would be the introduction of limited automation, together with the use of some of the more modern chemicals, such as the chlorine donors helping to improve colour. Despite this, fireworks manufacture can be considered a mature process which has experienced few fundamental changes in recent years. The same cannot be said for the manner in which we fire displays, the methods of which have advanced significantly over the same period with the introduction of electronic firing systems and new lighter weight firing equipment.

In this chapter, initially using the UK as the example, I would like to look at how the method of firing displays has changed in recent years and how to some extent, especially in larger displays, traditional methods have been abandoned to be replaced by a more generic global approach. Finally, almost as exceptions to prove the rule, I will look at four countries, that to some extent have resisted this pressure of change and stuck to their traditional way. In so doing, these countries provide a refreshing change to much of what can be seen today.

EARLY DEVELOPMENT

In the modern age, entertainment is piped to us in our own homes and the options available to us make our leisure time relatively easy to fill.

This was not the case 100 years ago, and certainly in the UK, much time was spent at the 'pleasure gardens', the earliest of which was founded as long ago as 1750. There were several in London, principally at Vauxhall and Ranelagh, then later and more famously at Crystal Palace and Belle Vue in Manchester. The pleasure gardens are long gone, the only traditional one remaining being the Tivoli gardens in Copenhagen. It was, however, these gardens that provided the first permanent sites for frequent firework displays, which in London became fashionable around 1870, when the Brock family first seized the opportunity presented by the increased patronage at the Crystal Palace site.

The advantage of the permanence of these sites did much to establish the early character of British firework displays. By modern standards they were quite incredible in their extravagance. At the core of each display were elaborate set pieces, the likes of which are never seen today. These could be 28 metres high and run to an average length of 60 metres, though this could be extended to over 180 metres. Considering the unpredictability of British weather, I marvel at the thought of how exciting it must have been to see on these great frames, the reenactment of the Battle of Trafalgar, the Eruption of Vesuvius, or indeed the great transformation pieces. The work involved to make these pieces must have been immense, the manufacture of thousands of colour changing lances, together with half length lances and the enormous time it must have taken to assembly such pieces. I envy my father who saw perhaps the very last display of this type when he was a boy, performed by the Brock company at Crystal Palace shortly after the war (Fig. 2.1). Perhaps the only modern equivalent, and much smaller in scale, would be some of the transformation pieces used as part of the Mexican Castillo.

The displays held at Belle Vue in Manchester immediately after the war captured much of the style of the time. On the site itself was laid a set of steel rails, similar to a train track, which led at either end to massive wooden sheds. Here the various Lancework pieces, such as the typical wild west bar scene, or replica locomotive, could be prepared and stored, protected from the elements, ready to be rolled out immediately prior to their use. Another characteristic of these shows was the 'Weird White Waterfall', The Belle Vue site had a wire cable from one end to the other, along the length of which could be strung a waterfall. Each stick had it own ignitor and at either end were two mighty maroons and two enormous benzoate whistles of approximately 30mm bore. On ignition everyone jumped with the bang, then squirmed

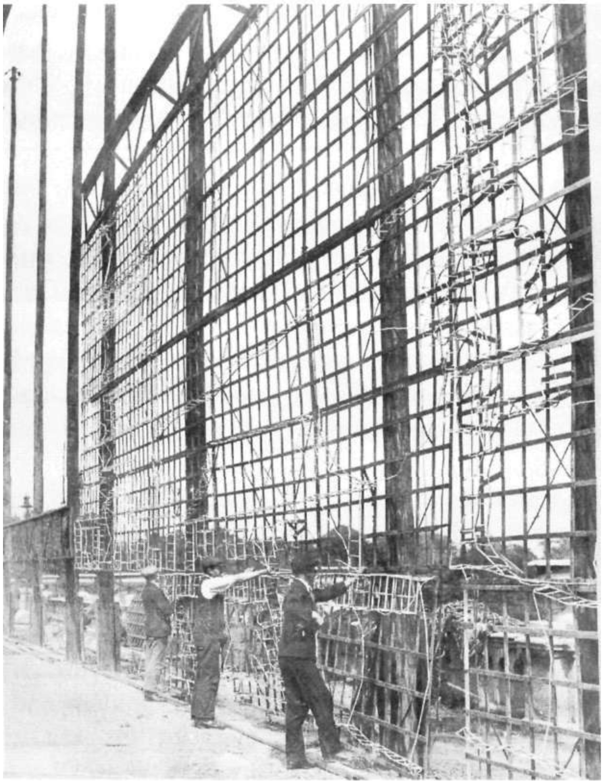


Fig. 2.1 Erecting Lancework at the Crystal Palace. London. Brock Fireworks

from the interaction of the two powerful whistles. The whole display had the degree of care and preparation that we sometimes lack today. It was not uncommon for even small displays to take up to three days to prepare on site, with a special marquee being erected for this purpose. Much of the work which we now do before we leave the factory took place on site, with many of the lancework frames being prepared from scratch.

Rockets were among the more frequently used traditional British fireworks which accompanied the magnificent lancework. Indeed if truth be known Brock's for one were not very skilled at shell making. Rockets seem to have been frequent trouble-makers over the history of displays. Perhaps this is one reason why, apart from Spain and the magnificent examples to be found in Portugal, they are infrequently used in modern displays. (As I write, following this year's ban on the sale of star shells to the general public in the UK, their popularity has staged something of a comeback.) In earlier times, rockets were a very important feature of any display in much the same way that they are used in Spain. The English rockets were big, usually with a bore of either 18mm and 24mm. These rockets were fired in groups but unfortunately, as we know, out of all fireworks which are projected into the sky, the rocket provides the greatest of dead weights to fall back to land. When fired in such volume, this inevitably presented a problem. This partly explains their demise in use at large public displays, the other is perhaps the relative inaccuracy of timing when firing a large number at once. A mass of flight rockets is a unique effect and, where we can, we do still use them, though alas the opportunities are becoming ever scarce. Roman Candles were also a feature of many displays; they provided careful tapestries and mosaics of colour, which could be done by the use of long tailed comets and the careful placing of the candles along the full width of the site.

Another traditional British firework which has lost favour in recent years are the Set Pieces. Normally stuck on top of a 18 foot wooden pole, they comprise just about every static ground piece imaginable, and their use overlaps with the magnificent lancework devices mentioned earlier. Wheels, Saxons, and Gerbs, all forming differing mosaic patterns, have always been a firm favourite with children and offer an interesting and different alternative to much of the aerial effects of displays. They are, however, both susceptible to the weather and difficult to waterproof, as well as being laborious to construct. They also suffer from being difficult to see by all but the first few rows of an audience. They are another traditional firework of which we see less and less in all but the more traditional country fair type show. The main exception to this rule, and one of the reasons for its inclusion in this chapter, is their use in Malta, where the variety and quality of the examples produced must be among the best in the world.

THE MODERN DISPLAY

Having identified the traditional elements of a British firework display: Intricate Lancework Devices, Set Pieces, Rockets, Roman Candles and Star Shells, it is interesting that perhaps only the last two are still extensively used and can be seen at all of our current displays. The other types are still used, depending on the site. The modern display often has to perform to audiences of much greater size than those of the past, which also can restrict choices in the use of some types of firework.

Perhaps the biggest factor in shaping our modern displays has been time. Despite an ever greater increase in facilities designed to make better use of time and cut the length of time needed to achieve various tasks, it seems to become an ever more precious commodity. The majority of our displays are now rigged and fired on the same day. The majority of the fusing and preparation takes place in the factory, long before the display site is ever reached, leaving only the final assembly and placing of Roman Candle barrages and racks of mortars into their positions on the display site itself. Gone are the days when marquees would be erected on site, and great teams of men would spend several days in preparation. Even a relatively large show can now be prepared by just two or three men in a day. Certainly the electrical firing of displays helps, but even now it may come as a surprise to some that we still fire smaller shows by hand. (As it happens, electrical ignition is not new, there are records of it being used to initiate the 'Royal Portraits' which were fired from the royal box at Crystal Palace as early as 1879.) The great long trenches that were once dug to bury the mortar tubes are no longer required, and we have recently replaced all of our firing stock with new, lighter, easy-to-handle fibreglass tubes. The new working practice is now so accepted that I even hear groans from our display operators if they are asked to erect simple lancework saying 'GOOD NIGHT'.

The basic formula for our modern displays relies Roman Candles and star shells. In its simplest terms, the Roman Candles are set out along the width of the display site and fired continuously to form the basis of the display. Star Shells are then fired over the top of the Roman Candles to add power and variety.

Roman Candles invariably burn for approximately 45 seconds. (Naturally, if required they can be made to burn for a shorter period, by varying the number of shots. It is however more difficult to have them burn longer, because of the limitations of the tube). The length of the duration of the Candles is used to stipulate the length of each of the different 'sequences' of the show. Imagining the area of the sky where the display will be fired as a picture frame, the Roman Candles will tend to occupy the full width of the frame, and the bottom third of its height. The nature of Roman Candles, allows the creation of an enormous range of patterns in this area, by carefully positioning frames and using long burning stars which leave trails. The Mosaics or patterns are perhaps the greatest characteristic of modern British style shows. Probably the biggest mistake is the overuse of Candles, where the sky is too full and the result is a mass of stars forming no pattern at all.

Comet Candles probably are used more because of the precise effect they produce, rather than the slightly more random results of a Bombette Candle.

Except in the largest shows, Star Shells are not fired continuously, as seems to be the pattern for a modern typical North American display. Clearly it is down to taste, but using Star Shells only seems restrictive, as you are forced to rely purely on the variety between the effect of the shells, and lose the added dimension that the use of Roman Candles can give. I accept, of course, that in some situations the site and audience dictate that it is almost impossible to use anything other than Star Shells, e.g. Hong Kong Harbour. Normally we use Star Shells in the last 20 seconds of a 45 second sequence, colour coordinated with the Candles. We start with smaller calibre shells, say 3" in diameter, in large numbers, slowly building up to the larger calibre shells, though we rarely fire anything larger than a 10". Often the last shell of a sequence, timed to fire as the Roman Candles finish is long burning, acts as a bridge to start off the next sequence. (It is interesting that many Japanese feel that the optimum size for a star shell is in fact 8".)

Back to our imaginary picture frame, it is important to try to vary the show as much as possible. By using the Roman Candles, the base third is always full, but with differing patterns. The top two thirds are full sporadically, the central third being filled first by smaller calibre shells, then slowly the upper third is filled as large shells follow. It is always possible to elevate people's feelings to great heights in a show, but very difficult to keep them there, which is why this variety in effect is so important.

From a colour perspective, the show is split into the same 45 second sequences, each one of which is colour coded, using some of the traditional combinations, violet and green, red and silver, blue and yellow. More recently however, we have begun trying to use some of the newer in-between colours we have developed, such as turquoise, lilac and citrons. Sequences may be overlapped with a transition along the spectrum, i.e., from citron to green. The rule we do try to enforce is that we will only succumb to the dreaded multicolour sequence at the finale. In our experience, it is all too easy to end up with a messy 'salad' of colours which allows you to show off nothing to its best effect. Another mortal sin is to have a wonderful Golden Willow Shell completely obscured by brighter low level fireworks. By the end of the show, we aim to have used each of our effects once, but once only.

Perhaps the greatest trend of recent years has been the introduction of the pyromusical. I would estimate that 65% of our total shows, and nearly all of our summer shows are now accompanied by music, which offers many advantages and adds an extra dimension to the show. When attempting to play with the audiences' emotions, much can be gained with the addition of music. There is now a growing culture, in Britain at least, of audiences eating a picnic on the grounds outside a stately home or castle in England, listing to a classical orchestral concert live. Then at dusk, the last piece, normally something original like the 1812 Overture, is accompanied by fireworks. The potential of this style of show is enormous; quieter moments accompany Roman Candles, and as the music grows, so to do the star shells, ending in a tremendous cacophony of sound light and colour. Performed well, it can be a wonderful sight.

Anyone will tell you that the synchronisation of a firework display to a live orchestra is not easy, a conductor never plays the piece at exactly the same rate, (often I'm convinced this is out of spite, as they normally resent the presence of fireworks distracting the audience from their beautiful music.) It is not surprising then, that most of us prefer to fire to a DAT recording which can at least be relied on to be consistent in its timing. By some, I am sure that we would be considered antiquated, but we still rely on a manually operating electrical firing system and have yet to entrust a computer to fire the show. Notwithstanding this, we spend considerable time working out our firing cues, for which we do use a computer, but I remain cynical about need for the millisecond timing computers can offer. Damp November nights do strange things to computers and pyrotechnical delays alike and, apart from enjoying the sanctity of ultimate control, sound and light do not travel at the same speed. We still rely on the audience to do 50% of the coordination for us. This is, of course, helped by the initial careful selection of music.

THE MODERN GLOBAL DISPLAY

If people read the above and wonder why I feel it uniquely describes a typically British display, when in its broad form, it could also describe a typically French, German, Italian, Dutch, Canadian or American display, this is precisely my point. There is little doubt that nearly all of the large important international displays held around the world are very similar in style, whoever performs them. This was a point drummed home to me in 1997, when I saw three of the largest displays I have ever seen all performed in Hong Kong over a period of three months. One by Kimbolton Fireworks, one by an Australian company and one by an American company. Whilst different in detail, they were the same in style. The site had something to do with this, but not everything. It clearly exemplified the ever increasing generic style of firing firework displays, particularly with the heavy, some might argue over-reliance on star shells.

Firework makers have always been guarded over what they consider to be their own formulas and production method. Some even delude themselves that they are unique in what they do. The reality is, of course, that individual development has been replicated simultaneously in different factories all other the world. Many of the skills and production methods individuals feel are unique to them, are in fact duplicated by others. It is true that formulas and working practice are not identical everywhere, but based on the guiding principles that we are all forced to follow in fireworks, strong similarities are inevitable. This said, there is little doubt that if you travel the world you will see an enormous variety of quality in the fireworks produced. It is after all, much easier to produce a bad blue star than a good one. Indeed, not every factory has the advantage of a hydraulic press and carefully gauged increment board enabling it to produce consistently performing fountains, but clearly some practices are better followed than others.

The exception always proves the rule, and perhaps one area where development has genuinely continued independently until recent years with interesting results is China. Here, after so many years of isolation, some unique and different effects have been developed and it is only in recent years that we in the West have been exposed to them. The intricate toy fireworks are good examples as I doubt if there is any factory in the Western World which would have the time or the economic inclination to make such pieces.

The modern world no longer allows people to work in isolation. People are exposed more and more to other people's products, and the exchange of knowledge is probably greater now than it ever has been. In the last twenty years we have begun to attend conferences, such as those organised by CANMET in Canada, where knowledge has been shared by those around the world. From a safety point of view, this exchange of information must be a good thing, as unsafe working practices such as the Chlorate/Sulphur admixture problem are slowly being superceded by safer ones. It would be wrong of me to suggest that the first edition of this book helped precipitate this process, but I know that it was felt by the author at the time that the greater the common knowledge, the potentially safer our industry would be. He always used to add with a wink though, that he'd not put all his best formulas in print.

In addition to the production process, to a greater or lesser degree, the same evolution has occurred in public display of fireworks. With some noticeable exceptions, which we will look at shortly, we are slowly moving away from national characteristics in the performance of firework displays to a more generic approach. The exchange of production methods has been mirrored by an exchange in display methods. The growth of international firework competitions such as those held at Montreal, Toronto, Stockholm, Cannes and San Sebastian have given a much greater opportunity to display operators around the world to examine the various techniques available to them. In the early days this must have been a good thing and the contrasting styles were often the source of the genuine interest for the competitions. I feel to some extent this is no longer the case and we are in danger of adopting a more prosaic generic approach. This is partly an understandable consequence of organizers of competitions insisting on a basic format for displays if their duration and the site available for the display to be fired), but factors channel styles into an acceptable generic format. I doubt, for instance, if the site or the audience at La Ronde in Montreal would really allow the intricacies of a Mexican Castillo to shine.'

A second factor which has led to this convergence of styles is the products themselves. The economic situation in the world has slowly forced more and more firework factories around the world to close and resulted in an over-reliance on Chinese material. (Certainly in the UK, firework factories after the war could be counted in the teens; now Kimbolton Fireworks is the only one still manufacturing display fireworks.) With the production of fireworks so heavily dependant on manual labour, it is an understandable consequence, but it is also a mistake. One day the economic advantage enjoyed by China will be eroded and the existing market segment for distinctive national fireworks will grow. The concern is of course, common to all craft industries. Once a factory closes and the knowledge is lost, it can never be regained without an enormous degree of effort. This over-reliance on Chinese material has naturally resulted in shows looking the same. Unfortunately, a Chinese 3" Peony Shell is going to look the same wherever it is fired in the world. It is no coincidence that in the examples at the end of this chapter, those countries that have resisted this globalization of style, have all retained a healthy national firework manufacturing base.

Traditionally, firework displays were performed by the manufacturers of fireworks themselves. Clearly it is not the case today, as by far and away the majority of 'firework companies' to be found in the telephone book have never even added a lifting charge to a shell, let alone manufactured one in the strictest sense of the word. In their defence, with the dominance of Chinese fireworks, this is inevitable. Since the majority of advancement in the firework world has been in the display side of the business, it can be argued that the displaying of fireworks is now an entirely separate skill. It is, however, a contributing factor to the slow erosion of individual national style. I feel that it is still an advantage to understand and participate in the manufacturing process when it comes to designing displays, for only with the thorough understanding of a firework that comes from its manufacture can it be put to its best use in a display. There is little use in designing a show that relies on split second electrical ignition if you fail to appreciate that a cold damp November 5th night is likely to add several hundreds, if not tenths, of a second to the delay fuse of a large star shell. On the basis that they are now separate skills, I hope people will forgive me if I now draw a slender line between a true pyrotechnist and a display operator.

The majority of firework displays around the world were traditionally linked to religious festivals. Indeed, in all of the examples I cite later where there is still a strong pyrotechnical style this is still the case. In recent times of course, certainly within Western Europe and the USA this is no longer the case. Countries still have their national days but it is corporate clients that now dominate and with them a certain style of show. Whilst doubtless November 5th is still our busiest single day for firework displays in the UK, the volume of business is dwarfed by the demand over the summer for corporate product launches, balls, pyromusicals and other such events. Any corporately driven event must conform to various requirements, normally for it to be short and sweet, resulting in an all aerial display of relatively short duration where it can be difficult to impress the audience with anything less than a massive array of colour and noise. This requirement contributes to further eroding that distinctive national style of event.

To a degree, it is at the smaller displays where national style can still be easily displayed and I would not wish to be accused of painting with too broad a brush. I cite here four examples of countries which still retain a strong independent identity in the techniques they use when displaying their fireworks. These are by no means the only examples; Portugal with its enormous rockets could just as well be used as an example, though at this time I have chosen just these four. However, it is interesting to note that, where distinct character has remained, it is often due to the close ties the events still have to religious festivals.

It seems that the modern corporate dollar has to take much of the blame for the erosion of tradition.

SPAIN

The typical Spanish Firework is perhaps the easiest to identify of all European fireworks. What it lacks in finesse, it makes up in power. Star shells are a good example. Unlike the Japanese, who rely on layer upon layer of paper on the outside the shell to provide the resistence before breaking, the Spanish rely on brute force, literally exploding the case and forcing the stars out at high speed. The result is characterized by a slightly ragged burst, but one of intense power and tremendous noise. Spanish shells have always appealed to me, not least because they are invariably of a single colour and provide an interesting, if expensive, alternative to Chinese products. We have had a long association with Spain and I remember well the passion that seems to go into every Spanish display I have ever seen. The brutal power of a display is matched by the fast and furious pace with which it is fired. If the French are the figure skaters of the firework world, then the Spanish are the ice hockey players, as their displays rely on tremendous volume and power and are designed to literally stun the audience. Displays are primarily aerial based, and with the exception of the Mascleta, little use is made of ground effects, though Roman Candles and Mines are used to supplement the large spherical shells. The Spanish are also masters at making interesting cylindrical effects shells, many of which seem to culminate in some form of noise!

The Spanish also make considerable use of small flight rockets. Normally with a diameter of about 14 mm, these are fired on mass, either from large metal cones or bins. The effect is stunning, but the flight of the rocket tends to be erratic, with one shooting off on the horizontal towards the audience. It is perhaps not surprising then that the Spanish audiences seem to treat the potential risk of injury of going to a firework display as one of the hazards that you accept by your attendance. One only has to witness the melee in any Valencian square at the Mascletas to realise that the principal reason for going is a love of fireworks, rather than to make a claim against the display companies' insurance.

The majority of Spanish displays at home revolve around religious festivals. Perhaps the best known of all the Spanish festivals is the Fallas de Valencia, held in the city over six days, normally during the third week of March. In an age when our bureaucrats seem determined to legislate the British Firework industry out of existence, this festival makes our Guy Fawkes day appear like a public safety demonstration. My first experience of the festival was in the early Nineties, when I went with my father. My first impression was one of astonishment, as the Valencians simply seemed to be prepared to set fire to their own city. From the first night, whilst fire crews stood by, flames sprouted upwards and the ancient streets disappeared into clouds of sparks and smoke, signifying that the start of perhaps Europe's greatest single firework festival had flared into action.

The origins of the festival are blurred, the word itself appears to stem back to the period when Valencia was occupied by the Moors, having its origin in the word 'facula' meaning firestick or torch. Records dating back to King James I mention 'falias' or bonfires to mark civic occasions, such as a royal birth or visit by a neighbouring monarch. Dating from the 16^{th} century, the region surrounding Valencia is also famed for its celebration in honour of Saints John and Anthony, by the building and consequent burning of high pyres or 'fogueres i fogates' in January and June of each year. It is known that these 'fallas' were simply barrels filled with firewood and tar, placed on top of a pole and painted, at first with grotesque designs, and later, with a hunch or 'buito,' the epitome of the modern paper-mache figuerines that can be seen in the modern festival. (Figs. 2.2, 2.3)

Fig. 2.2 March Fallas. Valencia, Spain

Fig. 2.3 March Fallas. Valencia, Spain

The modern festival within Valencia itself seems to owe its origin to the Valencia's Guild of Carpenters. At the end of winter, cleaning up their workshops of shavings, useless pieces of wood and other left-overs, they choose to celebrate on the eve of the day of their Patron Saint, Saint Joseph. Over the winter months, the carpenters worked using their lanterns or 'cresols' suspended from wooden candelabras to light their work during long winter nights. This item was then burnt on the bonfire on Saint Joseph's day, as it was no longer required. The festival grew and the community added all of their own unwanted items to the carpenters' bonfires to celebrate the 'Falla de Saint Joseph'. In time the satyrical spirit of the Valencians resulted in the dressing up of the torches with a jacket or pair of trousers. Slowly the grotesque effigies began to form.

Each district of the town now produces its own 'fallas'. Initially each was made spontaneously by the community, but as competition between districts to produce the best effigy has increased, a more professional approach was adopted. As early as 1903, districts had advanced to using wax to sculpt the hands and face rather than simply using gloves and a mask. Now artists specially employed by a district will first make a sketch, followed by detailed models of the proposed work. Once the idea is approved by the district committee, proper work begins with the making of plaster of Paris moulds for the various figurines. Still very much a community job, work on each of the fallas can take up to a year, with up to two hundred artisans involved, not to mention the countless painters and casual labourers. The results can be enormous. The statue in Figure 2.4 is over 80 feet high. Traditionally, all the fallas were burned at the end of the festival, but since 1935, by popular demand, the fallas voted the best each year are saved from the fires and exhibited all year round in the Monteolivete Museum.

Considered a working class festival, and despite being originally shunned by the middle classes, it was almost inevitable that the effigies would soon be used as a medium to poke fun at those in authority. The winning effigy in 1996 came from the Velluters quarter, the old silk district. Their model, at 105 ft, was apparently one of the largest ever seen. Entitled 'Outlaws', it ridiculed Spanish political life, corruption and injustice. Desperate Dan, cowboys, a pig, and a vulture all played their part in conveying the message. It was said to have cost the district over £70,000 to complete.

During the week of the fallas no one sleeps. In the city, streets are packed with hundreds of small girls and women processing towards the Plaza de la Virgen and a 30 ft Virgin Mary to whom they deliver flowers. Leading each district is their fallera, the queen of the district who will compete for the title of fallera mayor, the queen of the fallas. The processions are impressive, with everyone dressed in traditional Valencian costumes passed down through generations. But the real stars must be the effigies themselves—remarkable towering paper mache political statements, often with a heavy dose of satire and rich in sexual innuendo. (Figs. 2.4, 2.5, and 2.6).

As the sun sets, the marching bands hot up and drums get even louder, echoing around the city. The climax of each evening is the firework display fired promptly at midnight on the banks of the river in the centre of the city. Traditionally over four evenings, a different company fires each display. Whilst not technically a competition, there is little doubt that rivalry is fierce and little heed is paid to budgets. Historically each of the displays was fired by a Spanish company, though on occasion an overseas company has been invited to fire one of the displays. It is a relief, that despite economic pressure, the majority of the fireworks used are still Spanish in origin. A heavy emphasis is placed on single colour sequences and novel effect shells, invariably ending with gratuitous noise. They are capable of making excellent bright colour stars, but both their Roman Candles and Star Shells are characterised by the golden trail left behind both in the break and the black powder delays of Roman Candles. The Valencians are a knowledgeable audience and you are left in little doubt as to their views on

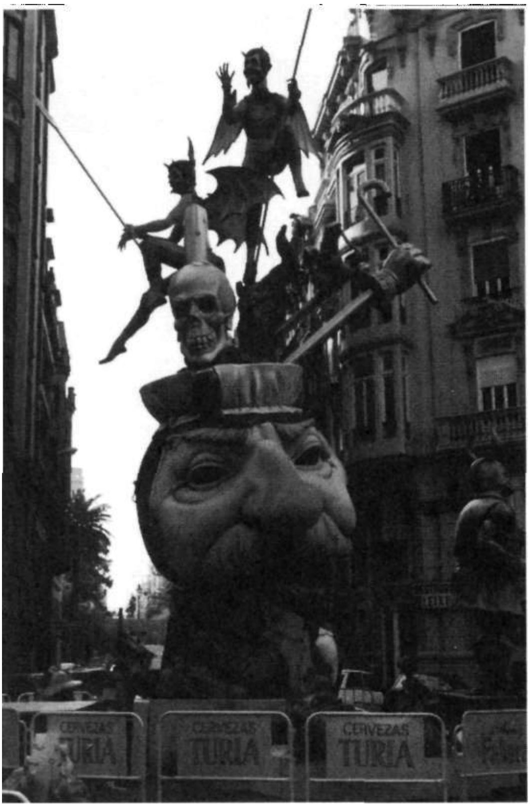


Fig. 2.4 Paper Sculptures ready to be burnt. Valencia Fallas. Spain

any particular show. It is not that they cannot appreciate some of the subtleties in colour and effect that fireworks can offer, but one feels their appreciation of a display is directly related to the noise it produces.

MASCLETA

As if to confirm a love for noise, every morning of the festival your slumbers are interrupted not by a chorus of chirping birds, but by the 'despierta' (a chorus of firecrackers proclaiming that the days festivities are about to begin). As if unable to wait until midnight for their next dose of noise, crowds flock to the towns squares for the daily 'mascleta' at 2 p.m. Probably the most famous Mascleta occurs in the Plaza del Ayuntamiento. Mascletas are simply strings of firecrackers

Fig. 2.5 Paper sculptures ready to be burnt. Valencia Fallas. Spain

of all shapes and sizes, woven on wires stretched across the square. The power of this event is indescribable. Pregnant women are advised not to attend. Without doubt this event is the scariest sight I have ever experienced in my time. Over 200,000 people crammed into that square to watch thousands of these Mascletas fired around them. The crowds love it and burns seem to be taken for granted. Once started, you feel for ten minutes as if the world is about to come to an end. It took four days for my hearing to recover.

The origin of Mascleta is thought to have been in the use of gun salutes honouring the start of civic or religious celebrations. The 'Masclet' itself was a small tube of approximately 4 inches long with a diameter of 1 inch. The tube was baseless, being fired vertically on its bottom using the ground to provide the resistance. The loud noise was

Fig. 2.6 Paper sculptures ready to be burnt. Valencia Fallas. Spain

produced by the heavy confinement of the blackpowder using plaster plugs. These devices were relatively easy to make and their sequential firing gave birth to the modern mascleta.

Further development occurred with the introduction of potassium chlorate flash mixtures, allowing for large bangs to be produced without the confinement, resulting in modern mascleta being prepared in flimsy cardboard tubes. Old gunpowder trails have been replaced by modern blackmatch connecting each banger. (Fig. 2.7)

The basic principle of performing a mascleta display has remained unchanged through the years. It is born through a combination of sounds through time, attempting to keep a distinctive rhythm. The show itself can be split into three sections: the beginning, main body and the end.

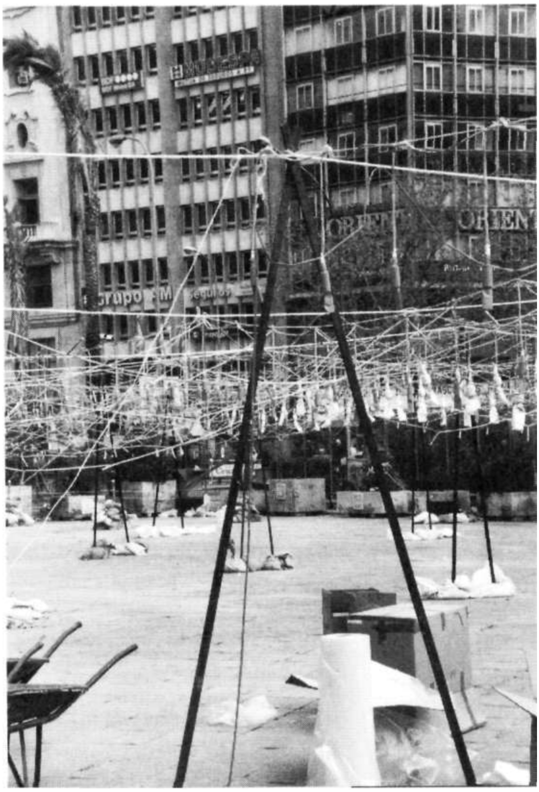


Fig. 2.7 Mascleta-March Fallas. Valencia, Spain

Beginning

Traditionally, the beginning consisted of at least ten aerial maroons to mark the start of the display. In modern times smoke whistles and hummers have also been added.

Main Body

The main body consists principally of the ground based elements of the show, the long strings of mascleta held on wires at head height, allowing their sound to reverberate of the floor. The fast tempo gradually increases to the 'traca final' or 'earthquake'.

End

Coinciding with the last effects of the main body of the show, the display heads to the air again, with a series of explosions which are of greater frequency than those on the ground. The frequency gradually slows, but as it does the power of the explosion increases, until the deafening finale.

Of all the European countries, it is perhaps Spain which has maintained much of its unique character in its use of fireworks.

MEXICO

Mexico is a country obsessed with fireworks. It has a strong tradition, with estimates of over three thousand festivals using fireworks every year. Probably the largest of these those fall on September 15th, Independence Day, and December 12th, the day of the Virgin of Guadalupe. Not surprisingly some of the largest displays are held in Mexico City, where thousands of spectators gather in the central square for the annual display. Away from the city itself, probably one of the best known for its pyrotechnical attraction, is the town of Zumpango, about 70 kilometres north of Mexico City where every year on the 8th of December the feast of the Immaculate Conception is held. The event takes the form of a fiesta where several different local companies take part. Whilst not a competition in the strict sense of the word, it is none the less highly competitive with the honour of producing the best display highly sought after. The Mexicans share a love of noise with their Spanish cousins. Their displays, however, take a considerably different form. Mexico is renowned for its ability to produce some of the most delicate and intricate fireworks to be found anywhere in the world. At a time when labour costs are soaring, it is a credit that they have continued to dedicate the many hours necessary to produce the delicate and highly engineered pieces that adorn their 'castillos'.

Without doubt the most important and central part of any Mexican display is the 'Castillo', the Spanish word for castle. The exact date this unique pyrotechnical tradition was started is unknown. It is believed that the Spanish brought it with them around the middle of the 16th century. With this in mind, it is not surprising that the Castillo holds much in common with the Spanish 'fallas', both share a similar heritage and role in acting as the focal point for the festivities and subsequent display. (Fig. 2.8)

The Castillo is a structure between 15 and 20 metres in height, and resembles an obelisk. Other types based on poles and triangular structures can be found around Mexico, but the obelisk is the most common. Traditionally it is built of wood, but in recent years aluminium ones

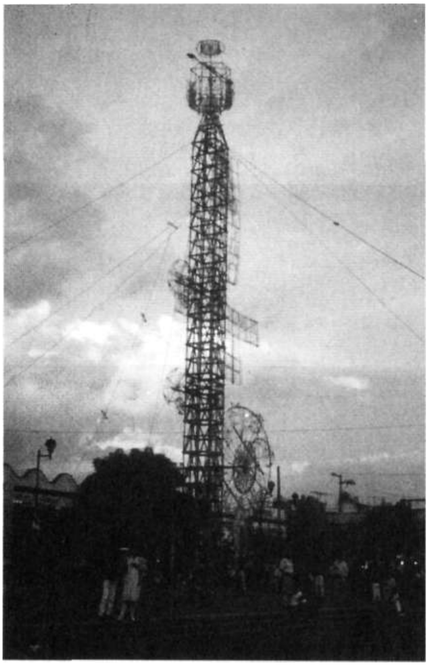


Fig. 2.8 Mexican Castillo. Courtesy David Hall

have begun to be used to aid the construction process. The Castillo is laborious to construct. Up to ten people performing different tasks are needed in its construction, with the average assembly time being three to four hours for factory prefabricated examples. The construction sequence begins with the transportation of the pieces to the place of the show. Larger communities have their own dedicated firework teams called 'coheteros', and local semi permanent Castillos. This feature alleviates the need for transportation and allows the building of more complex pieces, some of which can take several days to construct. The various elements of the Castillo are assembled and anchors are placed at the four corners to stabilise it. A complex series of ropes are used to place the various wheels on the frame and each segment is slowly added from below, forcing the structure ever higher. Each segment is traditionally secured together by 'lazos' a special tarred string. At the top of the frame, and perhaps the most important element of the Castillo is the crown, which acts as the finale to the display. Once the main body is in place, the various lateral or side wheels are put in position. Finally, the most delicate part, the massive wheels, which can be up to 12 metres in diameter, are placed in front of the whole structure.

The wheels are incredibly elaborate and can burn for several minutes. They are masterpieces of pyrotechnical art that rely heavily on pyrotechnical delays to transport their fire from one effect to the next, and the centres bear some resemblance to the old English transformation pieces.

The modern aluminium Castillos have enabled the Mexicans to manufacture bigger wheels, still the core to many of their displays. Another advancement in recent years has been the use of electrical ignition. Negating the reliance on pyrotechnical delays as has been the practise of the past, electrical ignition has helped synchronisation, but has also eroded some of the skills necessary in controlling the display through the ingenious use of these natural timing devices. The 'Castillo' is formed by an assembly of wheels of different arrangements which are then set off symmetrically, together with arrangements of several types of Gerbs, Fountains, Pinwheels, Cascades Mines, Roman Candles and Girandoles. Perhaps some of the cleverest and unique fireworks are the 'Tenedores'. Best described as a collapsable string ladder, they consist of lances secured to each end of a small tube. Each tube forms the step of the ladder and the strands are then gathered together in a bundle and secured to the Castillos. Once lit, the lances ignite, burning their tethering and allowing the ladder to drop down to form a row of lights. These often change colour, and by careful placing and separation of these lights, different patterns can be formed on the 'Castillo'.

Tradition dictates the order of the display, which normally starts at the base of the tower. Sometimes more than one tower is used, with two smaller structures on either side of the taller central one. Initially the lower lateral wheels on either side ignite and slowly the fire spreads upwards to other elements. Next, the larger central Castillo wheels ignite. Often these have colour changing lances to add to the effect. The core of the wheels contain differing images of, say a lancework Virgin, which will then be replaced by a second image as the time fuse passes to another set of lances. The climax to each Castillo is the lighting of the corona on top which takes off into the air. After a short pause, the finale moves away from the Castillo with the firing of Star Shells of differing calibres to bring the display to a dramatic and noisy conclusion.

A traditional effect at many Mexican displays is the 'lluvia' or rain. Similar to, but not quite the same as a long burning glitter, these stars are transported skywards either by the large 'voladora' wheels or rockets. At their apex, the lluvia is ignited and proceeds to float earthwards with its distinctive trail. It is common for this rain to be accompanied

Fig. 2.9 Mexican Fireworks. Courtesy David Hall

by a mass of maroons, giving a heart-stopping experience common to many a Mexican display.

The Castillo is the core of all Mexican displays and is normally accompanied by 'toritos' or bulls. Toritos are wooden constructions embedded with a variety of small wheels and crackers often carried by children. Highly dangerous by our standards, these children proceed to roar about the square dancing and weaving through the spectators' leaving a trail a chaos behind them. More affluent villages may also have a massive waterfall strung along structures in the town square. Invariably most festivals are concluded with an aerial barrage of large calibre Star Shells. (Fig. 2.9)

Whilst all Mexicans seem to share a love of fireworks, no two Mexican festivals are identical; many are based on castillos, but there is also considerable regional variation. Far from Zumpango, there is a festival at San Miguel in the centre of the country, where up to ten castillos are built and are purported to be the largest seen in the country. In the South, there is a unique festival at the village of Chiapa de Corzo, where mock Spanish galleons carry out sea battles with a blaze of fireworks.

JAPAN

Japanese star shells are generally regarded to be among the best in the world. It is the perfectly spherical bursts, bright colours and accuracy of the colour change stars that are the hallmarks of a high quality Japanese shell. The manufacture of these shells is dealt with in Chapter 23, and I do not intend to dwell on it here.

Japanese displays are unusually long by Western standards, with shows taking between one and two hours, but apart from the shells themselves, probably their most unique feature is the manner in which they are fired.

There are in principle two different firing methods for Star Shells: ordinary shooting and quick shooting. We shall look at each in turn.

Ordinary Shooting

This basic method relies on a mortar tube very similar to the one used in the West, but differs in the system of ignition. In the West we are used to a bag of gunpowder lifting charge to be secured to the base of the shell, from which a leader of piped match fuse extends over the brow of the mortar. To initiate the shell, this fuse is lit by a portfire which in turn transfers the fire to the lifting charge. Alternatively, a squib or electric ignitor may be placed directly into the bag of lifting charge.

This is not the system used for the ordinary firing technique in Japan. Here a measured quantity of gunpowder is dropped directly into the mortar. The shell is placed on top of this. Once the shell has been carefully lowered in the tube, a further small quantity of powder, called 'powder spray' is dropped on top. The powder spray helps to transfer the fire down the side of the shell. A special slow burning star, called 'sindoro', [a rough translation of its name would be 'cinder'] approximately 3 mm X 3 mm X 30 mm in size is pressed. This is then lit and dropped down the tube, its fire being transferred to the lifting charge by the powder spray. After firing, the mortar is cleaned of any remaining debris and the process repeated.

Quick Shooting

Quick shooting is a different format. A bag of gunpowder lifting charge is attached to the base of the shell, as in the western method, however, no leader is added. The top of the shell is connected to a short wooden

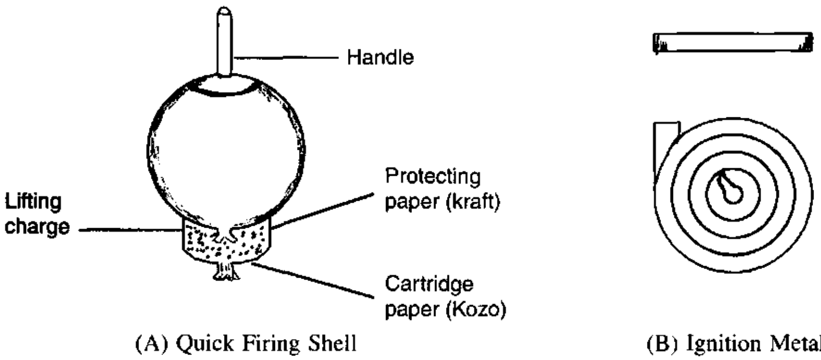


Fig. 2.10 Quick Firing Shell and Ignition Metal

handle, so the result looks very similar to the World War II German stick grenade. (Fig. 2.10)

To fire the shell, first small coils of iron are heated in a charcoal fire until red hot. These coils are then placed at the base of the mortar. The shells are then dropped into the mortar by use of the handle, obviously on contact with the hot coils, the lifting charge is ignited and the shell rises into the air. It is possible to light and fire about ten shells in quick succession using this method. (Fig. 2.11)

The mortar used for this method of firing is rather larger than that used for other methods in an effort to ensure that the shell does not stick to the sides when lowered. This is especially important as cinder is liable to collect on the walls. Obviously this system of firing is more dangerous than the ordinary system, but does have the advantage that it enables shells to be fired relatively quickly from a small number of tube. Also it prevents the premature ignition which can be caused by long lengths of piped match connecting series of shells.

MALTA

The association between Malta and fireworks is well documented. The majority of displays almost exclusively revolve around festivals held by individual villages, in celebration of their own Patron Saint. For example, the village of Luqa celebrates the festival of St Andrew and Kirkop that of St Leonard. In a staunchly Catholic country, the church is still the cornerstone of the community and hence these festivals are viewed with great importance. Matters can be complicated when individual villages have two Patron Saints, invariably resulting in two

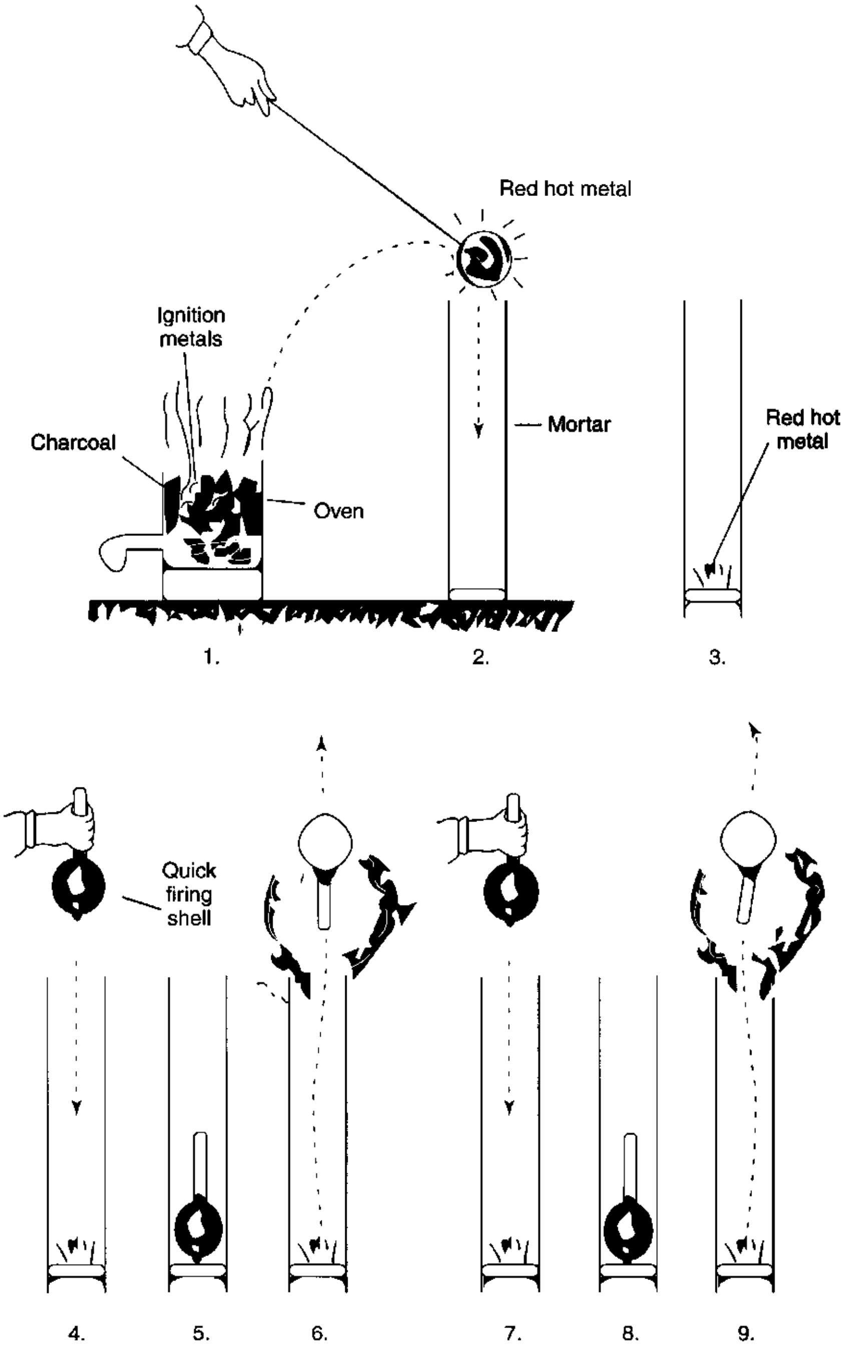


Fig. 2.11 Quick shooting operations. Courtesy Dr. T. Shimizu

sets of followers and their associated musical bands. Many of the firework factories (of which there are around 35 licensed in Malta) are based on these band clubs and enormous rivalry is all but guaranteed. The factories traditionally manufacture solely for the festival and all funding comes from donations collected at the previous year's festival. Such is the importance of the festivals to the community that they are run as non-profit making enterprises and the workforce is made up of volunteers from the community.

We have been to Malta around the time of August to see the fantastic displays for the festivals and I have little doubt that as well as providing some of my first experiences of fireworks outside the United Kingdom, they will inevitably be some of my last. My family's long and close relationship with the firework makers of Malta started in the late Fifties. My father's early visits to St Michael's firework factory in Lija, evoked suspicion as he was perceived as a young cleric from England obsessed by fireworks. Throughout the years a strong relationship grew. Kimbolton Fireworks is one of the few companies outside Malta that is able to import the wonderful fireworks made on this small island. (Odd as it may seem, for many years no money ever exchanged hands as Kimbolton Fireworks supplied some of the chemicals used in manufacture).

I have many happy memories of being packed off on my own to Malta for my summer holiday to take part in the festivities, (as fireworks seemed to revolve solely around alcohol, this was something of an adventure in itself as a 14 year-old). In later years I have begun almost to feel an embarrassment that I use fireworks as a source of income, as at St Michael, like many other factories in Malta, the majority of time dedicated to manufacture is voluntary and unpaid; stemming from a passion and selfless dedication to the community festival perhaps unequalled in any similar event anywhere else in the world. There is little doubt that this dedication is partly fuelled by the strong sense of competition, (mostly friendly) between the rival villages, and in extreme cases rivals groups within villages.

Maltese fireworks rely on this volunteer labour heavily. By modern standards, at a time when traditional manufacture in many countries is failing under pressure from cheap Chinese imports, Maltese fireworks are uneconomical to produce. They are, however, some of the most intricate and wonderful fireworks to be found anywhere in the world. Owing much to a strong Italian connection, the majority of fireworks produced are complex multi-break cylinder shells. The majority of the production seems to be six inches in diameter, though both smaller and larger calibres are made. Each break of the shell is often only a single colour, though wonderful married and splitting stars are also made. A Maltese shell is characterised by a relatively tight burst when compared to a Japanese shell, but has very intense colour. The Italian influence continues as the last break of any shell is a Maroon. In common with many others, my favourite Maltese shells are the repeating maroons where breaks of smaller multiple Maroons, (called crackers), are repeated with a final enormous single Maroon to finish. These Cracker-Maroon shells, anywhere from two breaks upwards never fail to stun audiences both in Malta and the United Kingdom alike.

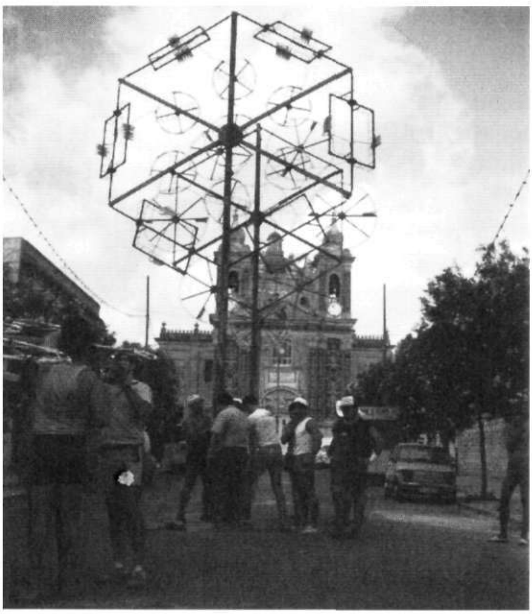
For people used to the more traditional American or European fireworks display of relatively intense but short duration, Malta offers something refreshingly different. Festivals traditionally last up to three days and can be split into differing sections. Whilst fireworks accompany the build up to the festival, the first major event is the removal on the first day of the statue of the patron saint from the church, accompanied by fireworks. Unlike the United Kingdom, daylight shows are common and play an import part of the daytime activities, the show is noise based with ample use made of the Cracker Maroons shells mentioned earlier, but also Smoke Shells are used to add colour to the proceedings. What makes Malta different is the manner in which the displays are fired. Apart from the finale to the display, fireworks are fired singularly, with a considerable gap of several seconds between firings. To the eye accustomed to the more manic overlapping way that shows are fired in the States, this almost appears amateurish. This is far from the case, but certainly allows each shell to be appreciated without its beauty being marred by an infringement of colour by another firework. Almost as beautiful as the fireworks themselves are the amazing snaking lines of mortars, laid one after another in a never ending line slowly winding its way up the hillside forming a continuous stream of fire, interrupted only by a darting figure, cigarette in hand, entering or leaving one of the several bunkers acting as a sanctuary for the firers. (I always recall Joe Portelli telling me how difficult it was to get the firers to use these sanctuaries, as each was determined to see the product of his years work. This I sense, however, is a problem of firework men the world over.) (Fig. 2.12).

In firework terms, a world away from the raw power of multi-break cylinder shells are the rows of intricate lancework devices which line the streets of Lija. Their closest firework cousins would perhaps be the Mexican Castillos, but unlike the Mexican Castillos, whose partial charm lies in their totality. Each of the lancework devices in Malta is a masterpiece in its own right. Traditionally associated with the second day of the festival, each is an example of firework engineering at its best, as even in daylight when the various pulleys, wheels and lattices that are obscured at night are seen, it is almost impossible to decipher how each works. My personal favourite is perhaps the first I ever saw. Simple in effect, it consisted of three different coloured circles which in turn shrunk and then grew in diameter, each inexplicably forming from the inside of a larger circle only to take its place in size. Difficult to describe in words, it is best imagined as the firework version of one of Escher's drawings. (Fig. 2.13)

The display itself seems never ending. The crowd stands in awe as each is fired, only to rush down the street past the freshly extinguished piece to be in the best position to see the next. As a child, I was secretly pleased at the gradual demise of Lancework devices. Those were always a feature of English displays, forced out of the display by the ever frenzied requirements of busy corporate launches where shows only lasted 3 minutes in a blaze of corporate colour. But having experienced the Set Pieces in Lija, I am determined and convinced that they do have a place in many of the modern shows at more traditional venues, demonstrating how simple engineering can be just as impressive and dramatic as that hidden away inside black firing boxes.

Fig. 2.12 Finale Shell Battery. Malta

A



B

Fig. 2.13 Set Pieces in the Street. Malta

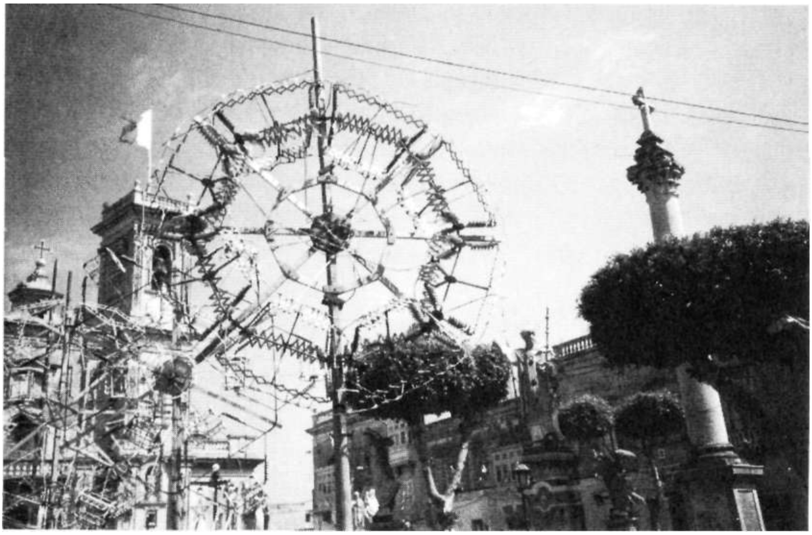
C 

Fig. 2.13 *(continued)*

The highlight of the festival is the third day, normally during the late afternoon, the statue is paraded through the streets for several hours accompanied by enormous amounts of noise. Finally, it is returned to the church where it stays for another year accompanied by an overwhelming finale of fireworks.

There is little doubt that Malta is a unique place, where fireworks in their purist form are enjoyed for their own sake, by some of the friendliest and skilled pyrotechnists I have ever had the pleasure to meet. Certainly one of my dying memories will be parading behind the Statue of Our Lady, around the streets of Lija, the sounds of the village band deafening in my ear, with a bottle of beer in one hand, and a bundle of donations for next year's display in the other. At the time, *as* a fourteen year old, it was my idea of heaven!

3

GUNPOWDER

It would be fair to say that the use of blackpowder in the firework industry is a splendid example of resistance to change as we look at the technological advances of the 19th and 20th centuries. The manufacture of blackpowder as a seriously mechanized industry did not begin in Europe much before the 16th century but thereafter it grew dramatically with sixty to seventy known sites in the United Kingdom alone over these three hundred years.

The Chinese consider that the properties of gunpowder were discovered during the period 475-221 BC with the rise of interest in alchemy and the urge to perfect the making of both gold and the elixir of life. During the Han Dynasty (206 BC) alchemy became increasingly popular, but precise details of the origins of gunpowder are not clear because this was not what the alchemists were primarily looking for.

By the 4th century AD the search for the elusive elixir was still active. Saltpetre was still the main ingredient, but as the experiments could be somewhat explosive, aqueous methods were also in vogue to produce the elixir utilising saltpetre and realgar. The fusion method used mixtures such as saltpetre, realgar, resin and hog intestines; it was found that under some conditions the mixture could be quite explosive.

The first serious formulations for gunpowder as we know it seem to stem from writings about AD 808 when sulfur and charcoal have clearly entered the trials though the object was not necessarily to produce explosions so much as to subdue them. It was reported that mixtures of saltpetre, sulfur, realgar and honey created fires which burnt hands, faces and houses. The addition of charcoal to hot mixtures of saltpetre and sulfur would certainly have been inflammatory!

The documents of AD 808 establish that the first formulation for gunpowder worked out as Saltpetre 46%, sulphur 46%, and charcoal 8%. It seems that the charcoal was from Birthwort (aristlochia debilis).

It has always been stated that the origins of blackpowder are Chinese and much of the evidence has been found in books printed in the West. We are happily in the position now to have more authentic evidence from a document forwarded by Professor Changgen Feng of the Beijing Institute of Technology. The authors of the paper 'The Origin and Development of Ancient Gunpowder' were Yang Shuo and Ding Jing (42).

Blackpowder is described as 'a bright pearl in the ancient Chinese civilisation' with its three components being known from the earliest of times.

Charcoal was already used at the Bronze Age in China and recognised as a fuel for the reduction of metal ores.

Sulfur was recorded in the 6th century BC and in other documents it was regarded as remarkable for its ability to dissolve metals like gold, silver, copper and iron. It is also featured in medicine.

There is considerable evidence of the existence and knowledge of Saltpetre. Once again, its reactivity with metals and its use in medicine in the elixir of life recipes established its importance in these times.

In later times, the Arabs called Saltpetre 'Chinese Snow' and the Persians called it 'Chinese Salt.'

There is no doubt that this protogunpowder can burn well and produce quite a quantity of gas.

While there have been several writings concerning the use of gunpowder and weapons in India and Muslim countries, Prof. Feng Jia Sheng, an authority on the study of gunpowder, is of the opinion that the origins are with China. It is possible that by 1225, gunpowder techniques were transmitted from China via India to the Muslim countries. Later on, the Arabs then transmitted gunpowder to Spain. By the middle of the 13th century it was transmitted to Europe. It is suggested that Roger Bacon discovered gunpowder through translations of Arab books.

Early Chinese formulations recorded in 1044 work out at approximately Saltpetre 60%, Sulfur 30%, Charcoal 10%, but formulations includes sesame fibre, bamboo fibre, arsenic, lead salts, oils, and resins. The assumption is that the organic materials would need to be carbonised. The addition of lead and arsenic compounds may suggest a poisonous smoke of military nature.

Table 3.1 indicates that the proportions are getting nearer to the present.

Table 3.1 Ming Dynasty (1368-1644) Tables

	Saltpetre	Sulfur	Charcoal
Night gunpowder	45.5	9.0	45.5
Flamethrowing gunpowder	74.3	3.9	21.8
Cannon gunpowder	78.7	7.9	13.4
Small Cannon gunpowder	75.9	10.4	13.6

Inevitably the biggest problem in some parts of the world, not the least in England was the availability of potassium nitrate. In the British Explosive Industry (24) Brayley Hodgetts tells how vegetable and animal refuse and the sweepings of slaughter houses were mixed with limestone, old mortar, earth and ashes. Piled into heaps this material was sheltered from the rain but kept moist with the runnings from stables and urine. The collection, fermentation and treatment of this filth frequently led to litigation. It is also on record that 'the saltpeter men abused their privileges and were hated and abhorred by the rest of the community.' For the production of nitrates from the decaying organic material the conditions are very important and needless to say it worked much better in the Middle East and India.

By 1626, The East India Company was importing saltpeter in the UK and this seems to have settled the problem. Importations were also made from Spain, Germany and Poland. In a paper to the Surrey Industrial Group B.J. Buchanan (25) sheds extra light on the saltpeter. Records reveal that in the 18th century saltpeter was imported into Bristol from Danzig. It seems also to be clear from the documents relating to the Danzig owned ships that the material was produced there and not transshipped from India.

In 1990 commercial gunpowder cost as much as eight times the cost of the basic ingredients and as such it is an expensive product to purchase. However, it was expensive even in the 16th century presumably because of the price of saltpeter. Again quoting Hodgetts, in 1788 George Napier said that he considered Russian saltpeter to be the best, but did not think that it was advisable to refine it more than four times 'as it was probable that on repeated evaporation part of the elastic and expansive fluid contained in the nitre might be liberated!'

Dr Buchanan points out that Bristol became an important centre of the UK gunpowder trade because of its strategic position on the west coast. Gunpowder was required in the colonies for blasting and for weapons and became a very important part of the Bristol triangle. Criminals and workers were sent out to work in the colonies. Black West Africans were bartered and purchased with a variety of manufactured goods which included gunpowder.

It is assumed that most of the sulphur which was used in earlier times came from Sicily or Marseille. Sulphur bearing rock was ignited on a hillside so that molten sulphur would run down into wooden boxes. This crude material was distilled in Marseille where it appeared in two forms in the cooling chamber. Liquid sulphur was cooled into sticks to form 'roll sulphur' and the powder which collected on the walls was sold as 'Flowers of Sulphur'. These 'Flowers of Sulphur' tend to be less dense and can be slightly acidic. Firework makers prefer ground rock or roll sulphur 'Flour of Sulphur', and in the 1990's feel a little uneasy about the abundant, but pure 'Refinery' sulphur which often smells too much of hydrogen sulphide for peace of mind.

Sulfur was imported into Bristol in earlier times from Ancona, Italy.

Earlier writers seemed to suggest that the type of charcoal used to make gunpowder was of no great significance but history reveals that this was not true and that in many ways it was the most significant problem once the nitrate issue had been solved. Every firework maker knows that many different effects can be obtained with available charcoals and at the end of the day it is often a question of what is readily available. (See Charcoal Chapter 4)

In the earliest times charcoal came from the forest where wood was burnt in piles covered with earth and needless to say there must have been great variations in the ash content. The resulting powders were found to be extremely variable and in the course of time the charcoal was made by destructive distillation in an iron cylinder.

The wood was cut and selected before it was packed into the long iron cylinders which were then sealed up in some way, but with a number of holes to allow the gas and moisture to escape. Alder and willow charcoal have always been favored for the manufacture of gunpowder but it has also been said that dogwood made the cleanest burning powder and the easiest to ignite. After the distillation process great care was taken to avoid air coming into contact with the charcoal in order to avoid spontaneous combustion.

In the Mediterranean countries charcoal made from grapevine cuttings is greatly prized and there can be no doubt that it produces a good result. In Chapter 19, Dr Shimizu gives details of the types of wood used in Japan.

In a delightful, scholarly book called Cornish Explosives (26) Bryan Earl has described the growth and decline of the industry there in great

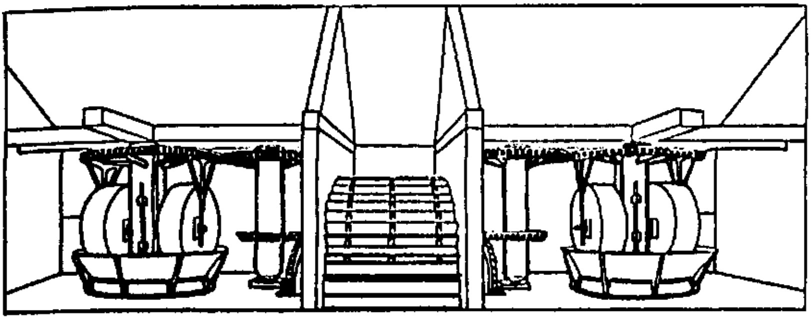


Fig. 3.1 A pair of water powered incorporating mills based on a drawing from the Royal Gunpowder Factory, Waltham Abby, 1830 courtesy of the Gunpowder Mill Study Group.

detail. As a general rule it must describe the industry over this period of history and he has made a splendid effort to document a part of it. It has to be said that this short essay is indebted to Mr. Earl.

In the early days much of the powder was ground or stamped by hand, but in the course of time, the familiar incorporating mills came into being. Inevitably these mills required power and so it is not surprising that powder mills grew up in places where water mills could be utilized. Many of these factories were sited by water courses in ravines where sufficient heads of water could be used at various stages of the process. However this was not the only factor, some mills grew up near places where it was easy to import saltpeter and sulphur, and where there were suitable woodlands for making charcoal.

The first stage of the process was to weigh the three components and roughly mix them together. This rough 'green' mix was often milled in a wooden barrel turned by a waterwheel.

The incorporating mills were a great advance because they incorporated the 'green' mix into a very fine powder, bringing each ingredient into close contact with each other to produce a faster, cleaner burning powder. However there are limits to this milling and it is said that beyond a certain point further incorporation actually decreased the burning speed even though it continued to improve the cleanness of the burning residue.

In some parts of the world stamp mills have been used to work the powder. A mechanical version of a pestle and mortar, the powder was worked in a marble or stone mortar set in the ground and stamped with

Fig. 3.2 Early Black powder Manufacturing sites in the 19th Century.

a wooden stamper operated with a belt drive and cam shaft arrangement to lift and drop the 'pestle.' The writer has seen these in Spain and the Far East after World War II.

Gunpowder has been manufactured in Europe for hundreds of years. It was made in Spandau near Berlin in 1431 and maybe earlier. Over many of these years, the manufacture has been something of a craft and it was not to reach its zenith onto the last century, when the study became a little more scientific. It might be argued that it saw its most powerful form as the prismatic powder which came in 1868.

In England the Royal Gunpowder Factory at Waltham Abbey went back to the middle of the 17th century and was one of Europe's largest producers. Production ceased after World War II, and it has been announced that the site will now be re-opened as a national museum. (Fig. 3.3)

In Germany, blackpowder was produced in large quantities in the Hannover area, the Harz mountains, and Spandau as well as many other places. A small company of the beginning of the 20th century eventually became the Werk Kunigunde near Goslar where powder is still produced today under the trade name WANO. (25)

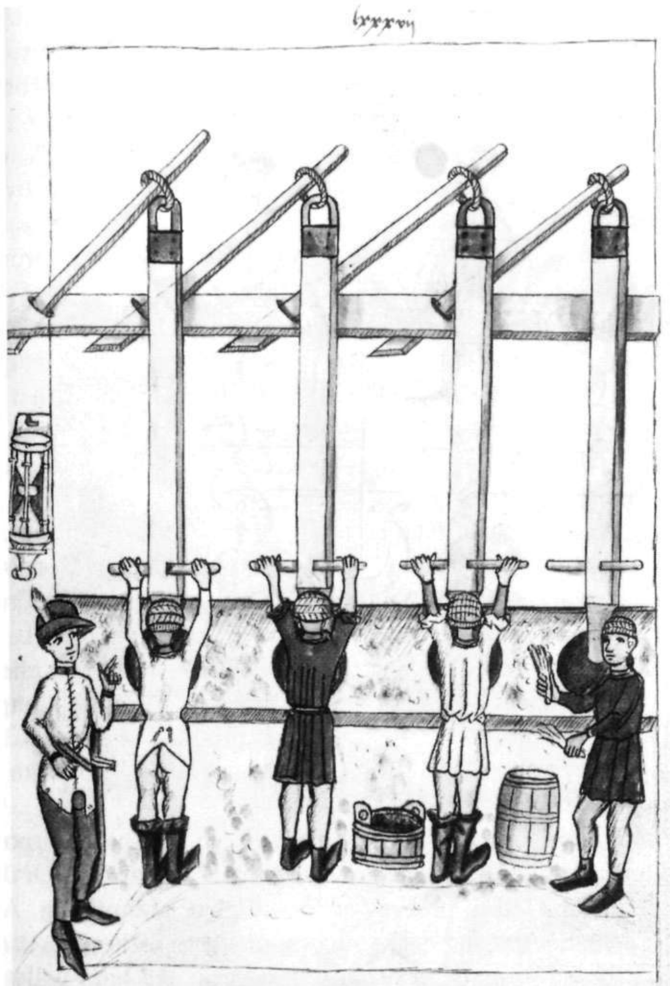


Fig. 3.3 "The Master Gunner supervising the pounding of the powder", from Firework Book [I.34], South German, mid 15th century. Reproduction courtesy of The Board of Trustees of the Armouries. Great Britain.

The author has in recent times seen a set of old stamp mills in the factory of Sachsenfeuerwerk in Freiberg. Such mills were used in the UK in earlier times, but were banned as long ago as 1772.

Although the words gunpowder and blackpowder are synonymous, the two words exist in German also. It has been suggested that the word blackpowder was adopted at the close of the 19th century in order to distinguish it from the newer smokeless nitro-compounds.

Edge runner mills have generally been preferred in the West, Again quoting Earl, These consisted of two large fine grained limestone, or marble discs rolled on their edge like two wheels on a common horizontal axel, the powder charge being spread over a limestone bed on which the wheels ran.' By the mid nineteenth century iron shod stone or cast iron 'runners' working onto an iron bed had been adopted by some powdermakers, weighing over seven tons each. Iron shod or solid iron runners were run on iron beds. 'Stone on stone' or 'Iron on iron' was necessary to avoid producing sparks.

Some of the stones were massive, up to $1^1/_2$ meters in diameter and 0.4 meter thick, and it appears that starting up was quite dangerous because of the intense strain and pressure on the cake at that point, resulting in ignition. To assist in this dangerous stage leather sheets were placed under the wheels as they came to a halt and these were pulled off when the machine restarted.

Powder produced at this stage after say two hours milling is frequently used in the firework trade as mealed gunpowder. Consistently produced material can be much more commercially reliable for firework manufacture than the sieved fine ingredients which tend to be more variable in burning speed and of course less dense. Modern chemical mills are very efficient and newly milled potassium nitrate along with charcoal and sulphur available at 50 μ can produce a fast powder but it tends to be rather light and fluffy, and needs to be mixed with water and if possible consolidated.

In earlier times this was clearly recognized, for the incorporating mills produced a mixture of fine powder and hard lumps which did not ignite evenly. This led to process of 'corning' or granulating. At first water was added at the end of the incorporation to make a thick paste. It was then forced through sieves and dried to make hard pellets.

In the course of time this part of the process was improved by pressing the mill cake in a damp state. The mill cake was moved with wooden shovels onto a wooden box. Powder and copper sheets 18mm thick were loaded alternately into the box and this was then subjected to powerful pressure. It appears that there were many accidents at this stage but it was concluded that these layers of mill cake and the copper sheets made up a voltaic pile and that sparks could be drawn from this.

Slabs of powder made in this way were broken down into small pieces. At first this was done by hand with wooden mallets but eventually this was replaced with toothed roller drums.

Earl makes the point that the powders were dried in drying rooms which were heated with iron flues from furnaces! Accidents happen in

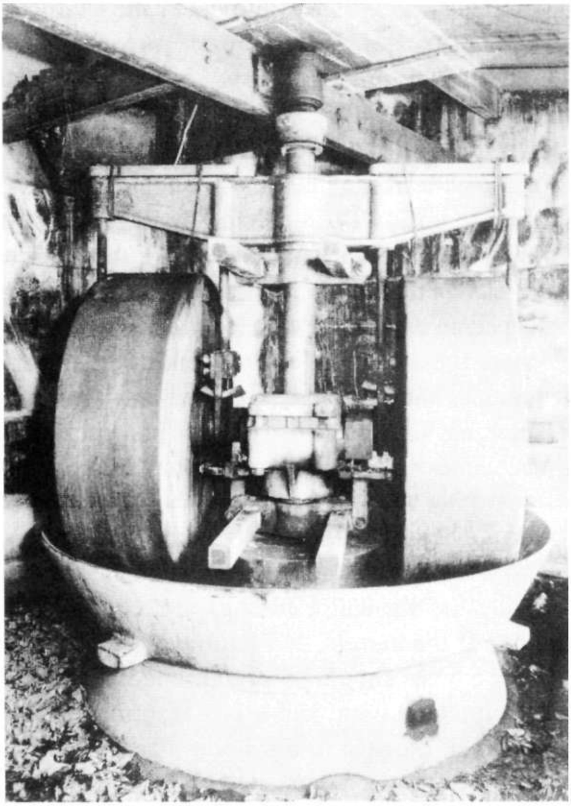


Fig. 3.4 Gunpowder Incorporating Mill. Courtesy John E. Dolan.

the Twentieth century, but it does make us think today when we realize that the old factories had open fires, oil lamps and quite a lot of ignitions! Such conditions lasted until 1850.

Gunpowder was transported in wooden casks, and there were many problems caused by the shrinkage of the wood and consequent spillage. However, the main problem was the absorption of water, particularly when it was transported by ship or stored on floating magazines. Experiments at the beginning of the 19th century found that storage in copper barrels was a vast improvement in preserving the quality of the powder. (25)

The transportation of gunpowder had a number of obvious problems with the result that the Port of London published a set of twelve rules (43) which make interesting reading. However as a fascinating comment on the times the following quotation reveals how they came about.

"Nevertheless, in such carriages, and under the charge of such people, are thousands of barrels of Gunpowder moved from the Mills at Hounslow, through the different town into London, by Piccadilly, along the Strand, Fleet Street, Past St. Paul's, the Bank, the India House, the Tower, and last of all by the London Docks, to Union Stairs, Wapping, where the carmen, with iron nails in their shoes, get into the wagons and carts, in order to unload them, which, by the time they arrive, are often strewed with Gunpowder from one end of the floor to the other, jolted out of the barrels through the saltpetre bags. That neighbourhood has hitherto escaped an explosion, which certainly would be destructive to all around; there these thoughtless carmen, in the midst of drunken sailors of all nations, and the most wretched and abandoned women, drinking and smoking, unload their carriages subject to accident from fire, and the wickedness of ill-disposed people, and carry the Powder to the waterside through a passage, into which a door of a public-house opens, surrounded by the lowest orders of society and watermen smoking and priming their boats, there are boats appointed for the purpose receive it; and the saltpetre bags are, contrary to the Act of Parliament, taken off the barrels, and returned to the wagons. The Act directs also, that the boats should proceed immediately down the river, which is rarely completed with; and it is a fact, that these small boats are often long on their passage to the sloop magazine or ship, and are very frequently and improperly managed by boys, who lay them most imprudently alongside houses, ships, the entrance of the docks, & c. & c. On the 27th January last, the sloop *"Success"*, lying above Blackwall, was with two boys, very nearly blown to atoms, in consequence of her being left by the master, with a fire on board, (in direct opposition to the Act. of Parliament), by which means two boys, (who had got possession of one pound cartridge of Powder) in making squibs, exploded it and were nearly killed, and nine barrels of Powder, each containing l00lbs had nearly exploded, the force whereof, from the improper situation in which the sloop was, might have done irreparable mischief."

The last part of the corning process consisted of sifting the grains in a revolving drum to remove the dust, and after that the grains were revolved in a drum for the 'glossing' or polishing process. In some cases graphite was added at this stage to produce the characteristic shining powders which are still produced. A lively comment made by a writer in 1859 mentioned that some varieties of gunpowder, especially those manufactured for the African market were made to shine with blacklead (graphite). He said 'the negroes seemingly think that gunpowder which approaches their own complexions most surely is the best.'

Glazing certainly helped the flow of these large grains, particularly the slower burning and larger grained blasting powders. However because of the heavy pressure, the grains are not porous and it has been suggested that the sulphur has colloidal properties which fills the space between the particles of the other ingredients.

Tenny L. Davis (7) includes quite a lot of information on this issue of graining. Little did they realize then how important a matter this would become in modern rocketry, in relation to the shape of burning surfaces with newer materials.

Gunpowder grains burn from the surface inwards and, as a consequence, the production of gas decreases as burning continues. It is clear that larger pieces required more time to burn and Napoleon's army apparently used cubic grains about 8mm thick in the smaller guns as well as larger ones. Later on grains were made in the shape of a prism with a central hole, the idea being that a constant amount of gas would be produced since the area of the inner surface would increase as the area of the outer surfaces decreased.

Davis makes the point that cocoa powder was the most successful form of blackpowder that was developed for long range rifles. In prism shape it looked like milk chocolate and gained its color from partly burned charcoal made from burning rye straw. There was little sulphur in these powders which made graining easier, but it was much more sensitive to friction than ordinary blackpowder. English cocoa powder was made with:

	(%)
Potassium nitrate	79
Brown Charcoal	18
Sulphur	3

In the UK the Acts of Parliament of 1875 made many changes and it has often been remarked that the work done at that time was so excellent that it still stands us in good stead today. Every age has its inexperienced young bureaucrats who have splendid ideas, but we were well served by the 1875 Acts. Limitations were placed on quantities, safety distances, and a host of other things. Workers wore woollen suits without pockets and leather boots without nails. Wet mats were situated at the building entrances to remove grit from shoes. Many of the buildings were lined with wood and frequently gloss painted to make them much more easy to keep clean and to prevent dust and grit falling into the operations. The somewhat dangerous press boxes were eliminated.

The 1875 Acts also required the publication of many notices. However as Earl points out, many of the workers could not read and so the foreman was required periodically to read the notices to the workers. However, although people can read nowadays, it is no guarantee that they do read the notices.

The last hundred years have seen some developments and refinements, but fundamentally the processes are very similar. It is interesting to note that the price of blackpowder in Cornwall in 1895 was about £33 per ton. In 1990, blackpowder manufactured in Germany and sold in the UK costs one hundred and twenty times this price - at least. It was noted earlier in this essay that commercial blackpowder costs about eight times the cost of the ingredients. It is clear that production has dropped dramatically in the last fifty years. Part of the problem, is that small family businesses have been gradually taken over by large corporate bodies and in small specialized business it is important to have small groups of dedicated people who have blackpowder in their blood, and a feel for the business.

For their part, the large corporate bodies have only one motive for their modus operandi, and they tend to get rid of anything that does not bring financial return. In the UK, for example, a number of small manufacturers of both blackpowder and fireworks were gradually bought out and then closed down. Gunpowder has not been made in the UK for many years, and there cannot be many people left who have the experience to restart operations even though some plants have been carefully kept 'in mothballs', we hope.

The high cost of manufactured blackpowder is a serious problem to the firework manufacturer, so it is no surprise that in some parts of the world it is still made by the firework makers themselves. Quite frequently this is still done with steel or wooden ball mills. In some cases copper lined barrels are charged with the 'green' charge, and then a number of bronze balls are added. The writer has even seen cement mixers used in some places.

The mixtures are not always milled dry, but the addition of water makes it difficult to mill the material properly. The best and probably safest way is to mill the nitrate with some of the sulphur in one mill, and then the sulphur and the rest of the charcoal in another mill. Finally, the two powders have to be incorporated in still another mill. The resulting powder can then be damped down, possibly stamped, and finally granulated by forcing it through a sieve. Clearly it is a dirty and

Table 3.2 Blackpowder Types and Grades

Type	Grade	Microns
ENGLISH		
Meal A	B	400-Dust
NPXF	B	780-140
FO/A	B	780-250
4FA	C	1580-940
5FA	C	780-440
Sulphurless Meal		105-Dust
Sulphurless Grain		Various
GOEX		
FA		5660-4000
2FA		4760-1680
3FA		2000-1190
4FA		1680-840
5FA		840-297
7FA		420-149
Meal D		420-Dust
Fine Meal		149-Dust
Extra Fine Meal		105-Dust
ELEPHANT BRAND		
FA		8000-4000
2FA		4760-1680
3FA		2000-1190
4FA		1680-840
5FA		840-297
6FA		590-297
7FA		420-149
Flour		420-Dust
Fine Flour		149-Dust
Extra Fine Flour		105-Dust

Note: English powder is 75:15:10 mixture using Beech charcoal and contains a maximum of 1.2% moisture and has a minimum density of 1.70

hazardous business, but in the future it may be necessary if the firework industry is to survive.

Blackpowder in the United Kingdom was manufactured exclusively by the Imperial Chemical Industries. It is now made in Germany. Table 3.2 shows the grades which are used in fireworks.

Sulphurless powder consists of 70.5% potassium nitrate and 29.5% charcoal and is manufactured in much the same way. It is used mainly in priming and igniter compositions, particularly where they come into contact with magnesium. The sulphur in the ordinary blackpowder, coupled with the moisture in the charcoal, tends to accelerate the decomposition of magnesium.

One of Her Majesty's Inspectors of Explosives produced a neat poem summarising the progression to detonation and we too end with these words:

Initiators fire the chain
Acceleration boards the train
Fierce and fast reactions zip
Ingredients, self-sufficient, whip
The pace beyond *"combustion"*
Past the point of *"Deflagration"*
Atoms fly with mounting pressure
"Explosion" then becomes the measure
Ah! but for some that's not enough
For they are made of rougher stuff.
And still the pace goes up and up
Until it reaches ceiling, top
The pace by now extremely hot
No more acceleration can be got
Energy loosed in *shocking wave*
Atoms agitated so behave
With truly violent reputation
The label then is *"Detonation"*

4

FIREWORK MATERIALS

The materials used in firework manufacture can be divided into the following categories:

(a) Oxidizing agents
(b) Fuels
(c) Color producing agents
(d) Substances which improve particular effects (color, light)
(e) Substances which produce smoke
(f) Binding agents
(g) Phlegmatizers which reduce the sensitivity of mixtures
(h) Stabilizers, which help to prevent chemical reactions
(i) Substances which accelerate or retard combustion
(j) Aids in production, such as solvents, and lubricants

The following list of materials would be more useful if it could be arranged in accordance with the categories mentioned above, but as there is a tendency for functions to overlap, the list has been arranged alphabetically. The list in no way represents a full list of materials used over the wide pyrotechnic range and represents only materials commonly used for firework manufacture.

Aluminum

Over the last seventy or eighty years aluminum has added tremendously to the brilliance of fireworks, and yet the great variety in production techniques has caused problems in the production of uniform effects. Ellern has covered the various grades of aluminum very well in his two works (5) but there is a little more to be said to supplement the specialized nature of this book. The powders are prepared in hammer mills, in ball mills, or by atomization. The first two techniques produce the so called "flake" powders and hitherto have been the ones most frequently used for fireworks. Powders made by this method are stamped or milled with stearic acid or other lubricants so that they form tiny plates of irregular shape and large surface area. Foil is used as a starting point and can end up in particles as small as 2 μ and finer. This type of aluminum is used also for making paint and is known as aluminum bronze, though paint aluminums can contain as much as 3% or 4% grease. The resulting "bright" or "brilliant" silver powders are used in the slower burning silver effects and are usually 120-200 mesh. Three samples of this powder from English sources were in accordance with the following:

Retained on 120	10	10	3
120-200	47	43	32
200-325	26	30	30
Pass 325	17	17	35
Grease content	0.03	0.25	0.4

Flake aluminum in larger mesh sizes is known as "Flitter" and there has been a tendency for manufacturers to sell this to the firework trade under the three categories of "fine", "middle" and "coarse". It has to be admitted that as a general rule, a wide variation in mesh size is permissible with flitter but in some compositions it makes a critical difference. Table 4.1 illustrates well the unfortunate variation from one company to another.

Naturally, with such wide variations in mesh size, there will inevitably be considerable fluctuation in aluminum samples because fine and coarse particles may tend to separate in the drums. As a general rule the following mesh size would appear to be the best for flitter:

Coarse	10-30 mesh
Middle	30-80 mesh
Fine	80-120 mesh

According to Ellern, stamped powders are less common in the U.S.A. and have been replaced with those made in ball mills. This was not the case in England, where the firework manufacturers preferred the denser stamped powders that are a little easier to handle and more consistent in quality.

The so called Dark Pyro Aluminum consists of a very fine flake powder that is produced in varying shades of dark grey, and although it has a nominal mesh size of about 200 it contains particles as fine as 2 μ

Table 4.1 Flitter Variations

	English										
	Sample A			Sample B			German Sample			Swedish Sample	
	Fine	Middle	Coarse	Middle	Coarse		Fine	Middle	Coarse	Fine	Coarse
5–10	—	—	5	—	10	5–10	—	2	22	—	100
10–20	2	—	54	45	55	10–20	—	45	66	59	—
20–40	32	7	41	30	35	20–40	68	53	12	28	—
40–80	30	78	—	20	—	40–80	30	—	—	13	—
80–120	22	17	—	5	—	80–120	2	—	—	—	—
Per 120	14	—	—	—	—	Per 120	—	—	—	—	—

It has been said that this powder was made in the past from burned paper-backed foil, or foil that has been sprayed with varnish which is subsequently charred. The writer has not met this practice but manufacturers incorporate a small percentage of carbon black in their pyro-powder. Large quantities of firework aluminum of good quality are produced by the Germans who also use the term Bronze and Flitter; they also use the term *schliff* for flakes and metal inks and *pyroschliff* for the finest firework grades.

Atomized aluminum is being used increasingly in fireworks, but up to the present time only limited use has been found for this material. The problem mainly stems from the fact that it is more difficult to light a spherical or spindle-shaped particle than it is to ignite a flake. One English production method seen by the writer consisted of the dispersion of molten metal which was poured into a stream of compressed air. The fine metal particles were then carried along into a large collecting chamber. Powder produced in this way certainly varies in shape and is not so regular as some of the spherical grade described by Ellern. This may also explain why some grades have better burning characteristics than others.

After extensive trials with atomized material, the writer has not been able to utilize any such material coarser than 120 mesh in firework compositions of the normal type (i.e. excluding thermites and incendiaries.) Beautiful effects can be obtained with powders such as 120-Dust or 300-Dust and a grade which passes 120 and is retained on 200 mesh, but these are extremely limited and tend only to be useful in gunpowder type mixes. Perhaps time will remedy the situation and make life a little easier for everyone by reducing the dirt and sensitivity which characterizes the flake aluminums.

Ammonium Salts

With the exception of the perchlorate, ammonium salts do not find any place in modern firework manufacture. The possibility of the formation of highly unstable and explosive ammonium chlorate by an ion exchange in the presence of water precludes their use. In the past, white smokes have been made with potassium chlorate and ammonium chlorate and it has to be admitted that the mixture appears to be reasonably stable, though at first sight theoretically this should not be so. (see Chapter 5)

Ammonium Perchlorate, $NH_4\ ClO_4$

In recent years ammonium perchlorate has been used extensively, not only in fireworks for the production of rich blue and red colors, but also in the manufacture of propellents. It can be safely mixed with pure potassium perchlorate but must not be used with chlorates and it is unwise to mix ammonium perchlorate stars with other chlorate stars in the same shell or rocket. This material is usually imported into England as a white crystalline powder of about 120 mesh.

Anthracene, $C_{14}\ H_{10}$

The pure form occurs as fine blue fluorescent crystals which melt at about 213°C. It is insoluble in water and rather sparingly soluble in most organic solvents. The main source of supply is from the distillation of coal tar, and the impure commercial grades are frequently greenish-yellow owing to the presence of other hydrocarbons.

Anthracene is mainly used in combination with potassium perchlorate to produce black smokes; an oxygen negative mixture is required for this purpose. During World War II the Germans used anthracene (in combination with hexachloroethane, magnesium, and naphthalene) for smoke production. In addition the shortage of shellac and accaroid resin (which come from India and Australia) caused experiments to be undertaken with a view to replacing these substances with anthracene and naphthalene. A German patent (No. 677532) was concerned with this exercise.

Antimony Sb

The powdered metal, known also as Antimony Regulus, comes to the trade as a dark grey powder fine enough to pass 200 mesh and often 300. It is usually prepared by heating the native sulphide (Stibnite) with scrap iron, or with poorer quality ores by burning off sulphur in a reverberatory furnace to produce the oxide which is then reduced with carbon. The metal melts at 630°C.

Antimony is mainly used to produce white fires in combination with potassium nitrate and sulphur or it is used in combination with aluminum to aid ignition. Antimony is also responsible in part for the well known glitter effect which is basically a combination of gunpowder, antimony (or the sulphide) and aluminum; glitters can also be made with out antimony.

Antimony Trisulphide, Sb_2S_3

The black powder used for firework manufacture is usually the ground native ore, Stibnite, which is mined in Bolivia, China, Hungary, and South Africa. The Chinese powder used in commerce is very fine, usually passing 200 mesh, and has melting point of about 546°C. As a fuel, its uses are much the same as the metal powder, though it ignites more easily. It has the disadvantage also that it is more dirty to handle than the metal powder.

Synthetically produced material is not usually used in fireworks and it can be difficult to get good glitter effects from it. The red precipitated form of this sulphide can be used for some firework mixtures but this is not common practice.

Arsenic Disulphide, As_2S_2 Realgar

The native ore, realgar, is sometimes ground to a fine powder and used to make white fires. It has also been used for making smokes. Realgar is also produced by sublimation when arsenopyrite is roasted. It comes from the U.S.A., Canada, France, Sweden, and Britain, and consists of a red powder, soluble in acids and alkalis, with a melting point of 307°C.

Arsenic Trisulphide, As_2S_3 Orpiment

This sulphide also occurs in a mineral form. The commercial powder has two forms, one yellow and one red. The yellow form changes to red on heating to 170°C. It is insoluble in water and hydrochloric acid, but dissolves in alkaline sulfide solutions and nitric acid.

The red form is often used to make white stars which have the advantage of being easy to ignite when moving at very fast speeds. Apart from the occasional use in smokes, orpiment is used in combination with carbon black for making. Flower Pots with their characteristic golden spur fire.

Arsenic is safe to handle of course, provided that precautions are taken to keep it out of the nose and mouth. Perhaps the name itself conjures up images of other uses to which some arsenic compounds have been placed, but it should be remembered that soluble barium, for example, is equally toxic.

Asphalt, Gilsonite

This is a blackish brown solid imported from Syria, Egypt, and Trinidad. It is possibly formed by chemical changes and the oxidation of high boiling point mineral oils. Asphalt with a melting point of about 100°C is normally used since the ones with lower melting points are more difficult to keep in powder form. It is insoluble in water and alcohol, but dissolves in coal tar naphtha, turpentine, and petroleum.

Asphalt is seldom used in English firework manufacture but seems to have found considerable use in American formulations. The possible sulphur content would possibly make it hazardous with chlorates and there is the additional disadvantage that it is very dirty to handle and tends to leave sticky deposits on tools.

Barium Carbonate, $BaCO_3$

Barium occurs naturally in England as Witherite (Barium Carbonate) or Barytes (Barium Sulphate). The barium carbonate of commerce is made either by precipitation or by the conversion of the natural sulphate into the sulphide and then its interaction with sodium carbonate.

Barium carbonate is no use as a coloring agent in low temperature flames but is often used to reduce acid formation in mixtures or to slow down the speed of some compositions.

Barium Chlorate $Ba(ClO_3)_2H_2O$

The fine white powder of commerce is usually of 99.5% minimum purity and is prepared by the electrolysis of barium chloride. It has a melting point of 414°C and is imported into England.

Barium chlorate is one of the most sensitive chemicals which is used in firework manufacture, but it is difficult to manage without it when deep green colors are required. It is wise to use this substance as little as possible and to use it in combination with other substances which will tend to reduce the sensitivity.

Barium Nitrate, $Ba(NO_3)_2$

This is perhaps one of the most useful and stable of the nitrates, but is somewhat limited in use. It is manufactured by dissolving the native carbonate in dilute nitric acid or by mixing solutions of sodium nitrate and barium chloride. It is marketed as a fine white powder of about 200 mesh and has a melting point of 575°C. Low temperature green colors are not very strong when they are made with barium nitrate, though the salt frequently features in compositions made with barium chlorate as the main coloring agent. On the other hand recent years have seen extensive use of barium nitrate to make high temperature green flames using magnesium or magnalium.

More than anything else this substance is used in combination with aluminum powder for the production of silver effects. Silver stars, flares and waterfalls invariably utilize barium nitrate, and the aluminum combined with it is frequently mistaken for magnesium by the uninitiated. Below 1000°C aluminum burns with a silvery gold effect, and this is characteristic of mixtures of gunpowder and aluminum. Above this temperature silver effects can be obtained with the aid of barium nitrate. Occasionally barium nitrate greens are used in situations where there is a danger of ignition from friction (as in filling green lances with a funnel and wire).

Barium Oxalate, $BaC_2O_4.H_2O$

Occurring as a fine white powder made by precipitation, this substance is insoluble in water, but soluble in dilute hydrochloric and nitric acids. The price and the weak flame coloration of barium oxalate make it unsuitable for ordinary firework manufacture, but it is sometimes used in more specialized items in combination with magnesium.

Barium Peroxide, BaO_2

Although barium peroxide is used in pyrotechnics, it is not suitable for use in fireworks owing to its very reactive nature. It decomposes in water and also at 800°C, and mixtures containing aluminum are likely to heat up in the presence of water. It is prepared by heating the monoxide in a stream of oxygen and has a melting point of 450°C.

Beta Naphthol, $C_{10}H_7OH$

Manufactured mainly for the dye industry, this substance has found an occasional use as a fuel in colored stars, mainly because of its carbon content. It melts at 122°C. Unfortunately this substance irritates the mucous membranes and is not pleasant to handle.

Boric Acid, H_3BO_3

This very weak acid is sometimes used in firework compositions to prevent the decomposition of mixtures containing aluminum. Since the decomposition of aluminum is an alkaline reaction, one or two percent of this acid will help to prevent the acceleration of the decomposition. Heat will sometimes accompany this reaction, but the boric acid acts as a buffer, preventing an alteration in the pH. The wet slurry of barium nitrate and aluminum which is used for making sparklers would be quite likely to react if allowed to stand for some time unless there were some buffering.

In dry mixtures, zinc oxide is sometimes added for the same reasons; in this case the oxide is not a buffer, but being amphoteric it may slowly react with any acidity or alkalinity present. In dry mixtures boric acid is a good lubricant.

Boron, B

Boron is a relatively rare non-metallic element which does not occur free in nature, but always in combination with oxygen and other elements, notably as sodium and calcium borates in the ores borax and colemanite.

Amorphous boron is a very finely divided dark brown to black powder of a particle size of usually less than 2 microns. It is normally prepared by the Moissan process where boric oxide is reduced by magnesium at high temperatures and the product, after acid washing, is boron of about 90% purity.

Over the past 40 years boron has found wide application in military pyrotechnics and its properties and performance in these compositions has been the subject of much scientific study. As a pyrotechnic fuel, boron has a high heat output and reacts readily with a large number of oxidants and other fuels to provide compositions having a range of properties.

Mixtures of boron with oxidants such as oxides, peroxides, chromates, nitrates and sulphates burn in different ways, the combustion ranging from rapid burning accompanied by long flames and showers of sparks to very slow combustion and the evolution of little or no gas.

Mixtures of boron and potassium nitrate produce compositions that consolidate well when pressed, and are easy to ignite as they are sensitive to flash. These are used as priming or first fire compositions because of their ability to transfer heat to other compositions. The addition of silicon enhances this effect.

Boron mixed with oxidants such as bismuth oxide, barium chromate or potassium dichromate form a range of gasless delay compositions which can provide a range of burning rates from 0.3 to 40 seconds per

25mm. These delays perform with high reliability and great accuracy at the extremes of environmental temperature and pressure.

The majority of compositions containing boron are very sensitive to friction and shock. Also the more reactive mixtures are very sensitive to ignition by electrostatic spark and these require special process rooms fitted with electrically conducting equipment.

Calcium Carbonate, $CaCO_3$

The precipitated form of this compound finds an occasional use as a neutralizer in some mixtures, in Armstrong's Mixture, matches, and snakes made with nitrated pitch. It is also used to make rockets. It is also used in high temperature flames for orange colour.

Calcium Oxalate, CaC_2O_4

A fine white powder, made by precipitation, it is not commonly used in ordinary firework manufacture. It has been employed mainly in signals to give depth of color to mixtures of sodium nitrate and magnesium and in other signalling devices. It is insoluble in water, but dissolves in dilute hydrochloric and nitric acids.

Calcium Orthophosphate-Tricalcium phosphate, $Ca_3(PO_4)_2$

This well-known "flow agent" is used in firework manufacture. About 1% can be added to many mixtures to enable them to move freely in a funnel and wire apparatus, or automatic machines and presses. The white amorphous powder is made by precipitation. It is insoluble in water, but dissolves in acids and has a melting point of 1670°C.

Calcium Silicide, $CaSi_2$

This material is a grey/black powder which is insoluble in cold water but is soluble in acids and alkalis. It is decomposed by hot water. It finds use mainly as a fuel for self-heating cans of soup and is often an important component in smoke compositions.

Carbon Black-Lampblack

These blacks are essentially carbon in a very fine state of division, and are prepared by burning oils in such a way that incomplete combustion takes place, so a large volume of smoke is produced; this smoke consists of unburnt particles of carbon and is collected in a specially constructed system of flues.

The quality of blacks vary, but they usually contain about 98% carbon, have a pH of about 8 and usually pass a 350 mesh screen. It is important to make sure that lampblack does not contain traces of unburnt oil which would be dangerous. Carbon blacks, vegetable blacks and gas blacks are all closely related, being made similarly by burning oil, gas or vegetable matter. As the quality varies so much, the firework maker has to experiment to find the material which suits his purpose.

Carbon black is used to make Flower Pots, the unusual little golden fountains with their own special type of gold spark. Golden streamer stars also employ carbon black for the best effects. It is a pity that the material is so filthy to handle; otherwise it might find a more extensive use. When compositions are made wet it is advisable to add a proportion of alcohol to reduce surface tension and make it easier to wet the mixture.

Castor Oil

Little use has been made of castor oil in English manufacture, but it appears to have found considerable use in the USA in the past. It is used mainly as a protection for magnesium, but it also acts as a binder or lubricant in that it reduces the friction of the powder against the walls of the container into which it is pressed.

Charcoal

The different kinds of charcoal that might exist are a constant talking point among the firework fraternity. The plain fact, however, is not so much what you would like, as what you can get locally in reasonable amounts. Consistency in quality is a problem, and the last U.K. manufacturer went around his woodyard with a truck collecting different types of wood so that a constant mixture went into the still in order to produce a constant blend.

When wood is heated in the absence of air, the volatile products distil off and the charcoal remains behind. In the large commercial stills, the burning products are fed back into the still as fuel.

In earlier times the wood was stacked in the forest like a wigwam, covered with inverted turf and then set on fire. Dr Jeacock (43) quotes a Forest of Dean charcoal burner who was asked by a radio interviewer how he knew what was going on inside.

The reply rather shocked the establishment when he said, 'I spits on the outside and watches it sizzle.' The combustion process had to be watched 24 hours a day and turf had to be replaced as necessary. This could be a very hazardous business and men have been burned to death after walking on the stack. In a private communication, Dr Jeacock makes the point that the operator also cut a suitable piece of wood, stuck it in the ground and then sat on it to watch the process. Perhaps this was the origin of the nitro-glycerine one-legged stool that operators had to sit on to prevent them from falling asleep as they watched the nitration process.

That a particular type of charcoal has vastly different burning characteristics from another, whether it be for the production of sparks or of gas, is well known. The writer however got one of the surprises of his life when testing a high quality Japanese hemp charcoal alongside a commercial United Kingdom grade. Using the traditional column test the United Kingdom charcoal burnt 27 seconds, the Japanese only 7 with the normal gunpowder mix.

Much traditional experience in charcoal production has been lost but it is generally known that the temperature of the distillation is crucial. Most people recommend that it should be below 500°C. A Swiss source states that black alder is used for blasting powder and that a lot of 1495 lbs would yield about 340 lbs of charcoal when carbonised at 500°C for six hours. Sporting powder was carbonised at 300° to 320°C. Undoubtedly, there has been a preference over the years for willow, dogwood, and alder, but even these woods vary depending on the time of the year they were felled.

One unusual grade of charcoal made from rye-straw was used to make the so-called 'cocoa powder' because of its colour. It was said to have been invented by Castner and had the proportions of 78:3:19.

All charcoals contain percentages of ash and moisture. The lower the ash content the better; about 2% or 3% would be ideal which seems to be the case with willow and dogwood. Some charcoals can be as high as 15%.

It has often been a pleasant thought that one could produce different kinds of charcoal and then employ them in the various firework mixes as a means of comparison. Happily such a series of tests have been carried out by Roger O'Neill et al and published in Pyrotechnica XVII (29). The results make interesting reading and conclude that handmade charcoals can give superior performances.

For charcoal tailed comets, hemp, peach, apple, and grape seem to be superior. For blackpowder, plum and paulownia are superior, with oak, willow, maple, peach, and apple giving excellent results.

Once again it has to be stressed that the commercial manufacturer has to use what he can get and in practice two main types have been used. The one is a very fine powder-as fine as possible-for making gunpowder or fast burning effects; in Europe, Black Poplar and Lime are sometimes used. The other is a softwood blend which the manufacturer may well put through this mechanical sieve to give grades of 40 to 80 mesh and material retained on 40 mesh.

For military and other special purposes more precision is required. A paper (47) gives details of work carried out on charcoals for the Ministry of Defence Procurement Executive.

The three types of charcoal used were identified as hardwood charcoals. They were alder buckthorn (Frangula alnus), known earlier as 'dogwood' or 'black dogwood', alder (Alnus gultinosa), and beech (Fagus sylvatica).

Adler buckthorn is used in gunpowder for making evenly burning fuses. Alder is used in many commercial gunpowders, and beech is used where precise burning is not required. It was also found that alder buckthorn had the lowest spontaneous ignition temperature and the highest porosity, and was possibly the best charcoal to use for ease of ignition.

Chlorinated Rubber, Alloprene, Parlon

This is a white, odorless, granular powder which is sometimes used as a color intensifier because of the chlorine content. Parlon is an American product and not the same as Parlon P, which is chlorinated polypropylene, and which is not used as a color intensifier. Parlon contains 66-67% chlorine and is soluble in acetone.

Clay

This material is an important part of firework manufacture, for it is used to block up the ends of tubes or to provide a washer through which fire can be forced in order to produce pressure. Almost any kind of clay can be used, but it must be thoroughly dried, and sifted to remove stones. When the dried clay is struck a few blows with a mallet and drift or pressed, it forms a very solid mass which does not crumble easily. White fireclay is the type most commonly used.

Copper Powder

Use has sometimes been made of the bronze and electrolytic copper powders for the production of the blue colors, or as intensifiers for green colors, but this is not very common, for the same effects can be achieved by more efficient means.

Copper Acetoarsenite $(CuO)_3As_2O_3Cu(C_2H_3O_2)_2$. Paris Green

This substance has been known by a variety of names (Brilliant Green, Imperial Green, Schweinfurtergrun) and it has frequently been wrongly named in firework literature. Copper arsenite (Scheele's Green) and copper arsenate are different substances and less useful. Paris Green is prepared by the interaction of sodium arsenite, copper sulphate and acetic acid. It has an intense green color, is insoluble in water and alcohol, but soluble in acids. Needless to say it is toxic, and sometimes caused nose bleeding and skin rashes.

Apart from the compositions employing ammonium perchlorate, Paris Green still provides the best blue colors.

Basic Copper Carbonate

Occuring in native form as malachite $CuCo_3.Cu(OH)_2$ and azurite $2CuCO_3.Cu(OH)_2$, the compound used for fireworks is usually made by precipitation. It is the best copper compound to use in combination with ammonium perchlorate for the production of blue colors, and quite deep shades are obtained in this way. An adequate blue star can be made with potassium chlorate and copper carbonate by adding PVC and cool burning fuels.

Copper Oxides

Black copper (II) oxide was used many years ago (along with the fused sulphide) in the production of blue colors, but calomel had to be used also as an intensifier, and it fell into disuse. Both copper (1) and spacing copper (II) oxides are used now for ignition and starter compositions in conjunction with silicon and lead (IV) oxide. However the availability of good halogen donors and the disadvantages of Paris Green have caused a revival of the use of copper oxide for making blue colors.

Copper Oxychloride

This basic chloride appears to have a variable composition and is possibly $3CuO.CuCl_2.3H_2O$. It is formed when copper (1) chloride is exposed to air. It is soluble in acids and ammonium hydroxide but not in water. Blue colors have frequently been made with this chloride and it still finds some use since it is cheaper than some of the other copper compounds, and the blue color is good.

Cryolite-Greenland Spar. Na_3AlF_6

The production of yellow color fireworks is something of a problem owing to the liability of sodium salts to absorb water, or to react with other substances and incidentally absorb water. Cryolite is one of the few sodium compounds which is completely insoluble and unreactive. The natural material appears to be better than the synthetic form in many compositions.

Dextrin $(C_6H_{10}O_5)_n$

This is the generic name for products of the partial hydrolysis of starch. As it is soluble in water and has good adhesive properties, it is used extensively as a binder in fireworks. It is fairly usual to add a few percent of the dry powder to a star composition during the mixing operation and then add water prior to star formation. While dextrin is very useful for these purposes, it also tends to be somewhat hygroscopic and so it is unwise to use more than about 5%, and preferably less. Dextrin is insoluble in alcohol; if alcohol is added to the water to promote faster drying during star manufacture, no more than 30% should be added or the adhesive quality of the dextrin will be inhibited.

Dyestuffs

The quality of the materials used for smoke production is important, particularly the particle size of the dyes and their freedom from inorganic salts. The sublimation temperature should be as low as possible. The field is very specialized but there is an adequate technical literature.

Flour

In the past, wheat flour was extensively used to manufacture paste, but most manufacturers now purchase their adhesives. It was also used in some compositions to retard the burning speed.

Gallic Acid 3,4,5-Trihydroxybenzoic Acid

The acid crystallizes as almost colorless silky needles of the composition $C_7H_6O_5$.H2O. It is soluble in water, alcohol, and ether, and decomposes at 220°C. The fine commercial powder is used sometimes for the manufacture of firework whistles and is the most dangerous of all the whistle compositions. Being highly sensitive both to impact and friction when combined with potassium chlorate, it has frequently been known to catch fire or explode, when charging operations are taking place. It can not be used with potassium perchlorate in whistle compositions.

Glass Powder

This is not much used in fireworks, but occasionally is used in match head and striker compositions.

Glue

Hide glues are invariably used in match heads and certain types of sparklers where a wire or stick is dipped in a wet slurry. Hide glue is also employed in some kinds of cheap smokes to cool the burning process.

Hide and fish glues have always been traditionally used for sticking various firework parts together, but these are gradually being replaced by the more modern PVA emulsion adhesives. These emulsions have the advantages of toughness and a certain amount of elasticity and do not require any heat for application.

Graphite

The fine black powder of commerce is not used as firework fuel, though it is frequently added to compositions which are to be pressed in molds to ease their ejection. It is also added to magnesium flash powders.

Guanidine Nitrate $NH{:}C(NH_2)_2.HNO_3$

This organic compound is a white powder melting at about 208°C and decomposing at 235°C to generate ammonia gas. Unlike nitroguanidine which can be explosive when detonated, guanidine nitrate is quite stable and not affected by either shock or friction.

The material is not hygroscopic and it can be quite useful in strobe compositions where it is decomposed by various substances such as copper or chromium oxides which act as catalysts. It is also used in some smoke formulations and was used as a fuel in JETEX which was a toy rocket fuel.

GUM RESINS

Accroides Resin, Red Gum

Information in previous editions was provided by the UK importer of this material from Australia but this has been considerably updated through the interest of Australian pyrotechnists and in particular Dr Mike Stanbridge (29).

Clearly there has been some confusion about Accroides resin which is derived from the Liliaceae family, Xanthorrhoea preissii and X. reflexa. As previously stated the resin exudes from the trunk and during the passage of bush fires the glasslike boules fall to the ground. However at this stage the chemical composition of the material has been changed by the heat from the bush fire (pyrolysis).

According to Dr Stanbridge, it is more than likely that the material reaching Europe has been Gum Yacca from Kangaroo Island off South Australia. Apparently the Xanthorrhoea trees known as Grasstrees or Blackboys, depending on the area, were felled and whacked on canvas sheets to gain small diamond-shaped fragments of resin. Grit and vegetable debris has to be primitively removed - which may account for the vegetable debris in the coarse powders available in the UK. Dr Stanbridge speculates on the etymology as the Aboriginal word 'yacca' refers to hard work. He also suggests that the destruction of trees, which may be six hundred years old, will necessitate the need for alternatives.

True Red Gum apparently comes from Eucalyptus trees and particularly the Redgum, Marri or Eucalyptus calophylla. Calo-resin is produced from the mill fines of this wood and may have promising commercial possibilities.

The chemistry of these resins is beyond the scope of this rather practical work, but the benzoin-like odour is very characteristic and the chemists say that the variable composition contains benzoresinotannols, benzoresorcinol and traces of other materials like cinnamic acid.

The brown powder varies in mesh size which can be used as a control for the burning rate. In slow burning illuminations, a powder passing 30 mesh and retained on 80 mesh would be useful. For fast burning compositions such as stars a powder passing 120 mesh is best, particularly with the more modern high temperature flames where smaller percentages of the gum are used. The gum replaced shellac long before World War II because it was cheaper and was one of the substances called 'shellac substitute'. However, it is in many respects superior to shellac in coloured flames. It is also surprising to learn that it has not been extensively used in Japan for making fireworks.

The gum is soluble in alcohols and alkalis and has a melting point below 100°C.

Gum Arabic

Known also as Acacia Gum, this material is obtained mainly from the various species of Acacia trees. Gum Arabic comes to the English market from Aden and Bombay and is mainly of use because it is more or less soluble in water. It occurs in roundish or avoid pieces of various sizes and varies in color from colorless or pale yellow to brown. The best qualities take up about one and a half times their own weight of water for solution, but the gum is insoluble in alcohol. Alcohol precipitates the gum from aqueous solution.

The solution tends to be acidic, particularly when it has been allowed to stand and ferment and is best avoided as a firework adhesive, particularly in chlorate mixtures. Quite frequently it is used for making quickmatch and in other black powder mixtures.

Gum Copal

The East Indian Copals, as their name implies, are obtained from Malaysia generally, and in particular from the Malay Peninsula, Borneo, Java, Celebes, Papua, Sumatra and the Philippines. Pontianac is the hardest material readily available, originating from Borneo, whereas the softer variety is known as Manila, Macassar or Papua. These latter copals are won from Agathis Alba by tapping and subsequent collection some three months later. Finally they are sorted and graded according to purity, color and hardness.

The material has a softening point of 80-88°C and a melting point of 110-125°C. The powder used in fireworks is light grey in color and has a characteristic smell with a particle size of approximately 60 to 200 mesh. It is soluble in alcohols, esters and alkalis, but insoluble in water.

Shellac

Shellac is the name given to the refined form of lac, and the word, derived from shell-lac, specifically refers to refined lac in thin flakes in the form in which it is most commonly marketed.

Lac is the resinous secretion of the lac insect (Laccifer Lacca), parasitic on certain trees principally in India, Burma and Thailand. Large numbers of the tiny red larvae, about 0.5mm long, come out of each mother cell and settle on tender portions of fresh twigs of certain trees, called lac hosts. They feed on their sap, and exude the resin from glands under the skin. The insect completes two life cycles in a year yielding two lac crops. When the material is collected, it is known as sticklac and usually contains about 60-70% of the lac resin and 6-7% of lac wax which is also secreted by insect.

The first part of the refining process consists of grinding and washing to remove coloring matter, sand, insect debris and pieces of wood. The lac resin is then finally produced by melting sticklac in cotton bags and pressing out the melted resin, or by dissolving out the resin with alcohol, filtering and subsequently recovering the resin and alcohol by distillation. The exact nature of the monomeric lac complex, whose molecular weight lies between 1000 and 1100 is still obscure. The present state of knowledge indicates the constitution to be as follows:

1. Dyes. Two distinct coloring matters are present to the extent of $^1/_2$%
   (a) Laccaic acid (b) Erythrolaccin
2. Wax. Lac wax exists as about 4-$^1/_2$% by weight of whole lac and consist of even-number primary alcohols from C_{26} to C_{34} and esters from C_{30} to C_{36}.
3. Resin. 90% of the total material is resin and consists in the main of hydroxy fatty acids together with their lactones and lactides. Treatment with ether produces two fractions:
   (a) Soluble, known as soft Lac Resin having an approximate molecular weight of 520, and whose principle component is aleuritic acid, 9, 10, 16-trihydroxypalmitic acid of melting point 100-101°C
   (b) Insoluble, known as hard Lac Resin, of approximate molecular weight of 1900 and consisting of about 70% of the lac resin. Its components are derivatives of aleuritic acid.

Shellac used for firework manufacture is an orange-brown powder, softening at 50°C and melting at about 75°C. Powder as fine as 200 mesh is sometimes used, but the normal powder of commerce has a wide particle size range and is approximately 30-200 mesh or 60-200 mesh. Material made by the original machine-made/hot solvent process is frequently used. It is insoluble in water, but dissolves readily in alcohols, organic acids and aqueous solutions of alkalis. Shellac, accaroid resin and copal gum are all used as fuels, mainly for the production of color. Shellac substitutes have been used in the past mainly because shellac is expensive. One is a similar looking resin obtained from Araucaria augustifolia. It is less waterproof than shellac.

Gum Tragacanth

This expensive gum comes from several species of Astragalus growing in Lebanon and Syria. The gum is exported chiefly from Baghdad and Basra. It is soluble in water but not in alcohol. Very occasionally it is used as an adhesive in fireworks.

Wood Resin-Pine Resin-Colophony Resin-Rosin

Resin is the residue of the distillation of turpentine oil from the crude oleoresin obtained from the pine trees, principally from Pinus Palustris and Pinus Caribea. The resin consists mainly of acids of the abietic and pimaric types with the general formula $C_{19}H_{29}COOH$. Colophony is soluble in alcohol, ether and benzene and has a melting point between 100 and 150°C.

The resin is used in blue colors and occasionally in smokes, but it is difficult to powder, for although it is brittle and straightforward, it tends to agglomerate on standing. A little starch is sometimes added as an aid to pulverization.

More useful appear to be the resinate, which are products of the reaction between colophony and hydrated oxides or salts of certain metals. For example, calcium resinate is made by fusing rosin with slaked lime. Resinates have the advantage of softening at higher temperatures.

Hexachlorobenzene, C_6Cl_6

Extensive use of this material as a chlorine donor in color mixtures appears to have been made in the U.S.A. in the past. According to Ellern, it has been superceded. Little use of the material has been made in Europe since PVC has been preferred. Hexachlorobenzene occurs as white needles which melt at 229°C. It must not be confused with Lindane, gamma—benzene bexachloride $C_6H_6Cl_6$ which consists of white crystals with a slight musty odors, melting at 112.5°C. This substance is the well known insecticide.

Hexachloroethane, C_2Cl_6

This is a white crystalline powder with a slight camphor-like odor. It melts and sublimes at 185°C. The main use of this substance is in the manufacture of smokes, and for this purpose the chemical is mixed with substances such as aluminum, zinc oxide, calcium silicide etc. Unfortunately it is very volatile at room temperature and therefore the chemical itself and the smoke composition made with it can only be kept in sealed tins.

Hexamine, $(CH_2)_6N_4$

Hexamethylenetetramine is formed when six molecules of formaldehyde condense with four molecules of ammonia. The white crystals burn with a steady yellow flame and have been used for small indoor fireworks in combination with magnesium and lithium salts. Metaldehyde has been used for the same purpose but has the disadvantage of giving off poisonous formaldehyde during burning. Hexamine would be quite useful as a fuel, but does not appear to have found much application, possibly because of the cost.

Iron, Fe

There can be little doubt that iron has been used in fireworks from the earliest times. Apart from the steel dust used for the manufacture of sparklers, the best iron for fireworks is the ordinary cast iron borings which have been broken down to a rough powder which will pass 20 mesh. The long needle like fragments give the best effects.

Unfortunately it is only too well known that iron will not keep in firework mixtures and it therefore has to be treated. The oldest method is still the best one and employs linseed oil. About 16 lbs of iron is mixed with 1 lb of linseed oil and the mass is slowly roasted in an iron pan until most of the oil is burnt off. Another method is to coat the iron in oil and then allow it dry slowly at room temperature, spread out in thin layers on trays. If preferred, the iron can be coated also with paraffin wax. In some cases where it is very necessary to be sure that corrosion cannot take place easily, the iron is pre-treated with a solution of dibasic ammonium phosphate.

Iron Oxides

In recent times, the two oxides have been increasingly used in pyrotechnics. The black magnetic form, Fe_3O_4 is used in thermite and incendiary compositions and the brown form Fe_2O_3 has been used in first fires and ignition compositions where high temperatures are needed.

Lead Oxides

The red form, Pb_3O_4 and the chocolate colored dioxide, PbO_2 have been used in first fires and ignitions for military purposes and are potentially useful for fireworks also. Combined with magnalium, it is used for crackling microstars.

Linseed Oil

For many years, boiled linseed oil has been used to coat magnesium powder to protect it from corrosion. Magnesium powder and oil are mixed together and allowed to stand in a warm place in shallow trays for about forty-eight hours, before the other chemicals are added. In practice, lithographic varnish is preferred to ordinary linseed oil. Lately there has been a tendency to replace these oils with polyesters or to use no coating at all, but there can be no doubt that linseed oil renders good protection and its period of usefulness is not yet over. Stores made with magnesium coated with lithographic varnish are good for several years, which is not the case with uncoated magnesium.

Lithium Carbonate, Li_2CO_3

The red coloration of lithium has no distinct advantage over strontium in firework manufacture and so the high cost of lithium salts preclude their use. An occasional use has been found for lithium carbonate in certain types of indoor firework, some of which use nitrocellulose as fuel and oxidizer.

Magnesium, Mg

Because of its high cost and somewhat reactive nature, magnesium is not used very much in commercial items. On the other hand, it is indispensable in situations where it is essential to gain high candle power in signal flares. The readiness of magnesium to react with other materials and decompose has been mentioned elsewhere, thus making it essential to choose the other materials carefully and to coat the magnesium prior to mixing. Linseed oil and drying oils have been extensively used in the past for these protective purposes, but in recent years there have been attempts to replace the oil with polyester resin. While these are very good, they are a little more messy to handle, and pressing has to take place soon after mixing. Experiments have been made with potassium bichromate as a means of protection, and it is now common practice. The modern practice of pressing magnesium compositions dry in aluminum or paper tubes is a great time saver, but finished product cannot be guaranteed for a long period of time.

The metal used for pyrotechnics is usually pure magnesium, but small amounts of manganese are sometimes added. Magnesium/aluminum alloys are also employed in varying proportions and are rather more stable.

A rough sieving of the English grades 0 to 5 produced the following result:

	0	3	4	5
40/80 mesh	51	22.1/2		
80/120	43	50		
120/200	6	32.1/2	47.1/2	5
200/300		4	42.1/2	25
+ 300		1	10	70

Comminution takes place by a process of atomization when the molten metal is dispersed by gas in an inert atmosphere or by a process of cutting from large pieces of metal. Of course, the density varies with the method of cutting. Grades 0 and 3 are turnings, or raspings, made by a process using a rotating cylinder rather like a very large food grater bearing upon a cylindrical billet of metal. The fine raspings are then milled and separated by sieving. Grades 2 and 4 are produced by a process of abrasion. A rotating cylinder 12" in diameter has continuous strips of wire brushes wrapped around its periphery. Against this rotating cylinder is pressed a slab of magnesium about 2" thick. The product from this process is called "cut" powder and is again separated by sifting.

Magnalium Mg/Al

The reactivity of magnesium somewhat precludes its use in fireworks. However the need to produce brilliance to colours has led to the extensive use of magnalium, and it is very probable that we have to thank the Chinese for precipitating the move in this direction.

There is the additional advantage that the use of magnalium can mean that smaller percentages of oxidiser can be used. The reactivity of the alloy tends to be somewhere between the properties of each of the metals alone, and while the normal alloy is a 50/50 mixture, other alloys have been made and used.

The metal is rather brittle and consequently produces quite sharp splintery particles which can increase the sensitivity of mixtures. It can also affect the eyes. The somewhat new use of this material to make crackling granules with lead oxide has led to some surprisingly sensitive mixtures.

Magnalium is used in fireworks for a variety of purposes:

1. In coarse powder of about 30-50 mesh the metal produces a sharp crackling noise in coloured flame fountains. The presence of cryolite seems to enhance this effect.
2. Dust free coarse powders produce pleasant sizzling effects in some stars.
3. The finer powders from 120 mesh onwards are used to enhance coloured flames, produce some silver effects and to produce the newer blinker/strobe effects. Strobe effects come from magnalium burning with the nitrates of barium or strontium where the vibrational burning can be varied with catalysts.

Magnalium is attacked by weak acids (e.g. boric acid) and sodium oxalate and, to a lesser extent, by other firework chemicals.

It is however protected by potassium bichromate which is often used for this purpose. (see Chapter 5)

Magnesium Carbonate, $MgCO_3$

It appears that this material is useful for making potassium chlorate or perchlorate free-flowing. American smoke compositions employ 3% of the total weight of the chlorate itself. 1 % of the light carbonate was not so successful in a lance composition as 1% tricalcium phosphate for promoting free flow in the funnel and wire apparatus, though it is obviously potentially useful as a neutralizer.

Since calcium chlorate and magnesium chlorate are very hazardous, it is probably unwise to use magnesium carbonate as a neutralizer with chlorate mixtures.

Mercury Chloride, Hg_2Cl_2 Calomel

Calomel is manufactured by the interaction of mercury and mercury chloride. It is a white, tasteless, insoluble extremely fine powder which was formerly used as a chlorine donor in color mixtures. The fantastically high cost of mercury salts precludes their use in fireworks, but there are good substitutes. Lead chloride has been used for a substitute, but it is not used now.

Naphthalene, $C_{10}H_8$

Naphthalene is produced commercially from coal tar from the fraction boiling between 180° and 250°C. It is white solid crystallizing in plates with characteristic tar-like odor. It melts at 80°C, is almost insoluble in water, but dissolves readily in benzene. The main use in pyrotechnics is for production of black smoke. See anthracene.

Paraffin Oil and Wax

Paraffin oil finds some use in fireworks and frequently performs more than one function at a time. When it is added to a colored fire mixture, for instance, not only does it help to reduce the influx of moisture and reduce the sensitivity, but it also makes the mixture easier to press. Normally about 1 % is used for these purposes.

Paraffin wax is usually used to coat metal powders or to waterproof finished fireworks, which are merely dipped in the molten wax.

Phthalic Acid Compounds

It has been known for some time that the modern whistling compounds from China contained phthalic acid compounds. In particular potassium hydrogen phthalate has been identified. The writer tried the normal laboratory grade without success. Some light could have been shed on this problem as a result of an article by Richard Dilg in the American Firework News (November 1987). The article suggests that the material used could be made from the para isomer rather than the ortho isomer. The whistles might therefore be made from a Terephthalic acid salt (1,4 benzenedicarboxylic acid). Potassium hydrogen terephthalate is now the subject of a patent.

Phosphorus, P

Only the red variety finds any application in the manufacture of fireworks and only then in the production of amorces and match striker surfaces. The production of amorces is a very dangerous and somewhat specialized business and it is quite essential to ensure that dry amorphous phosphorus and dry potassium chlorate never get near each other or they will explode violently when they are subjected to even the slightest friction.

Weingart describes liquid fire rockets which require yellow phosphorus to be placed in the tops of rockets. There is obviously no commercial future in this nor is it particularly recommended!

Pitch

> *"And the streams thereof shall be turned into pitch, and the dust thereof into brimstone, and the land thereof shall become burning pitch."*
>
> *Isaiah 34,9.*

Hard pitch, the residue from the distillation of coal tar, is sometimes used in powdered form in the production of cheap smokes used for making drain testers, but liquid tar absorbed on sawdust often gives better results. The powder has also found some use in the production of colors; good red and green lances, for example, have been made with pitch as a fuel. On the other hand the possible impurities could be hazardous with pitch as a fuel. On the other hand the possible impurities could be hazardous with chlorates and pitch is not much used. German formulations have sometimes employed Beechwood pitch—Buchenholzpech—and the Japanese have shown a partiality for Pine Root Pitch, a by-product of the distillation of oil of turpentine.

Polyvinyl Chloride, PVC. $(CH_2{=}CHCl)_n$

The Germans during the late thirties appear to have been the first to use this material extensively as a chloride donor. It is a white powder or granular substance with a softening point of about 80°C. It is soluble in dichloroethane and cyclohexanone. At about 160°C it begins to decompose with the liberation of HC1.

PVC contains 56% chlorine and is normally used in magnesium compositions. Normally it is marketed under various trade names such as Vestolith, Corvic, Igelith, Vipla. There is also a double chlorinated PVC marketed as Rhenoflex. It is very much superior to ordinary PVC for the production of barium nitrate/magnesium green stars, but it is also very much more expensive.

Closely related to PVC is polyvinylidene chloride or Saran, a copolymer—$CH_2{=}CHCl$(15%) + $CH_2{=}CCl_2$(85%), which can be used in similar ways to PVC. It is insoluble in most things but will dissolve in cyclohexanone.

Notes on PVC

In recent times, greater use has been made of chlorine donors with a larger percentage of chlorine. Cereclor 70, for example, is a chlorinated hydrocarbon which contains 70% chlorine and there is a chlorinated PVC called Lucalors.

These chlorine donors come in powdered form or in the form of fine granules. The granules are apt to get charged with electricity and adhere, but they are useful for producing denser mixtures—for example for ball stars.

Some processes use the PVC in the composition as an adhesive for making stars but this also has the additional problem of using organic solvents. Cyclohexanone could be a solvent of choice, possibly with the addition of Octyl phthalate, but it is not pleasant to handle industrially.

Potassium Benzoate, $C_6H_5.COOK$

Whistling compounds occasionally use this substance in combination with potassium perchlorate. The powder must be at least 120 mesh and needs to be kept very dry, since there is a tendency to absorb water from the atmosphere and the mixture will burn but not whistle.

Potassium Bichromate

Potassium bichromate $K_2Cr_2O_7$ is an orange red crystalline powder which is soluble in water and decomposes at about 500°C. It is poisonous and corrosive and care must be taken to avoid the material coming in contact with the mucous membranes.

While it is not very useful as an oxidising agent it is of great value for preventing the corrosion of magnesium and magnalium. In solution, potassium bichromate forms a reaction at the surface of the metal, thus preventing further corrosion (see Chapter 5).

Potassium Chlorate, $KClO_3$

One of the most important chemicals used in the firework industry, this material is prepared by the electrolysis of potassium chloride solution, and is frequently imported into England from Spain and Switzerland. It is a fine white powder passing 170 mesh and is normally of 99.5% minimum purity. The melting point is 360°C. The sensitive nature of potassium chlorate is a problem to the firework manufacturer, particularly in the presence of sulphur, ammonium salts, and phosphorus, and none of these materials should be used with it. Wherever possible, potassium perchlorate should be used in the place of the chlorate, but this is not always possible. There is also a tendency to use it more in commerce because it is cheaper than the perchlorate.

Potassium Nitrate, KNO_3

The modern method of manufacturing potassium nitrate is to mix hot saturated solutions of potassium chloride and sodium nitrate. Sodium chloride crystallizes out first followed by the potassium nitrate. Purification then takes place by re-crystallization. It has a melting point of 334°C and is usually imported into England. Two grades are used in fireworks, both 99.8% purity, but vary only in particle size. The fine powder passes about 180 mesh, but some use is made of a coarser crystalline powder of about 60 mesh. Unfortunately, the fine powder tends to cake and *invariably* has to be re-ground prior to use.

Potassium Perchlorate, $KClO_4$

It is obtained by the electrolysis of cold concentrated sodium chlorate solution, followed by precipitation with potassium chloride. It can be freed from potassium chlorate by digesting it with concentrated hydrochloric acid, with which the perchlorate has no reaction. Material of at least 99.5% purity is used and this is imported. The fine white powder usually passes 170 mesh. It decomposes at 400°C. Wherever possible the perchlorate is used in preference to the chlorate, but it still requires careful treatment. Mixtures of sulphur and potassium perchlorate are less sensitive than those with potassium chlorate. In view of this, people frequently add sulphur to stars made with the perchlorate to improve the somewhat difficult ignition, but this is not recommended. Charcoal will usually help the ignition of perchlorate stars without the addition of sulphur.

Potassium Picrate, $C_6H_2(NO_2)_3OK$

This uncommon salt is normally only prepared in small quantities for the firework manufacturers. It forms yellow crystals which are slightly soluble in water and which decompose on heating to about 300°C. As with picric acid and other picrates, it is sensitive to shock, but is reasonably safe to handle if care is taken. The salt is used for making whistles and can be pressed alone or mixed with potassium nitrate, stearine or asphalt. Asphalt is the least suitable as it is rather unpleasant to handle in fine powder. It is worth mentioning that since lead picrate is dangerous, lead ramming blocks should not be used. Picrate whistles have been superceded by other types.

Silicon, Si

The dark grey powder of commerce is known as "fuzed" silicon. It usually passes 240 mesh and contains about 94/95% of silicon. The material is only used in fireworks as an igniter in certain types of fireworks which need a hot slag to initiate the reaction, and for this purpose it is frequently mixed with potassium nitrate and gunpowder. Silicon melts at 1420°C.

Silicon Dioxide, SiO_2

Recent years have seen the appearance of very pure forms of silicon dioxide obtained by flame hydrolysis. Products such as Cab-o-sil or aerosil have an average particle size of about 16 μ and are used as grinding, sieving and "free-flowing" aids for hygroscopic and other products. They also help to prevent the electrostatic charge of powdered substances and have many other uses such as thickening and thixotropic agents for liquid systems, pastes and emulsions.

Pyrogenic silicas are either hydrophillic or hydrophobic. Hydrophobic aerosil R 972 adsorbs only 0.8 millimol water even at 80% humidity. Hydrophillic aerosil, on the other hand, adsorbs 20 times this quantity.

The material is of extremely low density and flies about the workshop, but there is no evidence that it caused silicosis. Some firework manufacturers are said to use the material for coating iron and for adding to flash powders in the proportion of about 0.1%.

Sodium Azide, NaN_3

Most azides are explosive and demonstrate high thermal and mechanical sensitivity. Exceptions are the alkali metal azides which decompose on heating but do not explode. Sodium azide is formed as follows:

$$NH_2Na + N_2O = NaN_3 + H_2O \ (T = 200°C)$$

Sodium azide is used in pyrotechnics as a nitrogen generator.

Sodium Nitrate, $NaNO_3$

Chile saltpeter, originating in the caliche deposits, comes to Europe for final refinement, but sodium nitrate is also manufactured from synthetic nitric acid by neutralization. The crystals are readily soluble in water and melt at 308°C. Sodium nitrate is not used normally in fireworks due to its hygroscopic nature, though the degree of water absorption is related to the purity of the salt. In combination with magnesium, it is useful for illuminating flares, but the stores have to be sealed so that they do not come into contact with the air.

Sodium Oxalate, $Na_2C_2O_4$

Prepared commercially by neutralization of oxalic acid, it forms white crystals soluble in water but insoluble in alcohol. It melts at about 250°C and is normally bought as a fine powder of 120/200 mesh.

There are two main uses for this substance. The first is for the production of yellow colors in combination with potassium perchlorate and suitable fuels. Potassium chlorate is unsuitable as it is likely that some double decomposition will take place with formation of deliquescent sodium chlorate. It is also advisable to use spirit only when making stars with this material since water will tend to accelerate any reactions which may take place. The second use is the production of yellow glitter effects, with gunpowder, aluminum and antimony.

Sodium Salicylate, HOC_6H_4COONa

This substance is made by heating sodium phenate in an autoclave with carbon dioxide. It forms white, lustrous, pearly scales, soluble in water and alcohol. The powder used for making whistles must pass 120 mesh and is used in combination with potassium perchlorate. As with potassium benzoate, the whistles are effective but are liable to deteriorate in storage, owing to the gradual absorption of moisture. The absorption of water also seems to be accelerated in the presence of natural resins.

Starch, $(C_6H_{10}O_5)_n$

Although it is almost insoluble in cold water, starch dissolves in hot water to form a thick solution which can be used as an adhesive. It is frequently used for making quickmatch, and some forms of it are used for making stars in Japan. Maize starch is sometimes added to compositions to cut down the burning speed. Flour can also be used for this purpose. Japanese soluble glutinous rice starch is a white or slightly brown powder which dissolves easily in water to form a very adhesive paste. It is manufactured by soaking glutinous rice in cold water, steaming, and subsequently pounding the material into a rice-cake. The rice-cake is then roasted and finally pulverized.

Stearine-Stearic Acid

The material is probably a mixture of stearic and palmitic acids obtained by hydrolysis from their glyceryl esters. The powder used for firework manufacture usually passes 80 mesh. The main use for this material is for adding it to some compositions which are somewhat sensitive to friction. It can also be used in those fireworks where it is desirable to have a long flame.

Strontium Carbonate, $SrCO_3$

Strontium occurs naturally in England and elsewhere as strontianite, $SrCO_3$ or celestine, $SrSO_4$. The natural carbonate is frequently used in firework manufacture and is usually a pale pink, fine powder of about 120/200 mesh. Purer forms are made by boiling celestine and ammonium carbonate or fusing celestine and sodium-carbonate. Strontium carbonate is used more than any other salt, for making red flames and stars, but it also finds an occasional use as a retardant in some gunpowder mixtures. It is insoluble.

Strontium Oxalate, $SrC_2O_4.H_2O$

This material is manufactured by precipitation. It is a fine, white insoluble powder, losing its water at about 150°C. It is often used to obtain red color as with carbonate, but is considerably more expensive. The water content is also something of a drawback. As with the carbonate also, it finds an occasional use in the manufacture of glitter stars with gunpowder and aluminum.

Strontium Nitrate, $Sr(NO_3)_2.4H_2O$

Needless to say, only the anhydrous salt is used for firework manufacture. It melts at 570°C and decomposes to the oxide at 1100°C. In many ways this is the best of the strontium salts for it gives a very rich flame coloration, but unfortunately the technical grades will very quickly become damp when mixed with potassium chlorate. The inconvenience of having to dry the salt, and use the fireworks made with it fairly quickly, somewhat limit its use. It is most commonly used in combination with magnesium and PVC for the manufacture of red stars and flares which are pressed dry. It also is used in the manufacture of bengal illuminations and road flares.

Sugars

Lactose, $C_{12}H_{22}O_{11}.H_2O$ is sometimes used as a fuel in firework manufacture. The water can be removed only at about 125°C and lactose melts with decomposition at 200°C. Used in compositions which are required to react at low temperatures, it is of use in the manufacture of some blue colors. It also replaces sucrose, which is more sensitive with chlorates. Perhaps the most extensive use is in the manufacture of smokes using organic dyes.

Sucrose-beet or cane sugar $C_{12}H_{22}O_{11}$- is used only in the production of colored smokes along with potassium chlorate and an organic dye or mixture of dyes. The finely powdered confectioners' sugar is used for this purpose, and it appears to be fairly safe in combination with the chlorate and an excess of dye. It melts at 160°C. Sorbitol, $C_6H_{14}O_6$, with a melting point of 98°C, and mannitol, $CH_2OH.\ (CHOH)_4,\ CH_2OH$ of melting point 166°C, have also found some use in special pyrotechnic products, the former in smokes and the latter as a fuel in some signal stars.

Sulphur

"... and he shall be tormented with fire and brimstone in the presence of the holy angels." Rev. 14, 10."

One of the most important fuels of the firework industry, it is a pale yellow, fairly dense powder, all of which should pass 120 mesh. Some use is also made of a rather coarse powder in the manufacture of pinwheels. During the distillation process and presumably the melting which takes place in the Frasch process in the USA, the sulphur solidifies to a solid mass of rhombic crystals. This mass, soluble in carbon disulphide, is powdered and forms the powdered sulphur of commerce. It must not be confused with Flowers of Sulphur, which is produced during the distillation process. The powder produced by cooling sulphur vapor always contains some free acid, maybe as much as 0.25%, and is therefore quite dangerous to use.

Sulphur melts at 113°C and ignites at about 260°C. It is in plentiful supply, is non-poisonous, cheap, and safe to handle.

Synthetic Resins

Recent years have seen the introduction of urea-formaldehyde, phenol-formaldehyde (Bakelite) and resorcinol-formaldehyde resins. They are generally used in the form of syrups which can be mixed with accelerators and oxidizing agents, and the resulting mass sets to a hard solid under various conditions of temperature and pressure.

Thio-Urea, $(NH_2)_2CS$

Thio-urea is a white crystalline solid melting at about 180°C. It finds some use in the production of white smoke in combination with potassium chlorate etc.

Titanium, Ti

Although titanium has found use in military compositions for some time, it was probably not until the first edition of *Fireworks Principles and Practice* that the metal became widely used in the firework industry. Trials were carried out about 1960 in the United Kingdom with material which consisted of swarf from the aeroplane industry.

The first material to be used consisted of sharp acicular fines of varying mesh size and there was also some other rubbish and oil as one would expect to find in a machineshop. The material is very hard and although it is not corroded by water -or dirty to handle- it is possible that some fires were caused by friction. There were certainly enough to give cause for concern, but the waste material was also cheap.

More recently there has been a move to using the sponge material, and it appears that there has been less accidents as a result of this. While no one can be sure, it is generally agreed that sponge material is the safest to use.

The metal is easily ignited to produce brilliant silver sparks, can be used in just the same way as iron powder, and has the advantage of not needing to be coated. Like all new things it may have been overused, but no one regrets the absence of the dirtier old aluminium powders.

Ferro-titanium is also very useful for making fireworks. Very much depends on the percentages in the alloy and the temperature of the flames. High percentages of titanium tend to be silver or silvery gold, but at levels of only 30–40% titanium some beautiful gold sparks can be produced. The alloy does not corrode easily.

Two accidents in the United Kingdom prompted the Government Flame Laboratory to conduct experiments to try to determine the sensitivity of the metal in firework compositions. One accident had involved pressing a mixture of 70% commercial blackpowder and 30% titanium. The conclusion has been published (48), (43) and comes to two main views:

1. That the particle size of the metal is not critical. Tests used sizes of 355–500 μm and 710–1000 μm
2. Compositions containing 15–30% titanium were the most dangerous and an 8% might be a considerable safety gain.

All information of this nature is a boon to the trade. However, we do not know what kind of titanium was used in the trials and most people are of the opinion that the sharp acicular turnings could be more dangerous than sponge titanium. We have to also remember that manufactured blackpowder is more energetic than mixtures of its basic components. Would that we could be certain of anything!

In a personal communication, Prof Yurii Frolov speaks of a novel type of titanium supplied by the Institute of Chemical Physics at the Russian Academy of Science in Moscow.

Powders of high surface area of titanium are made by the high temperature reduction of TiO_2 using magnesium as a reducing vapour. Commercial grade TiO_2 and fine magnesium powder (99.7%, 44 μm) were put in a reactor under argon (1 bar) and heated locally for ignition.

The heat of the reaction:

$$TiO_2 + 2Mg = Ti + 2MgO \ (H = -330 \text{ kJ/mole})$$

is sufficient to sustain the conversion reaction once ignited. In the reaction front of the combustion wave the measured maximum temperatures were in the range of 2100-2500°C.

The solid product which consists of a mixture of Ti, unreacted Mg, MgO and unreacted TiO_2 was leached with 10% hydrochloric acid, washed with distilled water, dried, milled and sieved. Analysis revealed the following impurities by weight, Mg 0.8%, MgO 0.5%, TiO_2 2.0%, Cl 0.01%.

The industrial Kroll method for the production of titanium sponge reduces titanium chloride in molten magnesium and yields metal powders which have a surface area in the order of 0.1 m/g after milling. However the combustion wave process has a higher figure (up to 20 m/g). Powder made in this way is more reactive than aluminium, magnesium and commercial titanium powder and more stable for use in pyrotechnics.

Titanium Dioxide, TiO_2

This oxide is not much used by the firework industry, but occasionally features in some smoke compositions and is sometimes added to waterproof paints.

Petroleum Jelly-Vaseline

The jelly has sometimes been incorporated into illuminating compositions where it waterproofs, binds and helps to de-sensitize-but little use is now found for it.

Zinc, Zn

Certain recipes in the old firework books included zinc, but little use is made of the finely powdered variety except in the manufacture of certain types of smokes. Zinc smokes are very efficient and very good but they are somewhat sensitive to moisture and have been known to react and ignite themselves. Most schoolboys know that a mixture of zinc, ammonium nitrate and ammonium chloride will catch fire when a small amount of water is added to the powder.

Zinc Oxide, ZnO

The principal use for this material is also in the manufacture of smokes. Many of the smokes used in warfare are basically mixtures of zinc oxide, hexachloroethane and calcium silicide. Zinc oxide has also been used by the Germans in mixtures of barium nitrate and aluminum in the manufacture of Very stars. Apparently it helps to melt the aluminum tube.

5

GENERAL PYROTECHNIC PRINCIPLES

The burning speed of a firework mixture is governed by a variety of factors, the three most important being particle size, temperature, and pressure. In commercial practice it is the particle size which produces the greatest problems, mainly because any material can vary from a coarse powder to a powder which is fine and impalpable. Naturally variations exist between these two extremes and chemical batches can vary from one manufacturer to another. Indeed it is even possible to get variations between different batches from a single manufacturer. In practice, materials are bought to a specified mesh size; potassium nitrate for example might be bought as 150 mesh powder.

Originally a 150 mesh sieve had 150 wires to the inch, but so much depended on the diameter of the wire itself that this inevitably led to standardization. In more recent times greater accuracy has come about by measurement of the opening between the wires. 1 μ in this system represents $^{1}/1000$ mm as shown in Table 5.1.

It will be noted that British and American sieves are much the same and are still used in commerce.

It is well known that a firework composition will usually burn much faster with the increasing fineness of the chemicals used. On some occasions the firework maker will use this principle in order to make fast burning stars or explosives, but he may also do just the opposite and employ slow burning compositions in portfires. The burning speed of a pyrotechnic composition is also affected by the surrounding temperature, and so it will be found that as the initial temperature increases, so will the combustion rate. Large quantities of gases are usually produced in these burning processes and although these gases normally escape into the air, the story is rather different if the burning takes

Table 5.1 Standard Sieves

American Sieves	British Sieves	Sieve Opening in Micron
12	10	1680
18	16	1000
20	18	840
30	25	590
35	30	500
40	36	420
60	60	250
70	72	210
80	85	177
100	100	149
120	120	125
140	150	105
170	170	88
200	200	74
230	240	62
270	300	53

place in confinement. In an enclosed space the combustion rate rises quickly and may become explosive.

Turning to the important matter of sensitivity, the firework maker is primarily concerned with the sensitivity to shock and friction. To some extent he is also concerned about ignition temperature, but the sensitivity to shock and friction is of greater practical importance, mainly because firework mixtures are usually more sensitive than ordinance compositions. In general firework mixtures which are more sensitive to friction are also more sensitive to shock, but this is not necessarily the case.

Shock sensitivity is usually determined with a drop hammer. A small quantity of composition is placed on the anvil of the apparatus and a known weight is allowed to fall on the anvil. The weight is dropped from various measured heights until a minimum distance can be recorded at which the material explodes. Several trials are necessary for any degree of accuracy, but the method provides a useful comparison between various mixtures. Sensitivity ratings can be produced in this way, one method, for instance, uses picric acid as a standard with a figure of 100.

Friction sensitivity is sometimes vaguely determined by striking the mixture a light glancing blow with a polished hardwood mallet, but a more accurate method uses two weighted porcelain plates. A small amount of the mixture is placed between the plates which rub against each other. A comparative set of sensitivity figures can be obtained by weighting the plates and determining when the mixture explodes or ignites. The Germans use a mixture of potassium chlorate and gallic acid as a standard with a sensitivity figure of 1. On this system a chlorate color star would have a figure between 2 and 8, a perchlorate and aluminum mix would be about 6, while gunpowder would be about 36 or more.

It can be seen from these figures that it is the chlorate mixtures which are the most sensitive, and there is no doubt that barium chlorate presents the greatest hazard in that compositions made with it are almost as sensitive as mixtures of potassium chlorate and gallic acid. Part of the problem seems to lie in the fact that potassium chlorate, for example, begins to decompose at a fairly low temperature, about 350°C, and that this decomposition is also accompanied by the evolution of a small amount of heat. Perchlorates and nitrates are much safer in this respect.

The extreme danger of mixing potassium chlorate and phosphorus is almost too well known to comment upon. Similarly chlorates and sulphur present a serious hazard when placed together and are not normally used. Indeed such mixtures were banned by law in England as long ago as 1894. The discovery of potassium chlorate by Berthollet at the end of the 18th century produced a major step forward for the firework industry. By 1830, the industry was able to produce colours which had never been seen before.

During these early years of the 19th century, fireworks were very much of a cottage industry with historical works like Brock describing factories in city suburbs and people drying stars in front of open fires. In the UK, the Gunpowder Act of 1860 and the Explosive Acts of 1875 did much to regulate the manufacture of explosives but it did not stop accidents, which occurred with monotonous regularity, many of them appearing to be caused by the use of a chlorate.

The annual report of Her Majesty's Inspectorate of Explosives in 1894 cites a number of interesting accidents. One of these concerns a Mr Hicks, who had manufactured signal lights which could be attached to a kite and fired by electricity. Mr Hicks had seven of these items hanging on a wall outside his central London premises and after about two years, exposed to all weathers, two of them suddenly exploded. The signals were made of barium chlorate and shellac and they were primed with a sulphur composition. They had been wet and they exploded during a period of hot weather.

In the report issued in 1890 there is a report of the explosion of a magazine at the factory of James Pain. This took place on the 6th July when about 7 tonnes of fireworks exploded just before noon on a Sunday when no-one was at work. As quite a number of possible factors could be eliminated in the circumstances, it was assumed that this was caused by spontaneous combustion. In the same report, a number of accidents all involved the destruction of drying rooms, thus raising the suspicion that there must be some chemical instability which was causing these problems.

Chemical investigations instituted by Colonel Majendie, the Chief Inspector, came to a number of conclusions about the chemicals in use *at that time.* These words are stressed because there may be some significance in this. Lampblack was found to contain free sulphuric acid. Chertier's Copper made by treating copper sulphate and potassium chlorate with ammonium hydroxide was alkaline when freshly made but 'acidic when it lost ammonia' They do not mention the possibility of ammonium chlorate. Paste for damping pill box stars was made with alum and found to be acidic.

Colonel Majendie issued a Memorandum to the industry on 1st January 1882 instructing the industry that care must be taken. Two further accidents established that sulphuric acid had been found in stearine, that linseed oil had been found to cause spontaneous heating even when it was partly polymerised by boiling, and that fountains containing chips of coloured stars had been known to cause spontaneous combustion. Warnings were also issued about the need to perfectly wash Flowers of Sulphur, the subject being discussed after a spontaneous accident from coloured fire aboard a pleasure steamer in Norwich. The report mentions as many as twelve accidents between 1873 and 1880.

Of particular interest is the manner in which lances were made in the factory of James Pain. The lances were charged with colour compositions containing either potassium or barium chlorate, and then they were topped with a white fire igniter which contained potassium nitrate, Flowers of Sulphur, and antimony sulphide. The report makes the point that either of these mixtures is quite safe when separated, but dangerous when brought into contact. In fairness to Pain, the investigator makes the point that careful charging had been done but he goes on to suggest that if a suitable intermixture took place at the junction, then this would be quite dangerous.

Alas, exactly 10 days after this report had been made, fire broke out in one of Pains filling sheds. This fire was caused by the observed spontaneous ignition of green lances which were lying on a shelf in the shed. There was only one workperson in the shed at the time and she was able to put the fire out promptly with a bucket of water which was there for the purpose. Shortly afterwards Pains informed the Inspectorate as follows: "I have received advices from America to the effect that some of our green lances caused an explosion there some days ago."

A number of accidents occurred due to the charging of Roman Candles with chlorate stars and the report goes on to say, 'by themselves these stars would not, I believe, give rise to danger, but closely packed into a mixture containing sulphur they are not, I think, quite free from danger of spontaneous ignition. On the one hand, no doubt the hard mass of the stars offers less chance of action than the contact of two but slightly compressed mixtures. On the other hand, however, the surfaces in contact are far greater, assuming no actual mixture to have taken place, and in view of the present accident it certainly seems in the highest degree advisable never to imbed a star containing a chlorate in a mixture containing sulphur.'

Roman Candles have been made with chlorate stars in the West until quite recently and in some cases they were imbedded in compositions which contained as much as 28% sulphur, though few people would use Flowers of Sulphur in these times. Good quality ground rock sulphur contains very little free acid. A candle composition which contained no sulphur but did contain a percentage of soft grain commercial gunpowder would be well within guidelines referred to later.

Work carried out by Colonel Majendie produced the Order in Council of 1894 which finally made mixtures of chlorates and sulphur illegal. This is just over one hundred years ago and the problem is still with us today. The research which had taken place also involved the detonation of star shells which had caused some very serious accidents. Indeed Brock had been involved in these exercises and it was widely believed that many detonations had been caused by soft chlorate stars which had crumbled to some extent. It was also stated that stars made with either sodium oxalate or copper acetoarsenite were particularly liable to create this problem. As a result Brock stated that large shells were always charged with these coloured stars mixed with lampblack stars to lessen the likelihood of detonation.

This information has been placed in its historical context in order to show how well these events have served those of us in the Western hemisphere. Changes of compositions had to come about in 1894 and the absence of sulphur in coloured mixtures was not a very great problem and after all, the prohibition was only for clear mixtures of chlorate and sulphur. However, some effects like stars did not ignite very well and it was accepted that a coating with a sulphur containing blackpowder type mixture did not constitute an admixture and usually the migration of sulphur into the chlorate mix was not very great. This was a very important and needful guideline and it will be seen that it influenced the thinking when designing a suitable Roman Candle fuse. It could contain manufactured grain gunpowder but not sulphur.

Some years ago the British Government once again looked at the matter particularly with the increase in importation from the Far East and raised a number of interesting issues. The first of these raised the question of how pure the chlorates were in the last century when these accidents were so common.

A part of the problem in this case is due to the tendency for sulphur to be acidic and so to accelerate decomposition. An article on the instability of chlorate-sulphur mixtures (21) postulates a trigger reaction caused by the formation of polythionic acids on the sulphur. It is possible that air oxidation produces sulphurous acid on the surface of the sulphur and that this immediately reacts with the sulphur again to form polythionic acids. Evaporation of aqueous polythionic acid or a rise in temperature causes the partial decomposition of the polythionic acid as follows:

$$H_2S_nO_6 = H_2SO_4 + SO_2 + (n-2)S$$

Sulphuric acid is likely to react with the chlorate to form chloric acid and is thought to be a cause of instability, but sulphur dioxide also reacts with the moist chlorate to form the highly explosive chlorine dioxide.

$$SO_2 + 2KClO_3 = 2ClO_2 + K_2SO_4$$

$$2ClO_2 + 4S = 2SO_2 + S_2Cl_2$$

The chain reaction is influenced by friction, impact, sunshine and heat. Experiments seem to suggest that natural sulphur is less reactive than sulphur formed by cooling sulphur vapor, and that the formation of sulphur dioxide contributes more to instability than the possible formation of chloric acid.

Undoubtedly the difference between the chlorate and the perchlorate ions is related to their structure. It could be that the chlorate ion is flat but that the perchlorate ion is tetrahedral with the possibility that elemental sulphur can approach the chlorine atom in one case but not the other. With regard to stability, the fact that perchlorate involves a chlorine atom sharing its four pairs of electrons with four oxygen atoms, must be an advantage over chlorate with three oxygen atoms and an unshared pair of electrons. Whatever it may be, it is agreed that a true mixture of chlorate and sulphur is hazardous and that a 'contact' is subcritical.

It must be remembered that potassium chlorate made by electrolysis is much purer than it used to be. The old-fashioned method of manufacture from chloride of lime must have had calcium chlorate impurities and this substance is highly unstable. It is common in these days to make sure that chlorate compositions are damped down with pure water particularly if the local supply is 'hard', i.e. contains calcium and magnesium salts. A wet process and a rise in temperature in sulphur-containing mixtures may lead to a deterioration of the sulphur and a risk of spontaneous combustion.

Chlorate stars are coated with blackpowder-type mixtures and it has to be admitted that in present times, this does not seem to be a major problem. Sulphurless gunpowder can also be used, but the price militates against this as manufacturers have to dedicate special machinery for the purpose.

The fact that it seems reasonably safe, therefore, to coat chlorate stars with blackpowder mixtures means that some degree of compromise is needed in those countries which have legislated against chlorate and sulphur mixtures.

As a result of various investigations, it has been unofficially agreed (by some) that:

1. The chlorate could be present as the ingredient of a consolidated star.
2. The sulphur could only be present as an ingredient of gunpowder or a similarly formulated composition used as an igniting or bursting charge. The charcoal to sulphur ratio should always be at least 3:2, i.e. with charcoal in excess.
3. The stars may be primed with gunpowder provided that there is no migration of the sulphur into the star composition.

Chlorate/sulphur mixtures have not existed in the many areas of the West for almost a century. However, the economic situation means that huge volumes of fireworks are being imported from the Far East and the growth continues. While importation was in the hands of manufacturers who understood the issues at stake, all was well. Now, however, the situation is out of control.

Importers now bring in fireworks in much the same was as they might import bananas and there is much ignorance. Where laws still exist, the onus is on the importer to test extensively, and this is very expensive and time consuming.

Some firework makers add sulphur to perchlorate mixtures, and while it has to be admitted that such mixtures are less sensitive than chlorate ones, they are best avoided. Tests seem to indicate that mixtures of perchlorate and sulphur are only marginally less sensitive to impact and friction. The main point really is that they are chemically more stable.

Mixtures of chlorates with magnesium, aluminum, metallic arsenic, the sulphides of arsenic, antimony and phosphorus are all highly sensitive both to shock and friction.

It is clear that nitrates are by far the safest oxidizers, but it is obvious that even they can be dangerous in some situations (e.g. when mixed with fine metal powders).

Very many factors play a part in the ignition of firework compounds, but the following general points contribute to an increase of sensitivity:

1. Mixtures with fine particles
2. Intimate mixtures of the chemicals
3. When the components are in stoichiometric proportions, an excess of fuel often decreases sensitivity.
4. Increase in temperature
5. Loose powder is more sensitive than compacted masses.
6. The presence of grit and impurities
7. Increase in pressure.

An increase of outside pressure will lead to an increase in the burning rate and this could lead to explosion with the destruction of both the charge and the equipment. Under high pressure, the combustion products, the hot gases, can easily penetrate the pores of the charge and so pre-heat the mixture. This leads to a higher rate of combustion, and what started as a stable process converts to convective combustion and possibly a detonation.

Needless to say, granulation of explosive composition increases the burning speed. A pile of colored star composition will probably flare up when ignited causing much heat and flame. If, however, the composition had been made into stars, their ignition could lead to detonation with considerable destructive force. Loose powder containing metal powder would also detonate if the quantity was appropriate.

Phlegmatizers are frequently added to firework compositions so that friction sensitivity can be reduced; stearine, vaseline and paraffin oil can be particularly useful in this respect. In some cases inert substances can be added and, although they do not take any part in the combustion, they effectively reduce sensitivity. Carbonates can be useful for this purpose and in addition are useful for reducing any tendency towards the formation of acidity. It is advisable for example to add a few percent of barium carbonate to green stars which are made with barium chlorate. Strontium carbonate is particularly useful in red fire compositions as it serves a double purpose of providing color and phlegmatization.

The decomposition of chlorate mixtures require little heat for their initiation and so are unlike either the perchlorate mixtures which do need a little, or the nitrate mixtures which need a large quantity of heat before decomposition can take place. In addition, the presence of fine metal powders provides an extra liability to decomposition; mixtures of chlorates and magnesium are particularly hazardous. Potassium perchlorate and aluminum is much safer than the chlorate, as one would expect, but barium or potassium nitrate and aluminum would be the better choice if the required effect could be obtained with these substances, though this is not always possible. Nevertheless, barium nitrate and aluminum mixtures present problems and have been known to produce very unpleasant explosions when handled in large quantities. The high ignition temperature of aluminum can make these mixtures difficult to ignite, particularly if atomized aluminum is used, but with the fine flake powders the mixture can be quite explosive. Naturally the addition of sulphur to a mixture of barium nitrate and pyro-aluminum will make the mixture easier to ignite, but it is also considered that this increases the sensitivity and it is best avoided if possible. Wet mixtures of these substances are apt to heat up from time to time and since the decomposition of aluminum is an alkaline reaction, it is advisable to add something to counteract this; one or two percent of boric acid can be added for this purpose.

Moisture is always a problem to the firework maker and since fireworks have to be stored for periods of time in varying conditions, and invariably in unheated buildings, they are bound to absorb some moisture. When large amounts of water are absorbed physical changes are likely to occur, making the fireworks useless or even dangerous to handle. Chemicals vary in their degree of water absorption, but it is essential to avoid the use of those materials which have a tendency to absorb moisture. Consideration has also to be given to the possibility that in the presence of water electrolytes will exchange their partners to form a partial double decomposition. The chemistry of this reaction is well known, but it would clearly be unwise, for example, to use potassium chlorate and sodium oxalate together since sodium chlorate is so deliquescent. Sodium oxalate can be used much more satisfactorily with potassium perchlorate of course, but all oxalates occasionally present their problems in the presence of water and impure chemicals. This does not seem to be the case however in gunpowder-type mixtures.

It is possible to produce some degree of protection from moisture by the addition of oils and resins etc, but it is essential to be careful in the choice of the most stable materials. Magnesium and aluminum are particularly reactive in the presence of moisture. Fortunately aluminum tends to oxidize only on the surface with the formation of a protective film of aluminum oxide. Magnesium, on the other hand, does not form such a protective oxide and the corrosion continues. As a rule, the magnesium is coated with protective layer of linseed oil, lithographic varnish, paraffin wax or one of the natural or synthetic resins.

Titanium is now becoming increasingly useful and easier to obtain, and has the great advantage of being both unaffected by water and quite safe, provided that its particles are not sub-sieve size. Titanium filings seem safer and more stable than most other metals used though it is very hard and friction sensitivity must be considered. It is worth recording that there have been several fires caused by people charging titanium compositions with a mallet and drift; pressing is safer. (See Titanium Chapter 4).

Since the Second World War the use of magnesium or aluminum with nitrate oxidizers has become increasingly popular, and while this has certain advantages during processing, it has been established that such mixtures are more likely to decompose in the presence of water with the formation of ammonia.

$$8Mg + 16H_2O = 8Mg(OH)_2 + 8H_2$$

$$Ba(NO_3)_2 + 8H_2 = Ba(OH)_2 + 4H_2O + 2NH_3$$

Since moisture is so critical in these mixtures, it is clear that barium nitrate is the most useful oxidizer and for much the same reasons aluminum is used much more for firework manufacture than magnesium.

The addition of sulphur to mixtures of barium nitrate and aluminum does not particularly affect stability, but it is unwise to add sulphur to magnesium mixtures as they are liable to react in the presence of moisture. During the Second World War, German igniter compositions for magnesium stars contained sulphur or blackpowder or a combination of these. Problems were encountered with the influx of moisture and an attempt was made to overcome the problem by using a mixture of potassium nitrate, aluminum and gelbmehl (tetranitrocarbazole) (12). According to Schidlovsky (4) powdered alloys of magnesium and aluminum are much more stable chemically for they are coated with a film of aluminum oxide.

From time to time barium peroxide appears in pyrotechnic formulas, but is rather too dangerous for use in fireworks and when mixed with aluminum it is liable to heat up in the presence of water. Ammonium salts need to be used with great caution and must certainly not be mixed with materials which can cause reactions in the presence of water. Potassium chlorate is hazardous with ammonium salts, particularly the nitrate, since the highly explosive ammonium chlorate can be produced by double decomposition. Magnesium is particularly liable to heat up in the presence of ammonium salts, the reaction proceeding at great speed with the evolution of hydrogen. (The author once had a "close shave" when ammonium perchlorate was accidentally added to a magnesium mix instead of the corresponding potassium salt.) Certain old-fashioned commercial smoke formulas were compounded by mixing ammonium chloride with potassium chlorate and are somewhat unusual because they appear to be relatively stable. In general, ammonium salts are not now used, with the exception of the perchlorate.

Dr Shimizu (34) has conducted many experiments on the stability of pyrotechnic mixtures. Although most pyrotechnic mixtures are mixtures of solids, the presence of limited amounts of moisture may allow the movement of some ions. It is therefore suggested that in planning combinations we should think of the mixture in terms of a concentrated solution.

Dr Shimizu sets out many examples to show that the constituents of a double decomposition reaction will proceed to the left or the right depending on the solubility of the materials. The reader must look this up for himself, but examples cited are the above mentioned dangerous mixture:

$$KC1O_3 + NH_4C1O_4 \rightarrow KClO_4\downarrow + NH_4ClO_3 \qquad A$$

10.1 29.9 2.6 53.4 Solubility gm.

However the comparatively safe mixture is:

$$KC1O_3\downarrow + NH_4Cl \leftarrow KC1 + NH_4ClO_3 \qquad B$$

10.1 41.4 37.2 53.4

In A, the reaction proceeds to the right because the $KC1O_4$ has the minimum solubility; it is dangerous and could lead to spontaneous combustion.

In B there is no danger because $KC1O_3$ has the minimum solubility.

Dr Shimizu also points out that mixtures of ammonium perchlorate with nitrates have a similar explanation. A mixture of ammonium perchlorate and potassium nitrate will proceed to the right with the formation of hygroscopic ammonium nitrate. On the other hand, when ammonium perchlorate is mixed with barium nitrate, no moisture is formed, the reaction stays to the left due to the minimum solubility of Barium nitrate (11.4) compared to ammonium nitrate (238) and barium perchlorate (320).

Related to these matters is the treatment of metal powders with potassium dichromate. The technique is well known for passifying the surface of metals. For many years powders were treated with hot solutions of potassium dichromate, quickly dried and then further treated with other materials like magnesium stearate. Dr Shimizu has again done much research into this important matter and more precise details are given in Chapter 23.

It has been pointed out that ammonium perchlorate is not the best material to use with magnesium and reactions occur during storage. The use of potassium dichromate also has its risks in such combinations but because of the theory above, Dr Shimizu makes the point that it would be better to use ammonium dichromate in this special case.

The use of potassium dichromate can lead to the formation of small amounts of acid and it would be wise to add small amounts of the appropriate carbonate, e.g.

$$K_2Cr_2O_7 + Ba(NO_3)_2 + H_2O \rightarrow K_2CrO_4 + BaCrO_4 + 2HNO_3$$

$$K_2Cr_2O_7 + SrCO_3 + H_2O \leftarrow K_2CrO_4 + SrCrO_4 + H_2CO_3$$

$$K_2Cr_2O_7 + SrSO_4 + H_2O \leftarrow K_2\ CrO_4 + SrCRO_4 + H_2SO_4$$

As a percentage of the total weight the amounts of potassium dichromate are small.

Further studies by Dr Shimizu (44) have concluded that the coating of magnesium is greatly enhanced by adding a sulphate (other than ammonium sulphate) and some guanidine nitrate to the dichromate solution. Experiments over many years including equally long storage times have concluded that these three together create a black film of CrO_2 on the surface of the magnesium. It appears that the additional chemicals make the film stick well on the surface of the magnesium grains.

Dr Shimizu proposed the following technique:

200 gm	Hydrated magnesium sulphate
90 gm	Ammonium dichromate
20 gm	Guanidine nitrate

The chemicals are dissolved in 500 ml of water.

The solution is stirred into 1000gm of magnesium powder in a suitable aluminium bowl and stirred until the coating is complete and uniformly brown.

The powder is dried well on paper and finally sieved through 30 mesh.

Care must be taken to avoid breathing the dichromate containing dust and protective gloves should be worn.

It has been well known for many years that magnesium and magnalium will burn intermittently with the nitrates of barium and strontium. Sulphur was also a part of these reactions. However the chemistry was not well understood and there was an inherent fear of using such mixtures for long term storage.

Recent years have seen a great fascination in the development of these strobe or blinking lights. The ideal of every manufacturer would be to have the ability to produce sharp colours which would flash on and off at something between 1 and 3 hertz. This can be achieved but the manufacturing techniques are not particularly straightforward and there are problems with regard to shelf-life and the influx of moisture. These comments come at this point because the protection of the metal involves the use of a dichromate and some strobes are made with ammonium perchlorate. (Pyrotechnica XI, 29)

Magnalium has always been used in fireworks, but usually in a coarse form where it produces a pleasant crackle with coloured flame-based fountains. There is no doubt however that in the post World War II period the advent of Chinese fireworks in the West has encouraged a greater interest in the use of magnalium powder for strobe and colour effects.

The earlier Chinese mixtures were based on mixtures such as barium nitrate, magnalium and phenolic resins with or without sulphur. There have been many imitations of these stars, but quality control is not easy and the stars need careful ignition. An excellent summary of the 'state of the art' was made by Robert Cardwell the Editor of Pyrotechnica in his Pyrotechnica No. 5 1979 (29). He quite rightly reports at length the studies made by Dr Uwe Krone of Nico Pyrotechnik Hamburg. These studies were clearly a landmark in this field (45). Dr Krone gives a number of leads in composition trials, most of them based on nitrates of barium or strontium, magnalium, a nitro-compound, small amounts of perchlorate and the important catalyst. The variations in the composition are quite critical and this certainly applies to the very small percentages of copper-chrome oxide or other catalysts. The flares formulated by Dr Krone were pressed dry at heavy loads.

Good strobing bengals can be made in this way but as with so many delicate devices, the result will depend on the particle size of the ingredients and the catalyst in particular. The metal powder will need to be treated if a long shelf-life is desired and even the tube is critical. It will probably be discovered that wide bore tubes are not suitable for bengals with loosely filled composition and the wall thickness of the tube can be quite critical in affecting the strobe period, in some cases leading to continuous burning.

Further trials by Dr Shimizu (Pyrotechnica VIII, 29) came down heavily in favour of strobes made with magnesium, ammonium perchlorate, a sulphate and potassium dichromate. Undoubtedly the use of magnesium gives a much better colour and flash precision, but problems come with the priming of stars. A nitrocellulose lacquer has to be used as a binder and a specially formulated igniter has to use a similar binder.

As these stars are usually coated with blackpowder type mixtures for ignition in shells, great care has to be taken to make sure that the central nitro-cellulose based core is quite separate from the water based igniter layer. Tiny bridges between the layers would allow a chemical reaction to take place and this in turn would lead to the cracking of the stars and deterioration.

Dr Shimizu's researches came to the conclusion that strobe lights are produced from a composition which has two groups of components, a dark reaction group and a flash light reaction group. The temperature of the dark reaction is lower than that of the flash light group at first, but it increases with the accumulation of heat until it reaches the ignition point of the flash light group. A flash is then produced. At the same time a small part of the dark reaction is preparing for the next flash ignition.

Materials which provide a suitable dark reaction are

1. Sulphur with magnalium or magnesium.
2. Ammonium perchlorate with magnesium or magnalium.
3. Potassium perchlorate, guanidine nitrate and PVC.

The components of the flash reaction might be

1. An ordinary oxidiser with magnalium or magnesium.
2. A sulphate and magnesium or magnalium.

The reader is referred to Chapter 6 and Pyrotechnica VIII. (29)

Quite the best blue colors can be made with ammonium perchlorate and one of the usual copper salts. A good green can also be made with barium nitrate and ammonium perchlorate, but these mixtures tend to be slower burning and, because of the amount of gas they produce, have been reported to explode occasionally. Perhaps we need to exercise some caution in using this oxidizer, though the fear which some firework manufacturers show is perhaps based on lack of experience and it maybe unjustified. Needless to say it would be foolish to mix stars made with ammonium perchlorate with other stars made with a chlorate and, in firework plants, ammonium perchlorate requires a shed of its own. Basic copper carbonate is the best copper salt to use with ammonium perchlorate for blue colors, but care must be taken not to add either magnesium or aluminum to such a mixture (or indeed to any blue mixture) since the corrosion of aluminum powder is accelerated in the presence of copper or mercury.

The commonest oxidizers used in firework manufacture are the nitrates of potassium, barium, strontium and occasionally sodium; the chlorates of potassium and barium; the perchlorate of potassium and ammonium. It is essential that non-hygroscopic salts should be used and it is not usual to employ sodium or strontium nitrate unless they are very pure. Lead nitrate was occasionally used in former times but it has fallen into disuse. Potassium bichromate is sometimes used in match heads but it has little use in fireworks because it does not yield enough oxygen.

Table 5.2 shows how Ellern (5), quoting Schidlovsky, provides a useful information to the firework maker on relative position of oxidizers.

A percentage figure lower than 92.5 is hygroscopic thus tending to eliminate sodium nitrate. Strontium nitrate is useful when it is mixed with materials which do not encourage ionization. A good red star for example can be made with strontium nitrate, magnesium and PVC (12). Provided that a good igniter is used, and that moisture is excluded, this star keeps well for a limited period. On the other hand it is unwise to use potassium chlorate and strontium nitrate together.

In general, firework compositions contain one or more oxidizing agents and a fuel or mixture of fuels. Charcoal and sulphur are the

Table 5.2 Relative Position of Oxidizers

Salt	% RH Over Saturated Solution, 20°C
$KClO_4$	99
$Ba(NO_3)_2$	99
$KClO_3$	97
NH_4ClO_4	96
$Ba(ClO_3)_2$	94
$Pb(NO_3)_2$	94
KNO_3	92.5
$Sr(NO_3)_2$	86
$NaNO_3$	77

most common fuels but extensive use is also made of natural gums and resins such as accroides, shellac and copal. The list is quite a large one, including materials such as lactose, sawdust or woodmeal, starch and dextrine etc. (The reader is referred to Chapter 4.) It ought to be mentioned that charcoal and woodmeal can absorb large quantities of water and have to be carefully watched. Dextrine similarly will absorb water, but it is used extensively in small percentages as a binder. Aluminum and magnesium are fuels though they also provide special spark or illuminating effects. Iron, antimony, copper and titanium are also quite useful, especially titanium which produces the most beautiful silver sparks and no treatment of the metal is required. Zinc powder is sometimes used in smoke compositions, but it is little used in firework manufacture mainly because it is so reactive with water and various electrolytes.

Colored light is produced by the vaporization of the compounds of certain elements. Red, green and blue colors are produced by the elements strontium, barium and copper and while the halides of these metals would be the best compounds to employ, they are unsuitable in practice. The chlorates, chlorides and perchlorates of these three elements are either hygroscopic or deliquescent (with the exception of barium chlorate) and are quite useless in practice. Strontium monochloride, barium monochloride and copper (1) chloride are the three compounds required for the color production and the excess of chlorine has to be present to ensure their formation. Polyvinyl chloride, Parlon and Chlorowax, chlorinated rubber (Alloprene), polyvinylidene chloride (Saran), hexachlorobenzene and mercury chloride (calomel) have all been used. Calomel is not much used now because of its extraordinarily high price and toxic nature.

For ordinary firework purposes red colors are usually made with potassium perchlorate and strontium carbonate while greens are usually made with barium chlorate. Blue is more of a problem and care has to be taken to keep flame temperature as low as possible and reduce the oxygen balance. Paris Green is often used in blue stars but in recent times copper (II) oxide is more common. Yellows are normally produced by using potassium perchlorate and sodium oxalate or cryolite. The latter is particularly useful because it is not affected by water. Sodium nitrate would be very useful if it was not so liable to attack from moisture.

The ignition of the majority of the firework compositions is a simple matter because they invariably ignite at temperatures less than 500°C, and a gunpowder prime or paper impregnated with potassium nitrate may be all that is required. The matter is not quite so straightforward when the ignition temperature is higher, as for example with a mixture of barium nitrate and atomized aluminum. Similarly it can be hard to ignite a highly compacted surface, such as a magnesium star which has been pressed at several tons. In these circumstances it is usual to employ a composition which produces a very hot slag which will ensure the transfer of sufficient heat to cause ignition. Mixtures used for these purposes usually contain potassium nitrate and silicon or lead dioxide, copper (11) oxide and silicon.

Time fuses and delays for ordinary firework purposes are usually made with compressed gunpowder, which burns at the rate of about 2.5. seconds per inch. The so-called Bickford fuses are usually trains of modified gunpowder which are covered with flexible and waterproof covers. Ellern, Shimizu and Schidlovsky have written excellent textbooks in recent years, and the reader is referred to these works if he requires to know more of these principles in detail, or to learn of the more complex or exotic materials used in pyrotechnics (4,5,30,34).

The following summary may be useful:

Never mix chlorates with:	sulphur or sulphides
	ammonium salts
	phosphorus
	pitch or asphalt
	picric acid or picrates
	fine metal powders

Avoid chlorate and oxalates (moisture problems).

Chlorates and gallic acid are very hazardous. Avoid friction or impact with chlorate mixtures, and do not charge them with a mallet.

Avoid using potassium perchlorate with:	sulphur and sulphides phosphorus picric acid and picrates.

Potassium perchlorate when mixed with fine metal powders is hazardous. The same points concerning friction and impact apply also. Treat barium nitrate and pyro-aluminum with great respect. Never use fulminates of silver or mercury.

Testing Fireworks

As a number of countries have started to ban certain mixtures in fireworks it has become necessary to conduct chemical tests at the point of import. This may be a requirement banning admixtures of chlorate and sulfur, for example, or the prohibition of certain toxic materials.

As some degree of chemical knowledge is required and as chemical testing becomes ever more sophisticated, there is little scope in this book for anything more than simple guidelines. There is little point in describing the usual ions and acid radicals which can be found in a textbook. The following, however, could be quite important.

Chlorate

A drop of aniline hydrochloride solution will turn a blue/green colour in the presence of chlorate. This can be done as an aqueous solution of the material in distilled water or as a spot test. The colour depends on the amount present, but a drop of the test solution added to a crystal of chlorate produces a strong violet/blue which will stain even a plastic spot test plate. Perchlorate produces no reaction.

The test solution is made by slowly stirring 18ml of colourless aniline into 370ml of concentrated hydrochloric acid in a large beaker. Slowly add 107ml of distilled water to the aniline hydrochloride and store it in an amber bottle.

Perchlorate

Simple spot tests are not straight forward. A 0.05% solution of methylene blue in distilled water will turn violet in the presence of perchlorate on a white spot test plate, but not with chlorate. It may not be quite so obvious in aqueous solutions. Furthermore, the test using a saturated solution of cadmium nitrate in concentrated ammonium hydroxide will give a positive result with potassium perchlorate and potassium chlorate.

Maybe it will be necessary, having first eliminated chlorate, to reduce any perchlorate with sodium nitrite and concentrated nitric acid. The chlorate produced by this reaction can then be identified. However, care needs to be exercised here lest the chlorate is further reduced to chloride and so missed. The presence of chloride only (having checked its absence to start with) will be an indicator.

Zwikker's reagent reacts with an aqueous solution *of potassium* perchlorate to form minute blue crystals in the already deep blue solution. The crystals do not form with chlorate. The solution is made with 4ml of a 10% aqueous solution of copper 11) sulfate, 1 ml of pyridine and 5ml distilled water.

Sulfur

Piperidine placed on a spot of the material on a spot test plate will produce a yellow/brown colour. However, this is not foolproof for red gum also produces a yellow colour with piperidine.

As a check it is better to place about 0.3 gm of benzoin in a small test tube and add a few mg of the material to be tested. The tube is gently heated over a flame with a piece of filter paper moistened with lead di-acetate in the mouth of the tube. The filter paper turns black if sulfur is present and there is a smell of hydrogen sulfide.

Ensure that the two materials are well mixed.

Ammonium Compounds

A simple physical test is to warm the mixture with a hydroxide when the characteristic smell of ammonia will be apparent. The standard test is to use Nessler's reagent which produces a brown precipitate.

Lactose and Sucrose

These materials occur in many chlorate combinations and can be sensitive to impact and friction. The red colour obtained when mixed with Fehlings solution and heated will indicate the presence of lactose. Sucrose is more commonly used in smokes, but does not react positively to Fehlings unless it has first been heated with hydrochloric acid.

6

CHEMISTRY OF FIREWORK COMPOSITIONS

Dr T. Shimizu

Degeneration

Firework compositions are generally a mixture of selected materials for a particular purpose. Each substance is in a powdered solid state, but some of them are liquid or a semi-liquid state. The different substances are mixed and consolidated into solid masses and, as such, are not natural but artificial things.

In the course of time pyrotechnic articles have a tendency to revert from this artificial state to the more natural state, striving to get to a more stable condition. The compositions, therefore, may crack, shrink or change in quality particularly when they absorb moisture. Flares, for example, can burn excessively quickly and burst out of their tube even though they had been tested safely a short time beforehand. In this case, the loaded mixture shrunk in the paper tube creating a gap between the mixture and the paper wall. The composition contained shellac as a fuel and the relatively low softening point (about 50°-80°C) caused the composition to shrink.

Blackpowder rockets quite often burst, especially when they are large in size. This could come about by the bridging of the potassium nitrate particles and crystallisation. In the Chichibu district of Japan, an old rocket making technique is preserved as a traditional art form. Large bamboo tubes are loaded with blackpowder to which a small amount of water has been added. The rockets quite often burst, possibly caused by the bridging of the potassium nitrate crystals.

In order to avoid these degenerations, the selection of the materials and the binder is quite important so that mutual reactions can be avoided. However, the manufacturing process is also important. As a general rule, the materials must be mixed uniformly. This is quite important where a small quantity of an ingredient is mixed with a large volume of premixed materials. The former small amount should be mixed well with a small part of the large mass, and in turn should be scattered into the rest of the mass. Inadequate mixing time often causes depression after loading, particularly when the mixture contains some liquid.

There are exceptions. The late Bill Withrow wrote to the author to point out that too much mixing is not good for the so-called glitter (sparkling) effect.

In order to avoid chemical or physical changes after loading, it may be better to age the material beforehand. Materials may be coated or mixed and then matured for many hours at elevated temperatures. As an example, magnesium may be coated with boiled linseed oil and then polymerised in heat to avoid reactions after pressing.

Burning Reaction

A firework composition generally consists of several materials: an oxidiser, a fuel, special items to obtain desired effects, and a binder. These mixtures use the oxidising effect of the oxidiser e.g. potassium nitrate, potassium perchlorate, potassium chlorate, etc. However, on the contrary, there are mixtures which use reduction effects to obtain a fire, for example, magnesium can be used as the reducing agent.

The author calls the former 'Positive Explosives' and the latter 'Negative Explosives' where inert materials which contain oxygen become the reactants (e.g. H_2O, $SrCO_3$, $SrSO_4$, $MgSO_4$, etc.). In general, when negative explosives are used (e.g. as a propellent) for lifting a shell in a mortar, they create silane type substances in the ash left in the mortar. This material ignites when the mortar is cleaned using water. The following composition may be a representative example of a negative explosive which does not create such a phenomenon:

Magnesium passing 80 mesh	60%
Anhydrous Magnesium sulfate	40%

This material is granulated with nitrocellulose solution in acetone for use as a lifting charge or a noise maker. The effect is much milder than that of blackpowder or a chlorate mixture. From experiments, the force of explosives is about 12% as large as that of blackpowder.

Table 6.1 Coloured Flames of Negative Explosives

	Red	Orange	Yellow	Green	White
Magnesium passing 80 mesh	50	50	50	50	50
Magnesium sulfate hydrated $MgSO_4.7H_2O$	25	25	50	25	50
Strontium sulfate	25	—	—	—	—
Calcium sulfate	—	25	—	—	—
Glass powder	—	—	10	—	—
Barium sulfate	—	—	—	25	—
Chorinated isoprene rubber	10	10	—	10	—
Nitrocellulose solution in acetone as needed					

Table 6.1 shows how it is possible also to produce coloured flames.

Blackpowder Reactions

Very many curious burning reactions occur with mixtures of nitrates, sulfur, and charcoal—with or without some additives. They produce a large amount of ash when they burn, which plays an important role in the effect. The ash is liquid at a high temperature. When it is dispersed into the air, the temperature of the particles rise because of the reaction with the oxygen in the air. A second reaction takes place at this stage, creating sparks explosively.

The following are examples of blackpowder reactions:

Senko Hanabi

This produces a most curious effect which is not clearly understood at present.

	Weight (%)
Potassium nitrate	60
Sulfur	25
Anthracene soot low temperature type	4
Hemp charcoal	8
Anthracene	3

The sulfur content is larger than that of blackpowder and while the soot is very difficult to burn, the hemp charcoal burns very easily. The good spark effect may come from the mixture of two carbons with different burning characteristics. The anthracene helps to stop the burnmg fireball from falling after the mixture burns in the paper twist.

Firefly

This effect occurs in a narrow range of composition: between 45-55% of potassium nitrate, 0-10% sulfur and 35-65% charcoal. The sulfur content is very small and the opposite to Senko Hanabi.

The charcoal is vital to get the best effect, and it is tested by heating it on an iron plate with some form of heat underneath. The charcoal is gently stirred to gain a certain amount of ash which must not be a powder but granular. The author has only been able to find this charcoal as an hemp charcoal produced in Tochigi-ken in Japan. In the absence of such a charcoal, additional material is necessary as follows:

Firefly *(using pine charcoal)*	Weight (%)
Potassium nitrate	47.5
Pine charcoal	47.5
Sulfur	5
Flake aluminium (18-30 mesh)	4.6
Barium sulfate	7 (additional)
Glutinous rice starch	5 (additional)

The aluminium particles flicker as if they were a group of fireflies. However, the flickering lights are not visible over long distances.

Micro Stars

These stars consist only of a nitrate and sulfur with a metal powder—magnalium or magnesium. They can produce an explosive flash when the mixture is formed into small stars.

		Weight (%)			Weight (%)
(A)	Barium nitrate	40	(B)	Strontium nitrate	30
	Sulfur	20		Sulfur	30
	Magnalium (50/50)	40		Magnalium (50/50)	40

100 grams of the mixture is kneaded with 20 grams of a 10% nitrocellulose solution in acetone to form a homogeneous mass. It is rolled out on a star plate of about 8- 10mm thick and cut into a few pieces. These are dried at room temperature for one day and then further dried in an oven at 50°C for five hours.

They are then crushed into angular grains with a wooden mallet and an aluminium roller. Finally the grains are separated through a sieve to obtain small stars of 1.5 to 3.0 mm.

The small stars do not ignite on their own but when they are mixed with a delay—type composition and loosely loaded into a paper tube to form a small fountain. When the fountain is ignited the stars are ejected from the tube and burn with a flash of light after a short delay.

Micro star delay composition	Weight (%)
Potassium nitrate	50.0
Pine charcoal	37.5
Sulfur	12.5

The delay should be mixed with the small stars in the ratio stars/delay: 3:7 by weight.

Glitter Effects

Potassium nitrate, charcoal, sulfur, metal powders (atomized aluminium or magnalium) and some additives (Fe_2O_3, $CaCO_3$, or $Na_2C_1O_4$) cause the glitter effect when they are mixed and made into stars or sparklers.

There is some variation in interpretation of what is meant by glitter and some forms differ e.g. when speaking of stars or sparklers. The two compositions shown in Table 6.2 are similar in effect.

The corrosion of the aluminium or magnalium due to the other components is quite critical, especially the potassium nitrate. The use of boric acid is not very good with the two mixtures shown in Table 6.2 as it is likely to interfere with the glitter effect.

To make stars, about 17% water is added, but to make a sparkler slurry about 33% water will be needed.

As boric acid is not used, the batches need to be kept small to avoid rises in temperature.

The stars should be dried at room temperature—between 5° and 32°C.

Dextrine should be used as a binder for larger stars so that they can dry more quickly. The stars should be kept in a cool, dry store.

Table 6.2 Aluminum and Magnalium Glitter Mixtures

	Aluminum Glitter Weight (%)	Magnalium Glitter Weight (%)
Potassium nitrate	50.0	50.0
Pine charcoal	6.9	8.3
Sulfur	20.0	25.0
Atomized aluminum	17.3	
Magnalium (50/50) 60 mesh		12.5
Ferric oxide Fe_2O_3	5.8	4.2

Nitrate and Sulfur Reactions

Nitrates mixed with sulfur do not burn easily but there are some additives such as realgar or blackpowder which promote smooth burning, even in small amounts.

When a mixture of potassium nitrate and sulfur is in the ratio of 50/50 it will burn to produce a white smoke (p 375). However if the ratio of potassium nitrate increases, the burning temperature increases and will even melt the iron nozzle of a rocket. The temperature increase may be due to a very large amount of molten ash (K_2SO_4, $SrSO_4$, or $BaSO_4$) and a small amount of gas (SO_2). The weight ratio of the gas and the ash in solid or liquid state is about 35/65 to 18/72. The value for the specific heat of the gas at high temperature may be much smaller than that of the gas. Thus the heat capacity of the total products should be very low in this case to create a high temperature.

An experiment showed that the flame melted a platinum wire which indicates a temperature exceeding 1769°C; that is sufficient to obtain a flame colour. This effect is utilised for long burning smokeless road and rail signals, where the large quantity of high temperature ash and SO_2 gas is no problem (H. Ellern: Modern Pyrotechnics (1961, p 275, (5). Using the same principle, Dr C. Jennings-White has recently written about Nitrate Colours (Pyrotechnica XV, p 23 (1993) (29).

Spark Composition without Nitrate and Sulfur

Christoph Bosshard in Switzerland suggested the following composition (1989).

Perchlorate Sparks	Weight (%)
Potassium perchlorate	30
Red gum	20
Atomized aluminium	10
Iron (111) oxide Fe_2O_3	40

Further studies may be developed with this type of effect.

Strobe Reactions

The strobe reaction is a solid mixture, consisting of several different materials. When the mixture is ignited, a part of the mixture which reacts easily, reacts to produce a quantity of heat.

This heat then promotes the other substances to rise in temperature in order that they may reach ignition point. At this stage, they ignite with a flash. Many mixtures could behave in this way, but clearly, those compositions which produce strobe lights are few in number.

The mechanism may be most clearly explained in the following composition guide.

Strobe Light	(%)
Magnesium (coated with K Cr O)	20-30%
Ammonium perchlorate	50-60
Metal sulfate	10-20
Potassium dichromate (stabilizer)	5

This example is a mixture of a positive explosive (magnesium + ammonium perchlorate) and a negative explosive (magnalium + metal sulfate)

The whistle may come from a strobe type reaction because it too is a repetition of burning and detonation:

burning — detonation — burning — detonation———

To clarify the mechanism of the whistle the author conducted the following experiments.

In Fig. 6.1, the whistling zone is surrounded by the burning zone and the detonation zone. When using other materials such as benzoic acid or anthracene in place of gallic acid or phthalic acid, the effect is the same. From these effects, the whistling must be a repetition of burning and detonation.

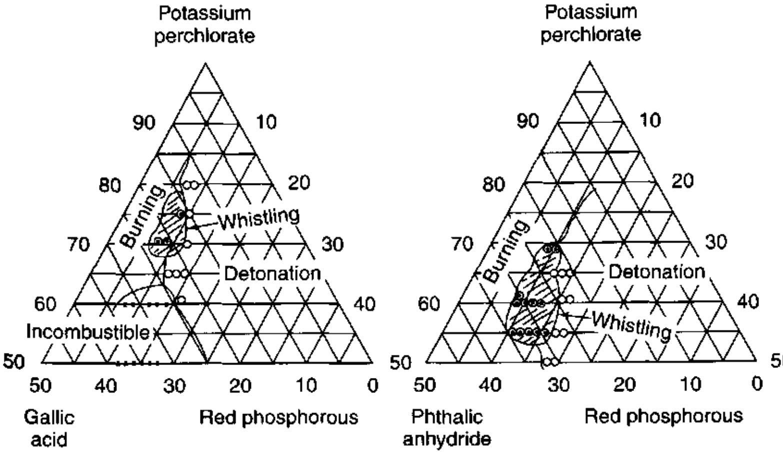


Fig. 6.1 Strobe Reactions. Whistling Mechanism

The experiment was carried out on a small scale: 2 grams of composition were loaded at a pressure of 1200 kg per cm into a tube of 12mm inside diameter and 76mm long. The wall thickness was 1.2mm. The author does not recommend the experiments as they are quite dangerous. Under pressure, such mixtures can be highly explosive.

Characteristics of Water Soluble Binders

Water soluble binders have a great influence in the manufacturing techniques for fireworks.

In the manufacture of cut stars, for example, dextrine is quite good because the stars dry rapidly and no cavities are created in the drying process. However, when they are then primed with a water-based slurry composition, the stars absorb the water and collapse. Similarly, when a star is dropped into a beaker of water, the star rapidly goes out of shape.

On the contrary, when glutinous starch is used as the binder this does not occur. However, the drying time needs to be much longer. When the stars are thick, it is easy for cavities to form. Nevertheless, there is one significant bonus; stars made with glutinous rice starch become waterproof. This is a great advantage for making colour-changing stars.

The charts in Fig. 6.2, 6.3 and 6.4 may useful for the selection of binders.

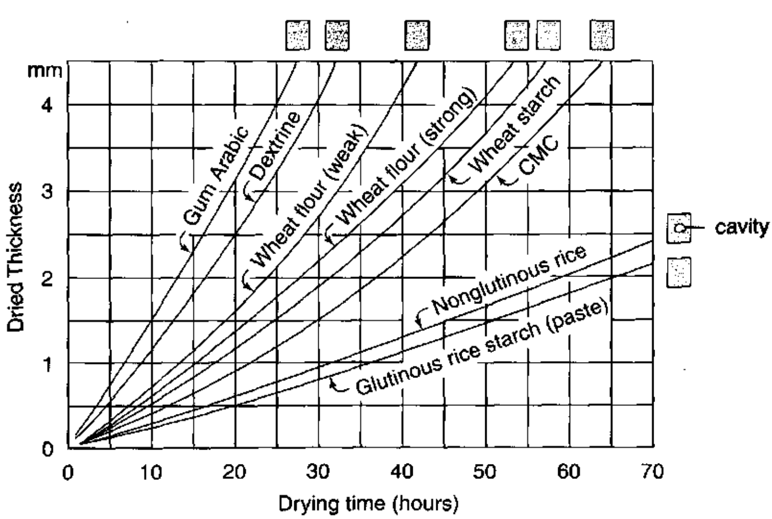


Fig. 6.2 Drying time of 9 mm cubic red stars with 6% binder at room temperatures

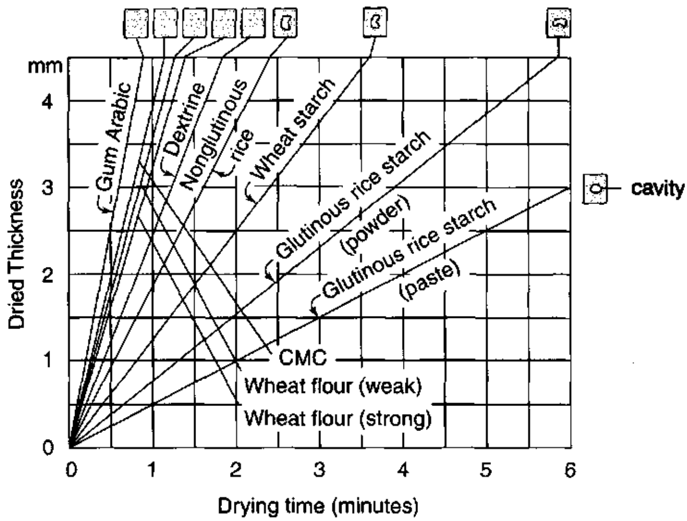


Fig. 6.3 Drying time of 9 mm cubic red stars with 6% binder at 51 °C in a drier with warm air.

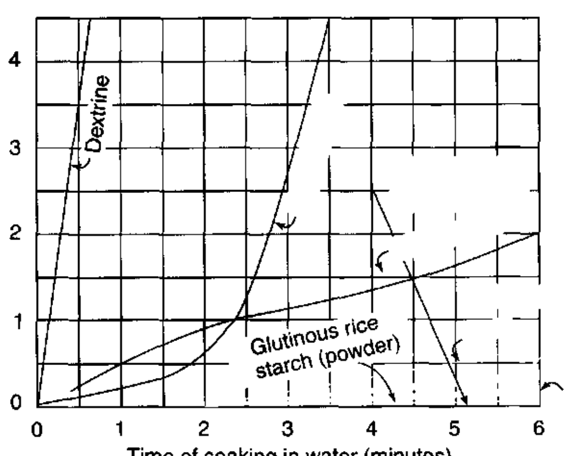


Fig. 6.4 The waterproof characteristics of 9 mm cubic red stars with 6% binder when dipped into the water

7

THE LEGISLATIVE FRAMEWORK OF FIREWORK CONTROL

Dr T. A. K. Smith

The explosive industry is said to be the most highly regulated industry after the nuclear industry, and indeed it often seems the case that it is over-regulated. However, the need for regulation is clear. Firstly, explosives in general are undoubtedly potentially dangerous. Secondly, the public perception of the explosive and chemical industries is such that a high level of legislative control is demanded by them.

This chapter necessarily focuses on the legislative situation in the UK, where most regulations are administered by the Health and Safety Executive (HSE), but where possible draws parallels with that in other countries, especially the USA. The natural emphasis is on fireworks, but references to more general topics are made where necessary.

THE UNITED NATIONS RECOMMENDATIONS FOR THE TRANSPORT OF DANGEROUS GOODS

Much current legislation is based on concepts derived from the United Nations recommendations for the Transport of Dangerous Goods (often referred to as the "Orange Book"). Although these recommendations are not mandatory, they are widely accepted and fairly widely understood. The fundamental problem with using the recommendations for general legislation is that they address only the hazard of materials in their state for transport. For fireworks this usually means packaged, and does not (and indeed cannot and should not) address their storage, use or manufacture. It is in these areas that legislation based on the UN scheme of classification of dangerous goods breaks down.

The UN recommendations classify all explosives in one of the following groups:

1.1 those packages that pose a mass explosion hazard
1.2 those packages that pose a projectile hazard
1.3 those packages that pose a hazard from fiery projections
1.4 those packages that pose only a limited hazard
1.5 extremely insensitive substances that pose a mass explosion hazard
1.6 articles containing extremely insensitive substances that do not have a mass explosion hazard

Furthermore, the UN assigns a compatibility group to packaged goods, and defines which compatibility groups may be packaged or transported together. The result of testing assigns any item to a particular hazard group, and compatibility group, and the item as presented is then assigned a four digit UN number, which identifies both the hazard of a particular packaged item and its correct shipping name. Thus all fireworks are assigned one of the following UN numbers:

0333	(1.1G)	Fireworks that pose a mass explosion risk
0334	(1.2G)	Fireworks that pose a projectile risk
0335	(1.3G)	Fireworks that pose a fiery projectile risk
0336	(1.4G)	Fireworks that pose a low risk
0337	(1.4S)	Fireworks that pose a very limited risk

It is essential to understand that the assignment of a particular firework package into one of the five groups above is critically dependent on the packaging of that item.

Table 7.1 shows a hypothetical example on how 75 mm maroon (salute) shells could be assigned to any of the five UN numbers if packaged in particular ways.

In general most fireworks fall into either the 1.3G (0335) or 1.4G (0336) classifications.

Table 7.1 shows that it is pointless to try to define which fireworks are suitable for consumer use by using hazard classifications. Although it is undoubtedly true that more powerful fireworks are likely to have greater classifications (eg. 1.3G rather than 1.4 G), careful packaging can reduce the hazard. Indeed, there are several ongoing trials which attempt to legitimately classify even large shells as 1.4G by using wire-mesh lined fibreboard boxes.

In addition, the UN recommendations define, in the most general terms, the types of packaging that are suitable for the carriage of all

Table 7.1 Hazard Classification of Fireworks

UN Hazard	Packaging	Comments
1.1G(0333)	Say 75 X maroons in an extremely strong walled box	There is the possibility of sympathetic detonation in this case
1.2G(0334)	Say 75 X maroons in a metal "ammunition box"	It is possible that the explosive fragmentation of the box will lead to metallic fragments of sufficient size and energy to force assignment into this hazard class
1.3G (0335)	Say 75 X maroons in a fibreboard box	In this case it is possible that the action of one maroon bursting will project fragments of the other maroons in such a way as to cause assignment into this hazard class
1.4G(0336)	A single maroon in a fibreboard box	In this case the hazard will be very local to the box
1.4S (0337)	A single maroon in an "elephant" sized box	With a large enough box the effect of the maroon busting will be confined within the box itself, thus leading to assignment into this hazard class!

dangerous goods, and explosives and fireworks in particular. This leads to the assignment of a UN Mark (not to be confused with the UN hazard code) to a particular package that has been tested to be suitable for transport of a particular item of combination of items.

This may appear to be a classic "chicken and egg" paradox. You need to have a suitable package, that is certified to hold a particular hazard type, in which to test the item to assign it that hazard type. Fortunately, most regulatory authorities have agreed methods by which this paradox may be overcome.

The basis of the UN recommendations for fireworks is that if packaged in a suitable way, the hazards arising from accidental ignition of a package are reasonably well defined and understood. This is particularly important for the emergency services in case of an accident. They need to be able to assess the risk of attempting to control the incident.

"DEFAULT CLASSIFICATION" IN THE UK

In order to determine the classification of a package of fireworks for transport, it is theoretically necessary to undergo full burn and drop

Table 7.2 Default Classification in the UK

Item	Calibre (mm)	Default Classification	Comments
Roman Candles	<=30	1.4G	
Roman Candles	>30	1.3G	
Gerbs/Fountains	<=24	1.4G	
Gerbs/Fountains	>24	1.3G	
Wheels/Set Pieces		1.4G	
Rockets	<=24	1.4G	With or without sticks
Rockets	>24	1.3G	With or without sticks
Mines	<=100	1.4G	
Mines	>100	1.3G	
Shells	<=125	1.4G	Not in mortar tubes
Shells	>125	1.3G	Not in mortar tubes
Maroon shells not in mortar	<=75	1.4G	Provided that there is only one maroon per package
Maroon shells not in mortar	<=75	1.3G	More than one per package
Maroon shells not in mortar	>75	1.1G	
Shells in Mortar	any calibre	1.1G	
Lancework on frames	unpackaged (see note blow)	1.4G	If additional pieces (e.g. Roman Candles) are attached, then the highest default classification applies and the item must be packaged
British Standard Category 4 Fireworks (other than types listed above)			No default classification. Separate applications with detailed test results must be submitted for each item.
British Standard Category 2 and 3 Fireworks	as appropriate	1.4G	The British Standard (see below) defines the maximum calibres for these items
British Standard Category 1 Fireworks	as appropriate	1.4S	The British Standard (see below) defines the maximum calibres for these items

Table 7.2 *(continued)*

Item	Calibre	Default Classification	Comments
Mixed Packs (selection boxes)			Highest individual type hazard division applies
Other Items (not described above)		1.1G	i.e. the applicant must make a fully supported proposal for lower hazard classification

Note There is an exemption in the packaging regulations in the UK that permits the carriage of lancework unpackaged, provided a number of conditions are met, one of which excludes the presence of other firework items (e.g. Roman Candles) on the lancework frame.

tests as defined in the UN recommendations. However, many countries have adopted simplified means of assigning a firework package to a UN class by analogy or by default classification. In the UK the firework industry and government have agreed a "default" classification regime (53) by which fireworks may be assigned a UN classification in the absence of any further information. Naturally, if the applicant for classification can demonstrate a lower hazard (it would be unusual to request a higher hazard classification!), by special packaging, or otherwise, this will override the default classification.

In this way, the process of classification should become a relatively simple exercise. The default classification regime is not perfect, and there are many arguments about the assignments made, but it has worked well for the UK firework industry for many years.

The default classification scheme relies on the use of UN approved packaging for the fireworks, and follows the usual UN rules that in mixed packaging, or combination items, the highest classification takes precedence (i.e. 1.1 > 1.2 > 1.3 > 1.4).

The default scheme does not remove the legal requirement to have all items classified in the UK, it merely aids the process. Applications for classification and authorisation of all fireworks manufactured in, or imported into the UK still need to be made to HSE.

It has also been agreed that full compliance with all aspects of firework design (e.g. fusing times, labelling etc) will be ignored when it comes to assigning a UN classification to firework. The presence or absence of the correct label will not affect the hazard in transport packaging.

At present, combination items, for instance a frame of 5 x 30mm Roman Candles, need to have a separate classification and authorisation to the individual components. This can cause problems, not least because of the almost infinite number of combinations that are possible.

HAZARD vs RISK

There is much confusion between the use of the terms HAZARD and RISK, even within dictionary definitions. In formulating and interpreting legislation, however, the distinction is clear and essential.

	Dictionary Definition (54)	**Comments**
Hazard	1. exposure or vulnerability to injury, loss etc. 2. at **hazard,** at risk; in danger 3. a thing likely to cause injury etc. ... 11 to expose to danger	The essential aspect of hazard is the potential to do harm, and the consequences of an event occurring
Risk	1. the possibility of incurring misfortune or loss. ... 5. to expose to danger or loss	The essential aspect of risk is the combination of the hazard AND the likelihood of an event occurring

It is right that the UN recommendations should confine themselves to the assessment of hazard. Indeed the tests that the UN recommend are relatively artificial. It is up to the users of fireworks to determine and minimise the risks of handling potentially dangerous items.

However, it is also important that the regulatory authorities do not allow themselves to overregulate industry on the basis of high hazard, when the likelihood of that hazard occurring is extremely small, and thus the overall risk is small. Accidents involving the manufacture, storage and transportation of fireworks are mercifully rare in the West, although there have been a number of spectacular incidents in the East in recent years. Undoubtedly, this is in part due to the existing legislative framework in the West, but it also in part due to the general prevailing culture and particularly to working methods that are taken for granted in the West.

TYPES OF FIREWORK LEGISLATION

In general there are two main types of firework legislation, those pertinent to the producer (which is taken to include the manufacturer, importer and professional user), and those pertinent to the consumer (that is of domestic fireworks).

Regulations Pertinent to the Producer, etc.

In the UK most firework safety legislation is administered by the Health and Safety Executive (HSE) and occasionally by the recently renamed Department of Environment, Transport and the Regions (DETR). In the USA legislation is mainly controlled by the Department of Transportation (DOT).

Legislation may be subdivided into the following broad categories:

Manufacture	Security	Selling
Storage	Importation/Exportation	Use
Transportation		

These regulations cover the time from the importation of a firework in to the country, as well as all the manufacturing operations that take place either for home produced, or modified fireworks. In most countries, there are also regulations for the use of fireworks by professionals which are also regulated by these authorities.

Regulations Pertinent to the Consumer

In the UK consumer legislation is administered by the Department of Trade and Industry (DTI). In the US, this role is mainly administered by the USA Consumer Product Safety Commission (CPSC).

These may be subdivided into two broad categories: Purchasing and Use

These regulations broadly cover the fireworks available for retail sale, and may include references to an individual companies established standards for consumer fireworks. The availability of fireworks, for instance within the USA, may further be controlled on a state by state basis, and in some cases the sale of fireworks may be prohibited altogether.

FIREWORK LEGISLATION IN THE UK

History

Much of the early history of fireworks and firework legislation in the UK has been covered earlier in this book. However, a very basic summary of early legislation is presented here. A comprehensive list of UK explosive legislation pertinent to the fireworks industry has been published by the CBI in the UK (55). A complete list of UK safety legislation and further comments by the author is available via the Internet (56).

The basis for most explosive legislation in the UK is the Explosives Acts of 1875 (57), known as the "Green Book". This remarkable piece of legislation, essentially written by one man, Sir Vivian Majendie, was a response to the poor safety record in the UK explosive industry at that time. The Explosive Act, modified periodically, still survives today, although in the near future it will be completely superseded by modern regulations. The Act covered in some detail almost all aspects of manufacture, packaging, transport etc. Although many subordinate regulations and amendments have been made to keep the Act up to date, there was a decision within the UK government some years ago to overhaul all old safety legislation and make new regulations under the powers of the Health and Safety at Work Act (HSWA) 1974 (58).

This approach has many advantages and disadvantages, but does mean that there is no longer a single definitive source for information.

At present one of the most important remaining aspects, covered by the Explosives Act, is the need to have every firework "authorised" as well as classified in the UK. Authorisation is the government "approval" of a firework and involves (in theory) details such as construction, chemistry, intended us, storage and disposal etc. All classified and authorised explosives are published in the "List of Classified and Authorised Explosives" (LOCAE), (59) but it is likely that in the near future fireworks will have a separate list, the "List of Classified and Authorised Fireworks" (LOCAF) (60).

Current Legislation

Modern UK explosive legislation is centred on the adoption of the UN Recommendations by the UK and their enactment in the classification and labelling of Explosive Regulations (CLER) (61) in 1983. The problem with basing regulations on the UN scheme is that the UN scheme is strictly only applicable to items for transport (as identified earlier) and thus can only be applied by analogy to items in manufacture or storage not in their transport packaging.

The Packaging of Explosives for Conveyance Regulations (PEC) (62) formalise adoption of the UN recommendations in respect of packaging in to UK law.

The Control of Explosives Regulations 1991 (COER) (63) control the security of explosives, but fireworks are generally exempt from these regulations.

The Carriage of Explosives by Road Regulations (CER) (64) defines what vehicles and loads are acceptable for transport of fireworks in the UK, but in due course will be harmonised to conform to the requirements of ADR (65), the European agreement on the transport of dangerous goods. The driver training requirements of CER have also been superseded by separate regulations applicable to the transport of all dangerous goods.

It will be noted that at present there are no regulations explicitly addressing the use of fireworks. Government argues that such activities are already adequately controlled by general health and safety legislation such as the Health and Safety at Work Act 1974, and the Management of Health and Safety at Work Regulations.

Importation Controls

Formal importation controls of fireworks into the UK were abandoned in the early 1990s, following the establishment of the single European market. Prior to this time, each consignment of fireworks in the UK had to be notified to the HSE and, if necessary, tested before sale. This level of control of fireworks has been superseded by reliance on classification and authorisation of all fireworks in the UK, but sadly this change has been taken as a relaxation by many with the consequence that many more poor quality fireworks are now available in the UK than ever before.

Consumer Legislation

In the UK, there are two major pieces of legislation that control the sale of any goods, and thus fireworks, to the general public. These are the Consumer Protection Act (66) and the General Product Safety Regulations (67). In essence, both pieces of legislation state that a product must be safe for the consumer to use without the need for any specialised training.

In 1996, following a season in which there were two deaths directly due to firework misuse, the UK government introduced emergency regulations banning the sale of certain items to the general public. They were revised and reissued as permanent regulations, the Firework Safety Regulations 1997, (67) in late 1997. The biggest aspect of these regulations was the banning from sale to the general public of any shell or maroon shell. Unfortunately the definition of who was a "professional", and thus allowed to purchase and use shells, was very vague and open to abuse.

It surprises many people that there is not at present any qualification for users of fireworks in the UK (although this is likely to change in 1999). The reason for this is mainly historical, fireworks have been available to the public for hundreds of years, and a large industry has grown up around the supply of fireworks to amateur groups for, particularly, the November 5th celebrations. It has been estimated that there are some 20,000 organised displays in the UK over the celebration period, ranging from small events such as sports clubs, to large Nation-scale events. It would be impossible for all of these displays to be fired by "true" professionals, and as a consequence many local organisations have formed groups able and willing to fire these smaller displays on an annual basis. The removal of shells from these smaller displays has been severely criticised, and the issues of who may purchase and use shells will continue for many years. The proposed Firework Act (69) addresses some of these problems. If enacted it will lay the foundation for a nationally approved and accredited training course for fireworks, in addition to other, less welcome proposals for further restricting the use and sale of fireworks in the UK.

Future Legislation

As noted above, the 1875 Explosives Act has been due for revision for many years. The manufacture of Explosives Regulations (MSER), (70) incorporating the requirements of the Seveso Directive, (71) are due to be in force in late 1999 and will finally repeal all the remaining clauses of the 1875 Act. MSER addresses the risks of storage of explosives in relation to their UN hazard division, and thus again has potential problems when items are in manufacture, or in storage outside their transport packagings. In order to overcome this problem, the UK have defined the following hazard types, which are essentially equivalent to the UN hazard divisions when items are packaged, that refer to storage and manufacture.

Hazard Type 1: Items posing a mass explosion risk
Hazard Type 2: Items posing a projectile risk
Hazard Type 3: Items posing a fiery projection risk
Hazard Type 4: Items posing only limited risk

It is argued that, for instance, bulk storage of 1.4G items could lead to a hazard type 3 event on accidental ignition. Unfortunately this type of effect is hard to quantify without tests on every possible combination of items within a store, and thus inevitably, and correctly, the hazard types should equate to the worst hazard divisions of the particular items in a packaged state.

The new regulations will place much more responsibility on determining hazard and risk on the producer, but will still incorporate many aspects derived from the 1875 Acts, including the concept of quantity/distance relationships that have formed the backbone of regulations for quantity distance manufacture and storage for many years.

Europe

Much of UK legislation is now driven by directives originating from the European Union. At this time there is still the possibility of a European Directive on Use of Explosives which will have tremendous implications for the structure of UK domestic legislation, which at present almost ignores this area. In fireworks this may mean mandatory training for all users of fireworks (with the exception of small domestic items hopefully), but it would at least achieve the ideal of a common framework of competence across Europe which may permit display crews from one EU country to work unhindered in another EU country.

British Standard

In 1988 there was published in the UK a British Standard (number 7114 (72)) which defines the performance and labelling requirements for those items considered safe for use by the general public in the UK. The Standard itself is in 3 parts:

Part 1 - Classification of fireworks
Part 2 - Specification for fireworks
Part 3 - Methods of test for fireworks

Table 7.3 shows the standard 3 categories of fireworks suitable for use by the general public:

Table 7.3 British Standard

Category	Definition	Fireworks	General Requirements
1	Fireworks suitable for use inside domestic buildings (generally known as indoor fireworks)	Cap, Smoke devices, Party Poppers, Table bomb, Throwdown, Novelty match, Non-hand-held sparkler, Hand-held sparkler, Cracker snap, Serpent.	Performance must comply with the standard (diverse - depending on type) Correct labelling for each item Item specific details re maximum weight, calibre etc In general (except sparklers) no items should be hand-held Batch testing of construction, labelling and performance.
	Fireworks suitable for outdoor use in relatively confined areas (generally known as garden fireworks)	Banger, Fountain, Roman candle, Mine, Wheel, Rocket, Non-hand-held sparkler, Hand-held sparkler, Combination	No lit debris outside 3m, below 3m (recommended viewing distance 5m) Fuse time between 3 and 13 seconds Correct labelling for each item Item specific details re maximum weight, calibre etc In general (except sparklers) no items should be hand-held Batch testing of construction, labelling and performance.
	Fireworks suitable for outdoor use in large open spaces (generally known as display fireworks)	Banger, Fountain, Roman candle, Mine, Wheel, Rocket, Non-hand-held sparkler, Shell, Shell-in-mortar, Combination	No lit debris outside 20m below 3m (minimum viewing distance 25m) Fuse time between 5 and 15 seconds Correct labelling for each item Item specific details are maximum weight, calibre etc Batch testing of construction, labelling and performance.

Category 4 is defined as: Fireworks which are incomplete and/or which are not intended for sale to the general public.

In this manner, for instance, fountains without the correct fusing or labelling are deemed Category 4, even though their performance is very limited. It is incorrect to assume that all Category 4 fireworks are by "definition" larger, more powerful items than would be permitted for sale to the general public. Fireworks that do not conform to the requirements of Categories 1, 2 or 3 are deemed to be category 4 and thus unsuitable for sale to the public.

Each "batch" of fireworks needs to be tested for compliance with the standard. A sample (the number is determined according to BS 6001) is tested for both performance and construction criteria. If the sample fails then the whole batch in deemed to have failed and must be re-worked and re-tested prior to sale to the general public.

The British Standard has undergone some modification since 1988, and in 1996 certain items were banned from sale to the general public even though they meet the requirements of the Standard as a result of the Firework Safety Regulations (see above).

European Standard for Fireworks

Work on a pan-European standard for fireworks has been ongoing for many years, and it finally seems that the European Standard for Fireworks (73) will be complete in 1998. The European Standard is very similar in concept to the British Standard and again defines four categories. The major changes in the proposed standard are

- Each firework type is the subject of a separate standard
- Additional fireworks (over the British Standard) are defined
- Changes in safety distances
- Changes in labelling requirements
- Type testing (in addition to batch testing)

There are, however, problems with implementing such a broad standard across Europe. Each EU country has historically permitted some types of fireworks for consumer use, whilst prohibiting other types. For instance:

1) Hand held fountains are not permitted in the UK, but permitted though out most of the rest of Europe
2) Shells have never been permitted in Germany but are available elsewhere (and maybe again in the UK)
3) The British standard does not permit friction-ignition items, whereas these are common throughout the rest of Europe.

There are also some anomalies that have been highlighted in the drafting of the European Standard, one of the most amusing of which is the proposed requirement that all Roman Candle batteries and mines should be buried to at least half their depth in the ground. The Scandinavian countries pointed out the impracticalities of this in frozen ground.

It will be difficult to argue that a firework type safe for use in, say, Germany is unsafe for use in the UK. If the Standard is incorporated into a European directive on "use" this problem may be resolved, but at present this seems unlikely.

FIREWORK LEGISLATION IN THE USA (74)

Modern firework legislation in the USA is broadly similar to that in the UK, the USA having adopted the UN recommendations in the late 1990s.

In addition the USA Department of Transport (DOT) assign an "EX Number" to each firework device (or type), indicating that it is approved for transportation. Fireworks must be examined by an authorized testing laboratory, or the manufacturer must certify that a new firework device complies with the provisions of the American Pyrotechnics Association standard APA 87-1 in order to be approved in this way.

The latter approach is similar to the UK default classification regime, and simplifies the process of classification. In 1987, the APA developed a standard for the construction, labelling and chemical content of fireworks which incorporated the requirements of the DOT and the US Consumer Product Safety Commission (CPSC). The standard also contained a list of "prohibited chemicals" which could not be used in fireworks for the US market, as well as a list of "standard chemicals" which were recognized as having been used with an excellent transportation and storage safety record in the US for many years.

The APA Standard recognizes that many firework mixtures are similar in their chemical composition, and thus to repeatedly test blackpowder, red star composition, etc. would be unnecessary, and a waste of time and resources. Provided that the weights of compositions with specified fireworks do not exceed those specified in APA 87-1, a new firework can be placed into UN hazard division 1.4G without the need to have full UN tests performed. In addition, an article that exceeds the weight limits for assignment into a 1.4G classification may be assigned to hazard division 1.3G without laboratory testing, provided that it contains only standard chemicals.

In addition to submitting a formal application along these lines, giving a complete breakdown of the types and amounts of composition contained in the firework as well as a detailed diagram of its construction, the manufacturer must also complete a thermal stability test (48 hours at 75°C) performed on the article or its components.

The USA system is quite flexible; applications may be as broad or as narrow as the applicant wishes. This system has certainly been of enormous benefit to the USA fireworks industry.

From the previous discussion of the relationship between packaging and classification it will be seen that this is potentially flawed method of assigning classifications, but *nonetheless* it is a system that, for the vast majority of cases, works well.

Both the DOT and CPSC assess penalties for failure to comply with their rules. DOT fines are typically $2,000-$20,000 for infringements such as boxes not being properly marked or labelled, or for shipping an unapproved device. The CPSC can assess fines up to $1,250,000 for failure to meet their rules, but typically the fines have been in the $20,000-$75,000 range.

Operator Licences

In the USA, operators are usually trained by a firework company, and a firework licence is issued by that company for the operator. There is some mutual recognition of these licences, but in other cases these licences may tie an individual to working with the issuing company.

FIREWORK LEGISLATION IN CANADA

Canada has similar laws to the ones in the USA. Indeed, the USA has added the Canadian Explosives Research Laboratory to the list of authorized testing facilities. Classification is that of the UNA scheme and all fireworks have to be authorized by the Explosives Branch of Natural Resources Canada. In addition all aspects of storage, importation, manufacture, sale and use of fireworks are controlled by the Explosives Branch. All authorized fireworks sold and imported into Canada are listed in the Canadian List of Authorized Explosives, and certain types of fireworks (e.g. flash crackers, trick fireworks) are banned completely.

Operator Licences

Canada has one of the most highly developed training schemes (75) for professional users of fireworks, consisting of two basic levels which determine which firework types and calibres may be used by the licence holder. The training course specifies mortar types, dimensions, safety distances, firing procedures and other requirements, as well as detailing accident and emergency procedures.

FIREWORK LEGISLATION ELSEWHERE

European Union

There is a wide variation of firework control within the countries of the European Union (EU). All members of the EU now subscribe to the United Nations recommendations, but domestic interpretation of the recommendations is not harmonized within Europe. Furthermore, in the important aspect of use of fireworks, there is little common ground, and virtually no mutual recognition, across Europe.

The availability of fireworks to consumers varies widely across European countries, in general reflecting the historical/cultural differences that exist between member states. A study in 1994, commissioned by the DTI (76) compared the regulatory regimes across Europe, and the number of reported accidents within each state. Table 7.4 shows an abbreviated summary of the main findings.

Table 7.4 Compared Regulatory Regimes in Europe

Country	Regulatory Body	Restrictions/Comments
Belgium	Ministry of Economic Affairs, Explosives Department	Restricted period of sale >500 g require a licence. Police keep register of purchasers. Other restrictions on types
Denmark	Fire Association, The Ministry of Interior	"Normal" fireworks available to public, "special" fireworks available only to licence holders. Restrictions on storage and types available.
Eire	Department of Justice	No legal market, organised displays only (this is under review for smaller fireworks)
France	Department of Industry Department of Environment	System similar to British Standard, but greater restrictions by age etc. Category K4 requires professional licence Authorisation of fireworks is expensive and time consuming Some regions have banned the sale of fireworks

Table 7.4 *(continued)*

Country	Regulatory Body	Restrictions/Comments
Germany	Ministry of Interior but administered locally	All fireworks must be approved by BAM. Class 3/4 fireworks require a licence to purchase/fire. Class 2 fireworks are only available for a very limited period at New Year
Greece	Ministry of State Security	Easter is main festival, no attempt is made to stop sales from street stalls at this time.
Italy	Police	Shops selling category IV or V fireworks require licence. In theory purchasers of category IV and V fireworks require a licence. Many fireworks available from street stalls
Luxembourg	Inspection de Travail et des Mines	Fireworks sold must be less than 500 g Age restrictions on sale
Netherlands	Inspectorate of Health and Safety	Consumer fireworks only sold at new year. Noise limit of 150dB Cat III fireworks for professionals only Many types of fireworks banned in Holland
Portugal	General Command of Urban Police	Age restrictions and strict control on use of fireworks. Large fireworks can only be bought with a licence.
Spain	Ministerio de Consumo Ministerio de Industria	Limits on weights/calibres of certain items Sale of fireworks authorised by each local administration Class 3 fireworks for professional use only
Austria	Ministry of Interior Ministry of Economic affairs	No official list of permitted fireworks Strict rules about instructions for use 4 categories of fireworks, category 4 require licence
Norway	DBE	Consumers have to apply for permission from local fire station Many types of fireworks are banned.

(continued)

Table 7.4 *(continued)*

Country	Regulatory Body	Restrictions/Comments
Sweden	National Inspectorate of Explosives and Inflammables	Sale times restricted, but from some shops all year round Code 154 fireworks need police permission
Switzerland	Police control fireworks in each canton	Some fireworks can be imported without restriction German BAM approval sets the standard Voluntary agreement bans "exploding" fireworks

THE FUTURE OF FIREWORK CONTROL

There is a need for greater harmony of legislation. The UN recommendations on the transport of dangerous goods are now widely adopted and have facilitated the easy transport of fireworks throughout the world. Aspects of firework legislation not covered by the requirements of the UN recommendations, however, are much less harmonious. The most pressing need is for mutual recognition of the authorization of fireworks between countries, and for the setting of internationally accepted standards for firework safety. In this way, the ideal of a manufacturer making to one worldwide standard may one day become a reality.

8

MIXING AND CHARGING

MIXING

Firework compositions are usually mixed in a special building. Indeed it is common practice to employ several buildings: one for sulphur mixtures, one for chlorate compositions, one for ammonium perchlorate and one for magnesium. Needless to say, even if the operator did not use chlorate and sulphur in the same composition; s/he would not use the same sieve for the two materials either. Sieves are made usually of copper or brass and are sometimes earthed against static electricity.

Sieving is usually a straightforward matter with gunpowder type mixes, but particular care needs to be taken with chlorates and perchlorates, particularly when fine metal powders are also in the mixture. Explosions or fires do not often occur, but the possibility of an electrostatic spark or friction caused by a fingernail scratching the sieve must not be overlooked.

Where hand mixing is employed, large circular sieves about 60 cm diameter are frequently used, the mixture being sieved on to a large sheet of paper. Frequently use is also made of a nest of square sieves, one on top of the other. (Fig. 8.1).

On top of the second and third sieve there is a sheet of cloth to retain the material which has passed through the sieve above. The mixture can then be hand-mixed on the cloth before allowing it to pass through the sieve.

As a general rule sieves of 14 and 25 mesh are used for mixing. Chlorate mixtures are usually passed three times through a 25 mesh sieve, while gunpowder/sulphur mixtures usually pass a 14 and a 25

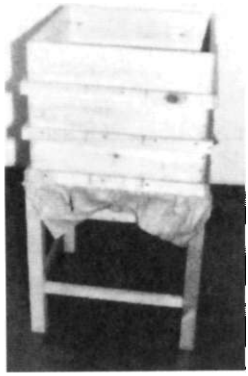


Fig. 8.1 Nest of Sieves

mesh. Rocket mixtures may be sieved once through a 14 and three times through a 25 mesh screen. It is usual to sieve the potassium nitrate or chlorate (i.e. the oxidizer) first on its own before adding the other materials. This is very necessary as most of the oxidizers tend to agglomerate on standing, unless a flow agent has been incorporated. The word saltpeter (Greek petros - a rock) is perhaps evidence of this. Since a good deal of pressure is needed to force lumps of oxidizer through a sieve, it is very unwise to have fuels mixed with it at the same time, particularly with chlorate mixtures.

There has been an increasing tendency over the last few years to use mechanical mixing methods which operate under remote control. The sieved materials are placed in a special drum made of metal or compressed fibre. After the drum has been securely closed, it is placed in a special apparatus which will cause the drum to turn and mix the contents. Earlier models simply turned end over end, but many people now use an apparatus which holds the drum at 45° to its axis and makes it rotate in a circular fashion. (Fig. 8.2).

The inside of the drum is frequently fitted with metal baffles but, in some cases, balls of wood, porcelain or rubber are placed in the drum along with the composition.

The whole mixing operation usually takes place in a concrete mixing bay made up of three solid concrete walls, no front, and a light roof extending over the top of the building to exclude the rain. The mixing operation is also usually connected to a gate by electricity, so that the mixing process will stop as soon as the gate is opened. No one can thus be inside the mixing bay during processing.

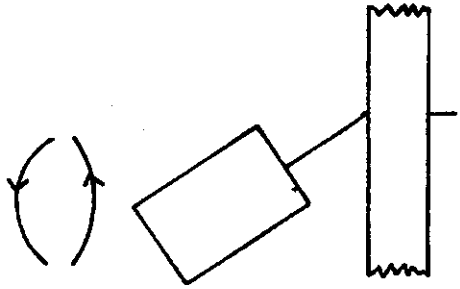


Fig. 8.2 Modern mixing drum

Open mixers fitted with paddles are also used occasionally, but these are only suitable for mixtures which contains a fairly high proportion of water or other solvent, or for those mixtures which are not particularly sensitive. In all these processes it is important to earth the apparatus against static electricity. Firework makers seem to vary very much in their preferences with regard to mixing methods. In some cases, dirty gunpowder and charcoal compositions are mixed mechanically to reduce the amount of dirt and dust and because they are less liable to explosion due to friction. For exactly the opposite reason, they also mix chlorate compositions by hand. However, some would argue that chlorate compositions should be mixed by remote control because they are potentially hazardous. Mixtures of potassium chlorate and gallic acid certainly come into this category and are best mixed in some out of the way place. Mechanical mixing methods can be useful, but they can also be time wasters in situations where a few kilos could be mixed quickly on the spot by hand. There is also a tendency sometimes for coarser materials to settle out, and rise to the surface or sink to the bottom of the mixture. In general it is wise to avoid mixing more than seven kilos of ordinary composition at one time and, after each batch of mixture is produced, it should be transferred to a suitable expense magazine situated at a safe distance from the mixing shed. It is not wise to work with more than 250g of flash powder.

The transportation of mixed powder has problems of its own. Care must be taken to see that the wooden or paper-board containers do not leak, and separate transporters should be used for sulphur mixtures and chlorate mixtures. One accidental factory ignition was caused by sliding a box of blue star composition along a transporter which had been carrying a sulphur mixture. The blue composition ignited but fortunately did not explode. Some companies divide their plants into sulphur-containing section, often called the "bright" or "black" side, and a chlorate division, often referred to as the "color" side. There is much to commend this practice.

Charging

Charging methods have slowly changed over the years and fewer and fewer manufacturers use the old-fashioned technique of charging single items one by one, except for special exhibition work. More will be said later about charging methods but the following techniques are available.

Hand Charging

It is fairly common practice to use a large block of wood as a base for ramming, about 40cm, square and about 75cm. high. In some instances it may be necessary to strengthen the floor of the building also. Mallets usually vary in weight from $^1/4$ to 4 kilos, depending on the nature of the work, and they are usually made of rawhide, box wood, or lignum vitae.

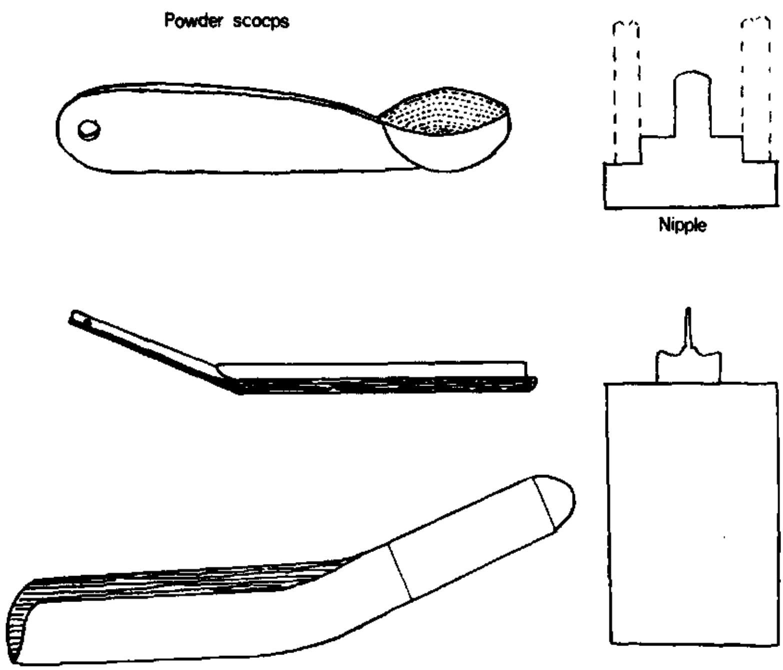


Fig. 8.3 Powder scoops and charging nipples

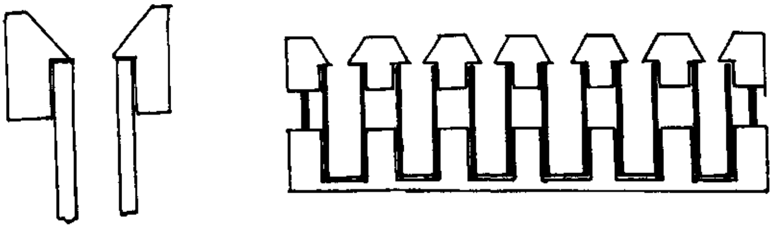


Fig. 8.4 Single and multiple collars for charging operations

Drifts used for ramming are normally made of box wood, or some of the new synthetic materials, and occasionally of brass. Nipples are normally turned out of a piece of solid brass, aluminum, or stainless steel. Powder scoops should be made of copper and are easily made to suit the needs of the charger. The scoops are usually semi-cylindrical and slightly smaller in diameter than the tube which is to be charged. (Fig. 8.3).

To make it easier to insert the composition, it is often convenient to place a little wooden collar on top of the tube. Where only light charging is required several tubes can be fixed in one frame. (Fig. 8.4).

The nipples are used for tubes which need some constriction such as fountains and drivers. In those instances where the tube is "pulled in" the nipple merely serves as a base and fills up the end of the tube. Clay also can be used to choke the tube and all that is necessary is to charge a scoopful of clay around the nipple before charging the composition. Mass filling methods are tending to revert to "pulled in" chokes as they are more convenient to handle. Nipples for fountains or drivers choke the tube down from a quarter to a half of the diameter.

Funnel and Wire

For charging narrow-bore fireworks, such as pinwheels, lances, and squibs, a funnel and wire often proves to be the quickest and most efficient method.

The narrow end of the funnel is normally turned out of brass, with the remainder of the funnel made of copper which is soldered on to the brass. The narrow brass end usually just fits into the end of the tube to be charged and, after filling, leaves a convenient empty space for the prime. (Fig. 8.5).

The brass or phosphor bronze rod is as large a diameter as possible, provided that it will allow the powder to flow down the side and into

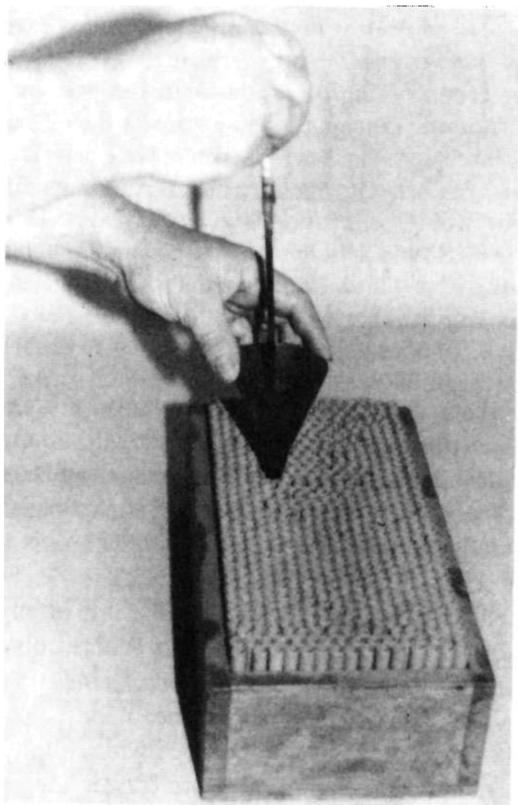


Fig. 8.5 Charging by funnel and wire rod

the tube. The wire is usually furnished at the top with a wooden or brass knob or handle. Tubes can be charges quite solidly by this method and it does not take long to acquire some degree of skill. Compositions filled by this method frequently need the addition of a "flow agent", or else the composition will tend to stick in the funnel. 1% tricalcium phosphate can be added for this purpose.

Many slow burning fireworks such as short squat fountains are filled upside down. The tubes are covered at one end with touch paper and then placed with the touch paper downwards in a large tray. The composition is merely pulled over the open tubes and shaken down by banging the container on the bench. The tubes are then closed up with a paper disc or cork. Needless to say, compositions which are filled by this method need to be very slow burning; otherwise a tube filled with a loose mass of fast burning material may explode.

Filling Machines

Firework manufacturers tend to develop their own machinery and, having spent a good deal of time and money on this exercise, they are naturally unwilling to pass on the information.

The most common English methods in the past have been those which used automatic ramming machines operated by a cam shaft. Naturally the distance over which the ram can operate depends on the size of the cam, but large banks of these machines can be modified for filling fountains, pin wheels, small rockets and other items. In some instances quite heavy pressures can be exerted by counterbalancing the table on which the tube rests. The machines are also so arranged that they can stop when the tube is full.

Another type of filler uses a shaking table which enables composition to be loosely charged by agitation. The method works well for slow burning compositions, but there can be a tendency for the coarse and fine materials to separate during agitation.

Screw feeding has been tried, but there appear to be many drawbacks and a tendency for the machines to get out of alignment and churn up the inside of the tubes!

There can be no doubt that the use of compressed air mechanisms have been a great boon to the firework manufacturer and they appear to be good deal safer than many other mechanism.

Presses

The chief drawback to hand charging is the fact that the operator becomes tired as the day progresses with the result that variations in

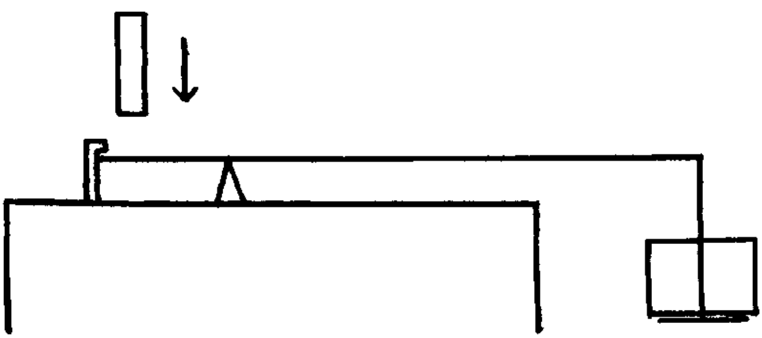


Fig. 8.6 "Dead load" press mechanism

quality are bound to occur. Presses on the other hand are more precise and controllable, giving good, consistent results. As a general rule it is usual to press sufficient composition to produce a pressed increment equal in height to the diameter. Pressing loads vary from a few pounds up to 100 tons or more. Indeed the burning characteristics depend, to some extent, on the pressing load. In the absence of any other readily available figures, interesting experiments quoted by Dr David Hart (11) are shown in Table 8.1.

Table 8.1 Effects of Loading Pressure on Luminous Intensity

Loading Pressure lb/in^2	Luminous Intensity in Candles/in^2	BurningRate in/mn
6,000	78,000	9.8
10,000	82,000	9.1
14,000	90,000	9.0
18,000	93,000	9.0

Hand presses are useful for work which requires pressing loads up to half a ton and it is quite useful to fit the press with some kind of counterbalanced table to produce a consistent dead load. (Fig. 8.6). Automatic presses are used for heavier loads, though it is usually necessary to protect the tube with some kind of mold (see Chapter 9). Pressing without a mold is also possible if the tubes are quite thickwalled, and in these circumstances as many as 120 tubes can be pressed at one time. The rams are usually fixed to the top of the press or are arranged to slide along rails. (Fig. 8.7).

Granulated composition is frequently charged into the tubes by means of a measuring tray with a sliding base.

Loading pressures can frequently present problems mainly because gauges can be inaccurate and vary from one press to another. Naturally it is also necessary to take the diameter of the ram into consideration when calculating tonnage. Conversion from English to Metric systems is as follows:

1 lb. = 0.454 Kg　　1 Kg = 2.205 lb.

1 in. = 2.54 cm.　　1 cm. = 1/2.54 in.

$$1 \text{ lb/sq.in.} = \frac{0.454}{(2.54)^2} \qquad 1 \text{ Kg/sq.cm.} = 2.205\text{x}(2.54)^2 \text{ lb/sq.in.}$$

$$= 0.0704 \textit{ Kg/sq. cm.} \qquad = 14.2 \textit{ lb/sq.in.}$$

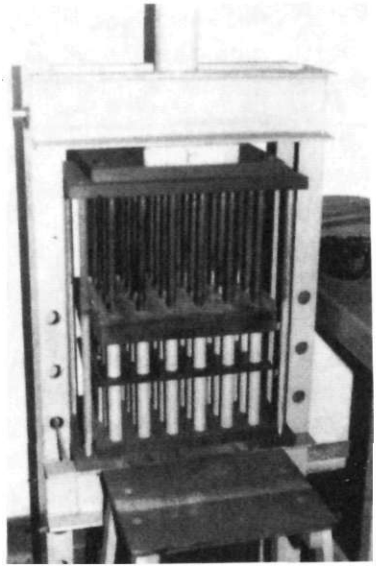


Fig. 8.7 Press for 24 tubes. (Courtesy Kimbolton Fireworks Ltd.)

Thus Multiply lb/sq.in. by 0.0704 to convert to Kg/sq.cm.	Thus Multiply Kg/sq.cm. by 14.2 to convert to lb/sq.in.
1 Tonne = 0.984 tons	1 Ton = 1.016 tonnes

A reasonably good fraction for covering the above pressures is 5/71

i.e. lb/sq.in. x 5/71 = Kg/sq.cm.

Kg/sq.cm. x 71/5 = lb/sq.in.

The drift of modern legislation has been to try at all times to separate the worker from the explosive. The ideals are laudable, but they can also be very impractical and expensive. Some forms of protective clothing are so hot and cumbersome that people hate to use them and do less work. Others seem to be as dangerous as they are protective. Face visors which are favoured in the UK would actually direct flames and hot gases to the face, if the fire was at bench level.

In all these situations, the answer is clearly between those in industry who do not take enough care and the legislators whose mission seems to be to leave no stone unturned in justifying their existence. The fact that they contribute to the decline in Western competitiveness is clear to most people except themselves.

The fact that fireworks are cheap and have to remain cheap means that the compromises are vital. This is not the case with signals, which often employ sophisticated engineering in order to provide the essential reliability of the product. They must also perform well in adverse weather conditions.

The mixing of flash powder is discussed in a later chapter, but it may well be that the greatest risk lies in the hydraulic pressing of firework composition in molds. An accident came from pressing almost a kilo of mealed gunpowder with titanium in a mold. The ratio was 70:30. Later trials determined that this was about the worst sort of mixture with regard to sensitivity (48). Blackpowder was in its most energetic form and the tube was inside a steel mold. The worker died because there was no effective barrier between the press and himself.

While there is no guarantee of anything by way of safety there are safer ways of doing things. In this case:

1. Do not use a mold. Free pressing with a thicker tube is always better, accepting that this is not always possible.
2. Use simpler mixtures, i.e. a mixture of nitrate, sulfur and charcoal which is less energetic and cheaper. Also add $^{1}/2$% paraffin oil to ease the pressing and lessen the dust.
3. Have a wall of concrete or steel between operator and press.

Many modern workshops are based on the principle that it is better to have the press in one room and the operator on the other side with at least 0.3 meter of highly re-inforced concrete in-between. The hole in the wall is large enough to operate the tooling and during the pressing the door is closed by compressed air. If the door is steel the operation cannot be observed without a mirror system. However 8mm polycarbonate screens are very useful.

In an ideal world presses could be loaded and set on fire to see what kind of effect is produced. It might well be every safety officer's dream to film dozens of such experiments at someone else's expense. However, in one experiment the author burnt half-charged 18mm gerbs outside the building.

The half filled gerbs had the press rams firmly clamped on top of the composition and an electric squib was inserted on top of the composition of one tube. The composition itself was blackpowder, potassium nitrate, sulfur and sponge titanium. The tubes were free standing and not in molds.

To our surprise there was no explosion. The flames shot up the side of the ram, ignited other tubes and eventually burned through the sides of the tubes. If the squib had been buried in the composition further down the tube, it might have caused an explosion but an ignition would not be likely to take place there during pressing anyway.

Priming

Fireworks which do not have touch paper ignition are usually primed. This consists of applying gunpowder paste to the mouth of the tube to ensure that ignition takes place. Mealed gunpowder containing about 5% dextrin can be used after it has been damped with water. Some firework makers pour a slurry of prime on the top of the firework and embed a piece of quickmatch into this. Only a small quantity of prime should be used; otherwise a large amount trapped inside a thick paper capping can be almost explosive. In fact it is often better to use a prime consisting of potassium nitrate, sulphur and charcoal in gunpowder proportions; it is much less fierce.

Capping and Labelling

Fireworks for display purposes are generally capped. This means that about three turns of brown wrapping kraft or white sulphite paper are pasted around the end of the tube. The paper overlaps the end by about 35mm. and is used to tie in the quickmatch pipe where several fireworks are to be fired together. The paper is only pasted at the edge and along the side of the paper which is in contact with the tube. Fancy colored labels are also pasted on the outside edge only; otherwise they dry out on the tubes in a very unsightly manner.

Factory Sites

In some parts of the world legislation has been very weak and little attempt has been made to regulate the danger buildings in firework factories. In the UK legislation in 1875 attempted to regulate manufacture, and remove factories from domestic sites and other places where people congregate. It is inevitable that further legislation is taking place at the close of the Twentieth century. However, the enactments of 1875 have served the UK well. There have been accidents but they have generally been contained so that the effects have been limited. In other parts of the world people have been less fortunate. There has been loss of life and large scale devastation of some plants. The 1875 UK Acts emphasized the obvious things:

Limitation on the amount of explosive in a workshop,
Limitation on the number of people in such a building,
Providing more than one escape route, and
ensuring that escape routes are not blocked with various objects.
Making sure all explosives are in covered containers.

Fig. 8.8 Modern concrete workshops (Courtesy Kimbolton Fireworks)

Having the minimum quantity exposed so there is a better chance of escape.

Wearing cotton or leather clothing and avoiding all synthetic materials which could carry electrostatic sparks. Covering as much of the skin as possible to minimize burns.

The UK has been somewhat preoccupied with the wearing of rubber or leather overshoes in danger buildings in order to avoid grit being carried into buildings. There is some wisdom in this where sensitive chlorates are involved, but there is no necessity with quite a lot of mixtures, and some of these overshoes can be positive hindrance to making a fast exit! Wet mats outside the danger areas are useful for cleaning shoes. Electrical switches are best on the outside of danger buildings. It is wise to have a copper earthing line in the danger buildings. Machines and carbon conductive matting can be connected to this. Lightning conductors are a matter of choice. In some cases lightning rods have been thought to attract lightning. In the UK it is more common to vacate danger buildings in these circumstances. In earlier times it was considered best to make workshops of lightweight wooden construction. Recent practice, however, has been to use concrete and save space. The wooden structure needed to be 23m apart but this could be reduced to 11m if a screen or mound was placed in between. The modern system tends to use concrete walls, well reinforced with steel. This wall is built on three sides with a lightweight roof and front. The walls project at the sides and the top in order to contain the effects of fire or explosion. (See Fig. 8.8)

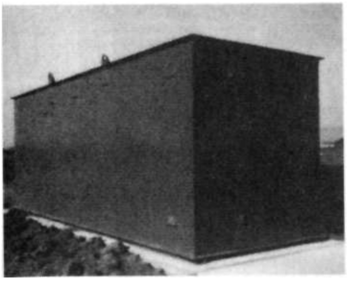


Fig. 8.9

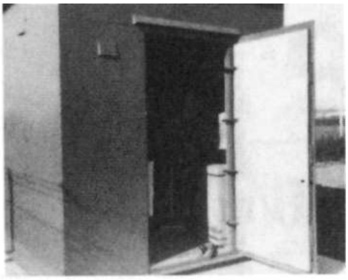


Fig. 8.10

Modern Movable Steel Stores
(Courtesy Kimbolton Fireworks)

In the UK it would be normal to work with about 7 kilos of dry firework composition in a room, or as little as 250 grams of perchlorate flashpowder at any one time. Rather, more wet star composition would be normal.

The distance of such a danger building or magazine from another building would depend on the quantities involved, e.g. the workroom block would be 50 meters from a store containing 4000 kilos of fireworks of UN category 1.3G or 1.4G or 600 kilos of 1.1G. Each magazine or store would be 20 meters from the next building.

Magazines are usually built of concrete or brick but it is also quite common to use freight containers lined with wood. This wooden lining helps absorb moisture and reduce the temperature just a little. In the UK it is common practice to use specially made steel stores. These stores are easily movable and in situ they are bolted down on the inside to a concrete plinth. They are also earthed with a copper strip which is connected to a copper plate some distance away. The assumption is that such an arrangement will produce a Faraday Cage. The doors of these stores are close fitting to prevent unlawful entry and escutcheon plates of very hard metal around the key holes prevent the locks being drilled out. The wooden matchboard lining is fixed with copper nails. See Figs. 8.9 & 8.10.

Stars are quite dangerous in large quantities and so it is probably also necessary to have strongly built stores and driers. The main danger with stars is the airspace around them which contributes to the burning speed. It is more than likely for example that a pile of loose powder will simply 'blow' when ignited. However a large pile of stars is likely to detonate. Star driers are usually only just large enough to utilize the

Fig. 8.11 Concrete Driers (Courtesy Kimbolton Fireworks)

hot air for the best purpose. Wooden or aluminum shelves support wooden trays for the stars. The heat source can be an oil filled electric heater or some other type of heated pipe. Some manufacturers use hot air.

Air circulation can be a problem. It needs to be sufficient to allow the humidity to escape but not so much that it allows the heat to escape unnecessarily. Hot stars are also more sensitive. A fire in the UK was caused by a worker scraping a tray where the stars had stuck to the bottom.

A good idea for a star drier is to use a reinforced concrete cross with four small chambers around it.

The floors of danger buildings can be covered with linoleum, modern industrial concrete coatings, or a coating of old-fashioned asphalt.

Good housekeeping is essential in a firework factory. They do say that cleanliness is next to godliness, and in the firework trade this is most important. Waste must be swept inwards and placed in covered containers to be taken away for careful burning. Floors and working surfaces must be washed daily.

Where it is possible, it is advisable to divide the factory into areas. 'Clean' areas where powder is used should be marked and painted. It is also compulsory in the UK to separate chlorate/perchlorate buildings from the sulphur/blackpowder ones. This is mainly because the admixture is prohibited by Orders in Council. It is a wise precaution. We look forward to the day when chlorate and sulphur admixtures will be outlawed everywhere.

9

CONTAINERS

All fireworks require some kind of container. In the past, tubes have been made out of paper or even wood, but paper is still the most common type of container to be used and is still the cheapest. The last few decades nevertheless have seen many changes in technique, and in some situations where high pressures are exerted, it has been necessary to use metals or resin-bonded tubes instead of paper. Signal flares are frequently pressed into steel tubes, but in those situations where it is necessary for the tube to burn away with the composition, plastic materials or thin aluminum has tended to replace paper. Plastic and aluminum also have tremendous advantages over paper which tends to swell or shrink depending on the water content. Since most of these thinner tubes have to stand up to large pressures during filling, they have to be protected with a mold to prevent the tube splitting. Molds are usually of two types.

The first consists of a block of metal into which holes are bored of such a diameter that they will just admit the tubes to be pressed. The inside surface of the molds needs to be highly polished. A plate on the underside of the mold keeps the tubes in place during the pressing operation, and when this is completed the plate can be moved to one side to allow ejection of the pressed tubes.

The alternative method is to use a split mold. This method employs three metal segments which completely surround the tube during pressing. The segments are held in position by a collar of some kind, and there is a taper on the outside of the segments to allow the collar to be removed easily. (Fig. 9.1).

Earlier works have expanded at some length on the various ways of rolling paper tubes. No purpose would be served by repeating this information and so the general principles are only outlined here.

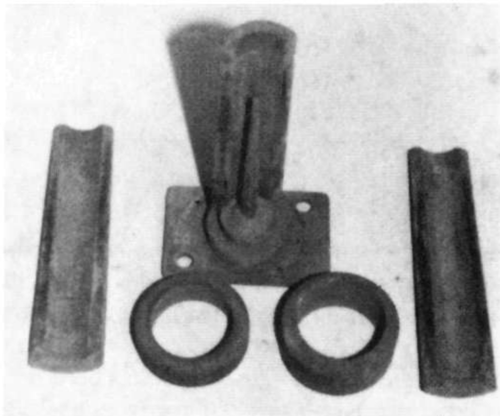


Fig. 9.1 Mold

Commercial adhesives are many and various and much will depend on the type of paper to be employed. Casein or dextrin based adhesives are frequently employed for strong tubes made with kraft paper, but a starch or methyl cellulose type of adhesive can be used for thinner or cheaper papers. Tubes made with dextrin adhesives unfortunately tend to absorb moisture in damp conditions.

A good cheap paste can be made by mixing one part of wheat flour into a smooth cream with sufficient cold water. Hot (not boiling) water is then added to make the total volume of water up to ten parts. This mixture is then boiled until it thickens. A small percentage of preservative (boric acid) should then be added to prevent bacterial action; otherwise there will be mold formation and rotting in damp conditions. The

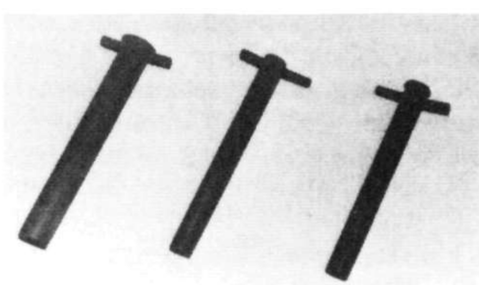


Fig. 9.2 Drifts

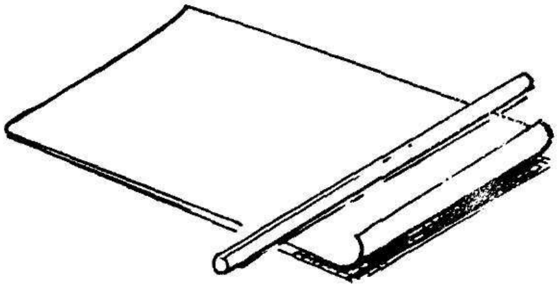


Fig. 9.3 Rolling narrow bore tubes

old manufacturers used to add alum as a coagulant, but this is neither necessary nor desirable.

It is not difficult to roll good tubes; it is just a question of the time needed to acquire the necessary skill.

Formers in the smaller bores are usually made of brass or aluminum; larger sizes are invariably brass tubing (Fig. 9.3). Wood of course is quite useless for wet straight rolling, but can be used for cones or other forms which easily slip off the former. The larger formers are frequently fitted with a wooden handle at one end. (Fig. 9.4)

Long narrow bore tubes can sometimes be difficult to get off the former. The best way to deal with this is to fix a spike on the edge of the bench and drill a hole through the end of the former. After slotting the hole over the spike, the tube is lightly held as it is pulled off the former. (Fig. 9.5).

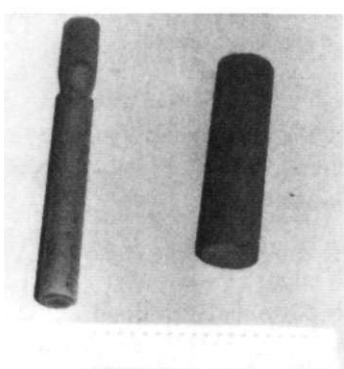


Fig. 9.4 Formers for wide bore tubes

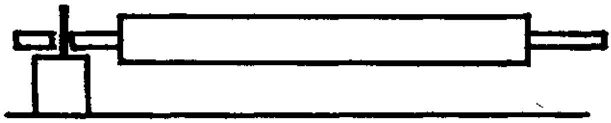


Fig. 9.5 Using a spike to remove a long tube from the former

The rolling bench needs to be made of heavy solid timber with a non-absorbent surface which can be easily cleaned. Marble or synthetic resin is very good for this purpose.

The choice of paper is naturally important but not usually as crucial as might be expected. Strong tubes which have to withstand pressure or hammering are usually made with unglazed kraft paper. The weaker tubes for Roman Candles which only take a light ramming are invariably made of cheap, unglazed, common brown paper (or "sugar" paper, as it is sometimes called).

Paper has a grain and so it is obvious that it must be cut in such a way that the "roll up" is with the grain and not against it. Gently bending the dry paper in the hands quickly shows that it folds more easily one way than the other and needs to be cut accordingly.

In order to obtain tubes with thick walls it is far more convenient to roll several sheets of paper together at once rather than attempt to roll up a single, long sheet of paper. It is often also more convenient to use a large sheet of thin paper on the outside and one or more liners on the inside of a somewhat thicker paper. By using this method it will be seen that it is easier to stick down the outside paper and by using a fairly short "roll up" there is less likelihood of making a bad tube.

The procedure may be best illustrated by an example. Assuming that a tube of 18mm. inside diameter, 45cm. long and having a wall thickness of about 5mm. is required, two pieces of paper would be needed for each tubes.

e.g.	1 piece	0.014 gauge	45cm by 53cm
	1 piece	0.025 gauge	45cm by 29cm

If, for example, twelve tubes are to be made, the twelve outside (014) papers are laid on top of each other, a quarter of an inch apart. (Fig. 9.6). The quarter inch edges of the paper which are laid bare are then liberally covered with paste and scrubbed with a wire brush to rough up the edge of the paper, to make sure that it will stick down easily on the tube. After this is completed, the batch of papers is turned over and the process is repeated on the reverse side without disturbing the

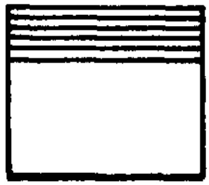


Fig. ***9.6*** Paper ready for pasting

positions of the sheets of paper. As a result of this, each outside paper has its outer edge pasted and scrubbed up, but on opposite sides of each sheet one edge will be on the inside of the tube and the other on the outside of the completed tube. (Fig. 9.7).

To roll the tube, one of these outer sheets is placed on the bench and covered with paste. Next, an inner (025) sheet in placed about 12.5cm up the sheet and is also pasted. The former is then placed on the paper; the paper is bent up over the former and checked to be square. After ensuring that the edge of the paper is biting closely under the former, the tube is rolled up, easing the liner a little during the process, if necessary. The edge must be well stuck down and the tube should be rolled on the former three or four times before it is removed. Sometimes a wooden board with a handle is used to roll the tube on the former. (Fig. 9.8).

When thicker tubes are required, more than one liner can be inserted, though it will be found necessary to space the liners about 12mm from each other to give a well balanced wall thickness. The paper should always be uniformly pasted or else there may be the possibility of uneven drying. Drying needs to be slow gradual process for very wet tubes, a week at room temperature being better than a shorter period at a higher temperature. Wet tubes which have been rapidly dried with ordinary adhesives frequently end up banana-shaped. During the rolling process the tubes become so firmly stuck to the former that they cannot

Fig. 9.7 Papers for scrubbing

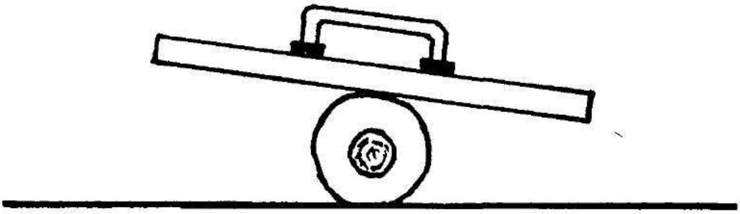


Fig. 9.8 Rolling board

be removed. This is because the rod has become dry, but this can be easily overcome by placing plenty of paste on the former, and the edge of the paper where the former is to lie. Tubes which are used for making lances, pin-wheels or match-piping are not pasted all the way through, the paper being merely pasted on the edge.

Sometimes it is necessary to constrict tubes which are used for rockets, serpents and fountains. The constriction is usually produced by a machine which contains six plates arranged similarly to those which control the aperture of a camera.

Alternatively a piece of piano wire or stranded wire can be wrapped around the tube so that when pressure is gently applied, the tube is constricted. Choking machines can also be used to constrict dry tubes provided that the wall is not too thick, but if the hand method is used, only wet tubes can be choked. Choking machines are also used to close up the ends of small thin-walled tubes. Choking machines are shown in Figs. 9.9 & 9.11. As choking is a somewhat time-consuming occupation, it is common practice to constrict rockets and fountains with a clay washer. The tube is fitted on to a nipple made of brass, stainless steel or aluminum and a scoopful of clay is hammered or pressed around

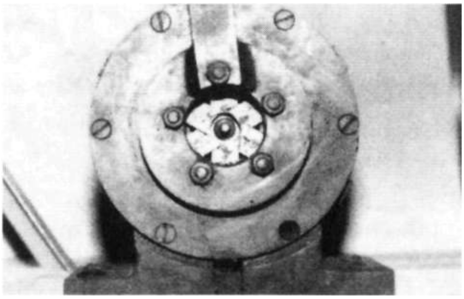


Fig. 9.9 Choking machine

Fig. 9.10 Tube Rolling. Early 20th Century. Brock's Fireworks

the nipple before the composition is charged into the tube. At the end of the operation the clay washer is left at the end of the tube after the spindle is withdrawn. (Fig. 9.12)

Cones and the swell heads of rockets are made by pasting a specially cut paper shape around the appropriate form. (Fig. 9.14) Cones are made from a circular piece of paper with a cut across the radius. (Fig. 9.13)

Wad cutters are used to cut the circular pieces of paper and for cutting

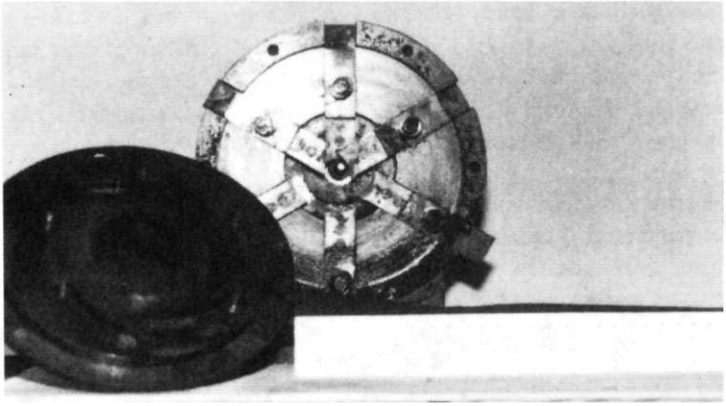


Fig. 9.11 Interior of a choking machine

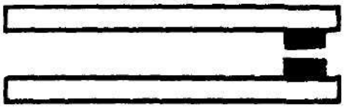


Fig. 9.12 Tube with clay washer

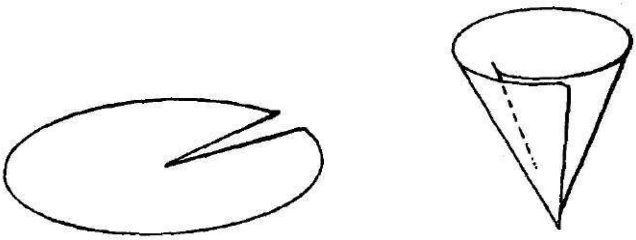


Fig. 9.13 Paper circle for **cone** manufacture

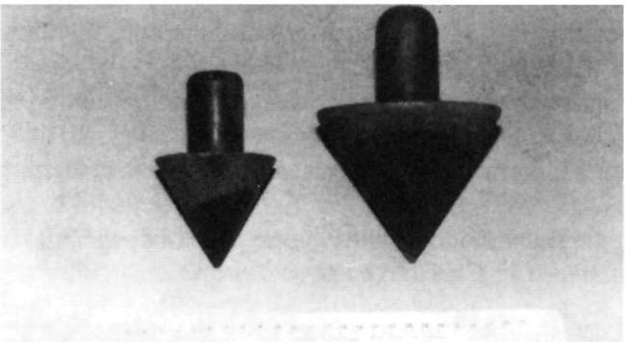
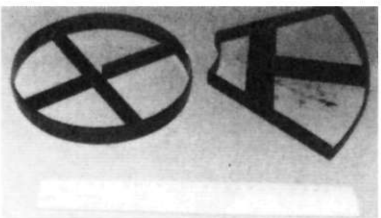


Fig. 9.14 Formers for cones



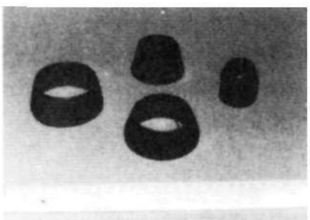


Fig. 9.15 Wad cutters

the millboard discs which are used for making cylinder shells. Wad cutters are shown in Fig. 9.15.

Spirally wound tubes are only slowly finding their way into firework manufacture. In those fireworks which do not place a great strain upon the tube they are quite useful, but as a general rule they are not so strong or efficient as the older convolute-wound types. Unless the inside of a spirally-wound Roman Candle tube has been carefully executed, it is common to find that the pieces of paper are also ejected with the stars.

More accurate details of the tube sizes will be given along with the description of the firework concerned.

10

STARS

In view of the fact that stars feature in many types of fireworks, their manufacture will be described first. An endless variety of effects may be obtained with the chemicals now at our disposal, though only five types of stars are commonly used: pumped (or cylindrical), cut (or cube-shaped), pill box, pressed and spherical stars.

Before the composition can be made into a star, it has to be moistened with some kind of adhesive so that it will set into a hard mass when it is dry. The amount of water which is added can sometimes be very crucial and care has to be taken not to add too much or too little. It is usual in Europe and the United States to mix a percentage of dextrin to the dry star composition and then add the required amount of water. From 3-5% dextrin will normally be adequate and it is unwise to use more than 5% unless it is absolutely necessary, since dextrin is very hygroscopic and stars containing large amounts of it tend to go soft in damp conditions.

Sometimes it is useful to use a mixture of alcohol and water for damping star mixtures; for one thing it reduces surface tension, making it easier to dampen lampblack mixtures, for example. It is also easier to dry the stars. On the other hand, dextrin does not dissolve in alcohol and so no more than $^{1}/3$ of alcohol to $^{2}/3$ of water must be used or else the adhesive power of the dextrin will be inhibited. Gum Arabic is also used as an adhesive. A 7% solution in water will be found to be adequate, but it can be time-consuming to make up the solution which has to be used the same day. When gum Arabic solutions are allowed to stand, they ferment and become acidic and consequently would be very dangerous if used to make coloured stars. Therefore, if it is essential to use gum Arabic for some reason, it should only be used on the gunpowder side of the factory.

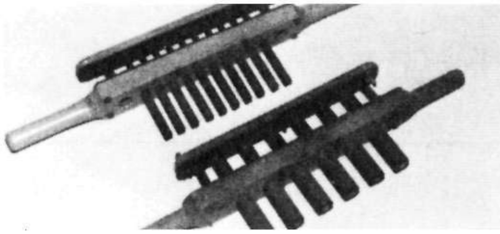


Fig. 10.1 Star pumps

The other important method of gaining adhesion is to use alcohol only with shellac or accaroid resin. It is common practice to have some of the finely powered resin in the composition and merely damp the mixture with alcohol, damping a small quantity at one time since it dries out quite quickly. Isopropyl alcohol is the best one to use since it contains no water. It will also be discovered that shellac is the best resin to work with, for it is much less sticky than accaroid resin.

Small pumped stars are usually dried in a gentle heat of about 35°C for two days. Larger stars and very wet stars will take much longer, of course. Drying cupboards are usually heated with hot water pipes and special oil heaters, etc. and some manufacturers use vacuum ovens and infra red heaters. In the summer it is often convenient to leave trays of stars out in the open air during the day but out of direct sunlight.

Pumped Stars

These are used more than any other type of star in the West, mainly because they can be manufactured easily and quickly.

A single star pump is very useful for making small quantities of stars. See Fig. 10.1. It consists of a short cylinder of copper or brass, fitted with a brass plunger and wooden knob. A stud in the side of the plunger, and a slot cut into the outer sleeve complete the apparatus. When a star is to be made, the plunger is raised to the top of the slot, the pump is pressed into the loose composition, and the star is ejected. Some manufacturers use six of these pumps fixed in a row on a wooden handle. The principle is the same except that instead of having slots cut in the sleeve of the pumps, the plunger is spring-loaded. The plungers are normally in the raised position, but the springs allow the plungers to move down the sleeves to eject the stars, afterwards returning to their raised position.

The other common method of making cylindrical stars is to use a star plate. Large quantities can be made by this method, though the stars often tend to be rather soft unless they are made carefully. The star plate consists of a sheet of brass furnished with a number of holes of the same diameter as the star. Underneath this plate there is another plate filled with spigots, each spigot fitting into the base of holes in the star plate. The two plates are fixed into the bench and the bottom plate of spigots has some arrangement attached to it so that the spigots can be raised to eject the stars. To make the stars, the damp composition is pulled over the surface of the plate and tamped into the molds by another plate filled with spigots. When the molds are full, the excess composition is removed with a scraper; the base plate of spigots is raised to eject the stars which are then transferred to a tray.

Roman Candle stars have to be very fast and fierce burning; otherwise they frequently blow out of the tube without igniting. For this reason they are usually made with potassium chlorate. Potassium perchlorate can be used of course, but a considerable percentage of charcoal must be added also and the stars always look smaller because there is not so much flame as with the chlorate. The following are good compositions for cylindrical Roman Candle stars.

Red	Weight (%)	**Green**	Weight (%)
Potassium Chlorate	70	Barium Chlorate	53
Strontium Carbonate	15	Potassium Chlorate	28
Accaroid Resin	10	Accaroid Resin	10
Dextrin	4	Charcoal 150 mesh	5
Charcoal 150 mesh	1	Dextrin	4

Yellow	Weight (%)
Potassium Chlorate	70
Cryolite	15
Accaroid Resin	10
Dextrin	4
Charcoal 150 mesh	1

Blue	A Weight (%)	B Weight (%)	C Weight (%)
Potassium chlorate	68	65	67
Paris Green	22	—	—
Basic copper chloride	—	11½	—
Copper (II) oxide	—	—	13
Colophony resin +60 mesh	6	—	—
Dextrine	4	5	5

Chlorinated PVC or Parlon	—	7	5
Lactose	—	$11^1/2$	—
Accaroid resin	—	—	10

White	Weight (%) A	Weight (%) B
Potassium nitrate	51	60
Sulfur	18	10
Mealed gunpowder	15	5
Antimony metal powder	10	—
Antimony sulfide	—	20
Charcoal +150 mesh	3	—
Aluminum dark pyro	—	1
Dextrine	3	4

Pumped stars usually have diameters of 8mm or 9.5mm, 14mm or 16mm, 25mm, 35mm, 40mm. Roman Candle stars are slightly less in diameter than the bore of the Roman Candle tube. Thus for a 16mm bore candle, the star would be 14mm diameter and approximately the same length. Gold stars are normally made with charcoal or lampblack, or a mixture of the two. Dr Shimizu gives details on page 356 of golden streamers made with charcoal only and the following also will be found to be quite useful:

	Weight (%)		Weight (%)
Meal Gunpowder	54	Meal Gunpowder	66
Charcoal 150 mesh	20	Lampblack	23
Lampblack	13	Antimony Sulphide	8
Antimony Sulphide	6	Accaroid Resin	3
Dextrin	7		

The star containing dextrin is damped with a mixture of two parts water to one part alcohol. The star containing accaroid resin is damped with alcohol only.

The following star is a modification of one quoted by Weingart and is said to be Japanese in origin.

	Weight (%)
Lampblack	49
Potassium Chlorate	$13^1/_2$
Potassium Perchlorate	$13^1/_2$
Potassium Nitrate	15
Dextrin	6
Shellac 120 mesh	3

The composition should be made quite wet with alcohol and water like the lampblack stars mentioned above, but they require a long time to dry out.

Gold Stars

It is not usual to employ lampblack in modern manufacture due to the extreme dirtiness and the problems of obtaining suitable material. The reader is however referred to Chapter 4 on charcoal, as there are supply problems with this material also. The following compositions are typical:

Gold Stars:	A Weight (%)	B Weight (%)	C Weight (%)
Potassium nitrate	57.5	53.5	55
Sulfur	7.5	6.5	15
Charcoal +150 mesh	35.0	—	—
Charcoal Pine +150 mesh	—	31.0	—
Charcoal Mixed	—	—	25
Dextrin	—	—	5
Gum arabic powder (additional)	2.0	—	—
Glutinous rice starsch	—	9.0	—

A is a good, all purpose small gold star using the fine commercial blended charcoal.
B is a Japanese willow effect. Pine charcoal from Japan is better than much that is available from Europe.
C is a comet mix. The charcoal is a blend of that which passes 150 mesh and some softwood or pine charcoal of about 40 mesh, to the manufacturers choice.

A good comet star is simply a mixture of two parts mealed gunpowder and one part charcoal with a suitable binder. To get a good sharply defined gold comet in a shell, possibly with a burst of flashpowder, a gunpowder type mix will be required unless the manufacturer has suitable ball milling facilities.

The well known glitter or twinkling effect often presents problems and some have been puzzled to find that they are unable to get the right effect even though they may have the correct formulation. The problem is very closely tied up once again with the particle size of the ingredients and the method of production of the composition. If the material is wetted with water or some other mixture this too can influence the final results. The old hands in the trade have always been aware of two things, even if they did not understand the chemistry:

1. That the glitter was produced from a bubbling molten mass; and
2. That adding charcoal spoilt the effect.

Dr Shimizu has written about these matters (p 358 and Bibliography 28) and it is clear that the main reaction involves the formation of potassium sulphide around particles of aluminum and that as this is spattered around in the air, the coated aluminum particle is able to ignite with a flash. Clearly the addition of extra charcoal would cause reduction and spoil the melt. (Chapter 6)

The old manufacturers in Europe concentrated very much on mixtures which contained gunpowder, sulfides of antimony and arsenic, sulfur and lampblack. The lampblack was thought to contribute to the fused mass but storage and the influx of moisture caused chemical reactions which disturbed the glitter. It is more than likely that in the unheated magazines, the alkaline carbon black reacted with the aluminium. The situation is not a lot better with the use of sodium oxalate, but the addition of boric acid has changed this.

The author has reason to believe that the use of boric acid is distinctly English in origin and that the dissemination of this information took place in the first edition of this book. In mixtures cited by Dr Shimizu (Chapter 6) he is of the opinion that it is better to do without boric acid if possible; it all depends on the mixture and you would certainly need boric acid in a barium nitrate/aluminium sparkler slurry.

An example for academic interest of the earlier UK mixes would be:

	Weight (%)
Mealed gunpowder	45
Antimony sulphide	16
Potassium nitrate	18
Aluminum + 120 bright	6
Dextrine	5
Barium nitrate	5
Lampblack	5

But who knows what kind of lampblack was used in these mixtures? In the course of time it was eliminated and the next two mixtures would be fairly typical:

		Weight (%)			Weight (%)
(A)	Mealed gunpowder	50	(B)	Mealed gunpowder	16
	Potassium nitrate	11		Potassium nitrate	35
	Sulfur	5		Sulfur	4
	Charcoal +150 mesh	—		Charcoal + 150 mesh	5

Barium nitrate	—	Barium nitrate	15
Antimony sulfide	18	Antimony sulfide	14
Aluminum 'Bright'	8	Aluminium 'Bright'	6
Dextrine	5	Dextrine	5
Wheat flour	3	Wheat flour	—

Looking at the matter in a more scientific way a number of people have quite reasonably assumed that all that is really needed is to take the basic materials and keep the matter as simple as possible, in order to avoid the problems associated with the variations in too many ingredients.

In commercial terms one big problem comes from the use of manufactured blackpowder. It is now very expensive and most manufacturers need to use as little as possible and simply use the basic ingredients. Nevertheless the author is convinced that some of the best glitter effects—particularly those which are to be viewed at a distance in the big firework displays—do need to use manufactured blackpowder and some of that blackpowder should preferably be fine soft grain powder (UK grade NPXF). This raises the issue that glitter mixes should not be sieved in fine sieves. The best screens to use are about 18 mesh (840μ). Some amateurs have reported that ball milling of glitter mixes destroys the effect (it also risks destroying them.).

The grade of aluminium used to be especially important. The author is in no doubt that the best effects were made with old fashioned flake aluminium ('bright') powders which were made in stamp mills and about 120-200 mesh. Some ball-milled powders are satisfactory and some are not and the same applies to atomized aluminium. In general atomized aluminium works well, and some USA powders seem to be more reactive than some European grades. A formulation provided by the late Bill Withrow is a little unusual in its proportions and was probably formulated as a sparkler slurry:

	Weight (%)
Potassium nitrate	37
Barium nitrate	16
Antimony sulfide	10
Sulfur	10
Charcoal + 150 mesh	10
Dextrine	10
Aluminium atomized	7 (+ 53 microns)

Some would consider this a high proportion of dextrine and not suitable for damp climates. For most formulations 3 to 7% would be the norm and it is arguable whether dextrine helps or hinders these glitter formulations.

The reader needs to study some of the recent writings about the glitter phenomenon, particularly those written by Winokur (27) and Shimizu (29). Many different substances have been used in the trials and it is clear that fine iron (111) oxide has become one of the favourites. However at the end of the day it should be made clear that there can be a world of difference between observing a beautiful glitter fountain at 5 meters and a glitter star moving through the air at a few hundred meters. In the two cases the formulations may be quite different. In practice, the author has found (and perhaps he has not looked widely enough) that barium carbonate or strontium oxalate serves both purposes very well with the materials at his disposal. Some quite splendid effects can be obtained, but like so much of firework manufacture, it is very much a mixture of chemistry and cooking and once again we are brought face to face with the problem of the materials. It is essential to maintain the quality control of the ingredients. In practice this is often a question of particle size and most manufacturers at some stage realise that a commercial vibratory sieve is a *sine qua non.*

It is more than likely that the first glitter stars to be made were those made with sodium oxalate. In some regards they are the easiest, and they work quite well using atomized aluminium.

The following are typical:

Yellow Glitter	A Weight (%)	B Weight (%)	C Weight (%)
Mealed gunpowder	70	—	60
Soft grain gunpowder	—	27	—
Potassium nitrate	—	32	—
Charcoal + 150 mesh	—	6	—
Sodium oxalate	10	10	7
Antimony sulfide	8	8	21
Aluminium flake 'Bright'	7	—	6
Aluminium atomized + 350 mesh	—	7	—
Aluminium flitter 30-80 mesh	—	—	1
Sulphur	—	8	—
Dextrine	5	—	5
Gum arabic	—	2	—
Boric Acid (about 0.5% additional)			

Composition C has a large (and expensive) quantity of antimony sulfide but it does have an unusual glitter which has a slight strobe-like quality. The stars should not be made too large and are for use in shells. A and B are suitable for all types of stars.

The best white glitters are made with blackpowder, though good ones are also made with the basic raw materials of gunpowder. Not every one would agree, but if manufactured gunpowder is not used (i.e. certain burning characteristics are established for this main ingredient), then unexpected variations will appear from time to time in bulk manufacture.

White Glitter	A Weight (%)	B Weight (%)
Mealed gunpowder	26	24
Soft grain gunpowder	40	40
Antimony sulfide	14	12
Stontium oxalate	8	—
Barium carbonate	—	12
Aluminium flake 'Bright'	8	5
Aluminium flitter 30-80 mesh	—	2
Dextrine	4	5

Quickly dried and utilizing the grease-containing flake aluminium powders, boric acid is not vital.

By using atomized aluminium powders in these white glitter mixes, some quite interesting variations can be obtained for viewing at a short range, but the upper and lower limits of the mesh sizes must be closely defined.

Strobe Stars

If there are problems with glitter stars the situation is even worse with strobe stars. The author asked one well known European manufacturer how he got along making strobe stars and was told that it all depended. Depended on what the manufacturer was not sure. Some days the stars were good, some days they were less good!

Many people have looked into the manufacture of good strobing stars (29) and many of us have had a degree of success, but there are considerable problems for consistent manufacture of large quantities.

The effect is essentially based on barium nitrate and magnesium with or without ammonium perchlorate. It seems to be clear that the Chinese were the pioneers of the firework strobe effects more particularly because post-war Chinese thinking has made great use of magnalium. The basic idea is the same as with glitters, in that particles of metal are brought to ignition in a smoldering molten mass. The addition of small amounts of 'catalysts' can produce flashes with a very clearly defined frequency such as one or two flashes per second. Such flashes of one or two hertz are ideal for fireworks.

The first mixtures were based on barium nitrate, fine magnalium and sulphur. The percentage of sulphur is quite high and the stars are not easy to ignite. The stars are made quite small, say 5mm spheres, and need to be very heavily primed with a hot igniter. A good green effect can also be made by adding a suitable chlorine donor. At first hexachlorobenzene was used, but now that this is becoming exiled, Parlon or Alloprene can be used.

The main question is how to make the stars into pellets, bearing in mind that the addition of dextrine can upset the chemical balance and prevent strobing, and the use of water based solvents can cause heating with some forms of magnalium. The other problem is that organic solvents can be extremely inconvenient when working with commercial quantities. Red gum in an alcohol or nitrocellulose solution can be difficult to work with and to clean up. The delicate balance of the mix, the grades of chemicals, chemical reaction and the amount of solvent make the whole process quite idiosyncratic.

Mixes without sulphur are much the best and the reader is pointed to the articles by Dr Shimizu on Japanese practice (29,34). Very good strobes can be made with ammonium perchlorate, magnalium and a sulphate, but again care must be taken to look after the chemistry since ammonium perchlorate and magnalium react quite dangerously under normal circumstances.

Many people are looking for good strobe effects that can utilize simple materials, and be made in commercial quantities that have a good shelf life. It will be interesting to see what happens.

Crackling Stars

There can be no doubt that this Chinese discovery has been a source of great interest in the West over the last years. The effect is a source of delight in its use both in small fireworks and at the large displays.

Most of the fireworks made with these microstars come from the Far East, not only because of the price advantage, but also because western legislation makes it difficult to work commercially with lead compounds.

Readers who wish to know more about the background to these mixtures should refer to Pyrotechnica (XIII, XIV, XV). Dr Shimizu's work (XIII) establishes that any of the three lead oxides can be used along with atomized aluminium of 60-100 mesh and magnalium of something between 60 and 200 mesh. An optimum magnalium alloy could be Mg/Al 31/69 if it were commercially available.

The following basic combinations have been explored

Crackling Stars	A Weight (%)	B Weight (%)	C Weight (%)
Magnalium	11	17	15
Lead oxide Pb_3O_4	89	44	—
Potassium nitrate	—	4	—
Sulphur	—	4	—
Copper (II) oxide	—	31	10
Bismuth (111) oxide	—	—	75

The next and most important discovery was by Dr C. Jennings White, who found that bismuth oxide not only works well but also is virtually non-toxic (Pyrotechnica XIV). There is always a snag, of course, and in this case it is the high price of bismuth.

The stars are made into small grains of 0-4mm and probably are best made with nitrocellulose dissolved in an organic solvent such as amyl acetate or acetone. The Chinese may well use a phenolic resin. Dextrine can also be used but this would be a snag if the stars were to be incorporated into the mixes of other stars which are bound with a water-based adhesive. A technique is described by Dr Shimizu in (Chapter 6).

It is important to remember that these stars are quite sensitive to impact and friction (Pyrotechnica XV). Tests conducted by Tony Cardell in the UK on the bismuth formulation bound with nitrocellulose established the following results: Rotter Impact Test. The figure of insensitiveness is 35.

Comparisons	0-30	very sensitive	
	30-90	sensitive	
	90+	comparatively insensitive	
Examples		Blackpowder about	100
		RDX	80
		Blackpowder/titanium	60
		Lead azide	50

The Rotary Friction Test gave a result of 0.9

Comparisons	3 or less	very sensitive	
	3-6	is sensitive	
	6 or more	is comparatively insensitive	
Examples		Lead azide	0.07
		Gunpowder/titanium	2.25 possibly
		RDX	3.0
		Gunpowder	+ 6.0

It is difficult to make silver pumped stars which are safe. Very good stars can be made with potassium chlorate and aluminum, such as the following:

	Weight (%)
Potassium Chlorate	56
Aluminum "Bright"	19
Aluminum Dark Pyro	19
Dextrin	6

but they are sensitive and dangerous. A much safer and more beautiful star can be made with potassium perchlorate and aluminum, but these often refuse to ignite and are best made as pill box stars. The following is an example of a cheap electric streamer without chlorate, but it lacks the brilliance of the chlorate/perchlorate stars.

	Weight (%)
Potassium Nitrate	45
Aluminum dark Pyro	30
Aluminum atomized 120 mesh	10
Sulphur	10
Meal Gunpowder	5
Dextrin about 5%	

The reader is also referred to Dr Shimizu's discussion of silver star effects on page 358

Cut Stars

Dr Shimizu on page 386 has described the manufacture of cut stars, and little more needs to be added as this corresponds more or less with Western practice. Considerably more water has to be added to cut star composition so that it will beat down into the frame in a tacky, pliable mass like pastry. If it is too dry, the mass will not cut into cubes, and just crumbles. After cutting, the stars are usually agitated in a bowl of mealpowder which coats the exterior. This has long been the practice and it is wise to have some dextrine mixed in the blackpowder so that it adheres well to the wet star.

Reference to chapter 6 will make it clear that it is not easy to coat stars which are cut or cylindrical once they are dry. As dextrine is invariably used, the water/slurry is very quickly absorbed and the stars are quickly deformed. For example, it might be a nice idea to place stars in a star tumbler, spray them with water, and then add the priming composition. Once tried, the operator soon learns that speed is essential!

Some people maintain that the sharp corners improve the chances of ignition of these stars, but this is doubtful. The gunpowder coating undoubtedly improves ignition, but it also increases the danger because of the sulphur and the chlorate being in close contact. Many of the pumped star compositions are suitable for cut stars, but the following are specifically used for the cut variety:

Red	Weight (%)	**Yellow**	Weight (%)
Potassium Perchlorate	70	Potassium Perchlorate	70
Strontium Carbonate	15	Sodium Oxalate	14
Accaroid Resin	9	Accaroid Resin	6
Charcoal 150 mesh	2	Shellac 80 mesh	6
Dextrin	4	Dextrin	4

Green	Weight (%)
Barium Chlorate	72
Accaroid Resin	12
Charcoal 150 mesh	8
Dextrin	4
Barium Carbonate	4

Chinese Formulations

There is much to commend the Chinese technique of using magnalium instead of magnesium for making high temperature stars. These mixtures are certainly more stable.

There is a certain amount of room for manoeuvre so that variations can be obtained by using more perchlorate and less magnalium or the other way around using more magnalium and less perchlorate. The remainder of the components of the mixture can remain as normal, i.e. a percentage of colouring agent, halogen donor, accaroid resin and binder.

The following would be typical:

	(%)
Potassium perchlorate	30-60
Magnalium	15-30
Strontium carbonate	10-25
Parlon	6-14
Accaroid resin	5- 8
Dextrine/rice starch	4- 5

Pill Box Stars

Although these stars are rather more time-consuming to manufacture, some of the best effects can be obtained with them. Not only do the

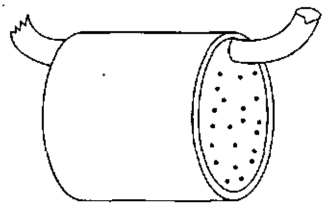


Fig. 10.2 Pill box star

stars have a longer burning time, usually about 5 seconds, but they always ignite because of the piece of quickmatch which is embedded in the composition.

The stars are made in thin walled paper spools of various sizes, a common size being 10mm inside diameter, 14mm long and a wall thickness of about 1mm. The match is inserted into the tube and the damp composition is firmly pressed into the tube with the thumb and first finger. The match extends over the outside edges of the tube by about 14mm.

The compositions are somewhat slower burning than pumped stars, the following being fairly typical:

Blue	Wt (%)
Potassium Chlorate	70
Paris Green	20
Shellac 60 mesh	10
add alcohol	

Blue	Wt (%)
Potassium Perchlorate	39
Ammonium Perchlorate	29
Copper Carbonate(basic)	14
Accaroid Resin	14
Dextrin (add water)	4

Red	Wt (%)
Potassium Chlorate	64
Strontium Carbonate	19
Accaroid Resin	13
Dextrin	4
add water	

Green	Wt (%)
Barium Chlorate	48
Potassium Chlorate	17
Accaroid Resin	17
Barium Nitrate	11
Barium Carbonate	4
Dextrin	3
add water	

Amber	Wt (%)
Potassium Perchlorate	60
Sodium Oxalate	26
Shellac 60 mesh	14
add alcohol	

Silver	Wt (%)
Barium Nitrate	55
Potassium Nitrate	13
Aluminum Dark Pyro	21
Dextrin	6
Sulphur	4
Boric Acid	1
add water	

Silver	Wt (%)	Silver	Wt (%)
Potassium Perchlorate	64	Potassium Perchlorate	64
Aluminum "Bright"	14	Aluminum "Bright"	24
Aluminum Flitter 30/80	14	Aluminum Dark Pyro	4
Shellac 60 mesh	8	Shellac 60 mesh	8

(damp these stars with a 10% solution of shellac in alcohol)

Green/Silver	Wt (%)	Red/Silver	Wt (%)
Barium Chlorate	25	Potassium Perchlorate	47
Barium Nitrate	25	Strontium Carbonate	20
Aluminum "Bright"	19	Accaroid Resin	10
Potassium Chlorate	13	Aluminum "Bright"	10
Accaroid Resin	7	Aluminum Flitter 30/80	10
Dextrin	5	Magnesium + 200 mesh	3
Barium Carbonate	4	add alcohol	
Charcoal 150 mesh	2		
add water			

Purple stars can be made by substituting about half the Paris Green of the blue star composition with strontium carbonate.

Yellow Illuminating	Wt (%)
Barium Nitrate	68
Cryolite	10
Aluminum Dark Pyro	11
Sulphur	5
Accaroid Resin	5
Boric Acid	1
add alcohol	

Two very old-fashioned but beautiful Pill Box Stars were:

	Crimson Weight (%)	Lilac Weight (%)
Potassium perchlorate	57	60
Shellac +60 mesh	14	10
Strontium nitrate	29	—
Strontium carbonate	—	5
Copper oxychloride	—	5
Mercury chloride (calomel)	—	20
Damp with alcohol		

The use of calomel to-day almost makes one gasp considering both the price and attitudes to toxicity. In the case of mercury, calomel used to be taken internally in medicine. It is now clear that mercury vapour is dangerous and methyl mercury in the food chain from the sea was a disaster. The question is, where are the uninformed to draw their lines on toxicity?

Pressed Stars

Some stars are pressed dry in a hydraulic press or they can be pressed on a modified tablet press. Roman candle stars can be made by the latter method, but the scope is limited to certain gunpowder type mixtures. Chlorate stars are very sensitive for pressing in this way and usually become so hard when they are pressed that they will not ignite. Gunpowder, potassium nitrate and sulphur mixtures press quite well, but charcoal is not easy to press and stars containing a large amount of charcoal tend to break up as they are ejected from the molds.

Most of the pressed stars are magnesium stars used principally for signalling in Very cartridges. The magnesium composition is pressed dry in a sleeve of paper or aluminum which has to be supported in a mold. Nitrates mixed with magnesium and PVC can be pressed dry in this way, though there is a limited shelf life for these articles since the magnesium is uncoated. In some compositions the magnesium is coated with linseed oil or drying oil and allowed to stand for some hours, prior to mixing in the other ingredients. Polyester resin is also sometimes incorporated into the composition prior to pressing.

All magnesium stars require an igniter composition when the stars are pressed and so it is common practice to press an increment of igniter composition on top of the illuminating composition and finally an increment of some type of blackpowder. Igniters are usually mixtures of silicon powder, potassium nitrate and some type of gunpowder, but mixtures of silicon, lead (IV) oxide and copper(I) oxide are also used. According to the BIOS reports (12) the following were used during the last war:

Red	Wt (%)	Green	Wt (%)
Strontium Nitrate	55	Barium Nitrate	55
Magnesium	28	Chlorinated PVC	29
PVC	17	Magnesium	16

Illuminating	Wt (%)	Yellow	Wt (%)
Barium Nitrate	55	Sodium Nitrate	55.5
Potassium Nitrate	10	Magnesium	17
Aluminum Dark Pyro	21	PVC	27.5
Sulphur	8		
Barium Fluoride	6		

Igniter	Wt (%)
Meal Gunpowder	50
Potassium Nitrate	16
Barium Nitrate	16
Aluminum Dark Pyro	10
Sulphur	8

The stars were pressed at about 10 tons on 24mm.

Magnesium grades 3 to 5 are used in these stars, but it is necessary to experiment with the grades of magnesium to get the correct burning time. The red and green stars also make good Pill Box Stars if 5% accaroid resin is added to the mixture which is then damped with alcohol. English and American formulations normally incorporate a percentage of potassium perchlorate into the composition in order to obtain a higher candle power, e.g. Formula 62 in Ellern (5).

	Weight (%)
Magnesium	30
Strontium Nitrate	42
Potassium Perchlorate	9
PVC	12
Laminae (Polyester)	7

Dr Becher (10) quotes the following star composition which is of interest:

White	Weight (%)
Barium Nitrate	50
Strontium Nitrate	10
Aluminum Dark Pyro	25
Sulphur	8
Meal Gunpowder	7

Spherical Stars

Originally this was very much a speciality of Japan, but it is now an almost universal practice. There are more ways than one of using this technique and the degree of care which is taken in making this kind of star will depend on the ultimate use.

Stars can be made very precisely in quite simple equipment and the reader is referred to Dr Shimizu's description on page 387. If the starting point is some kind of seed, there is no fast way that stars can be made. The tiniest sprays of water have to be introduced to a handful of seed and then powder is added. The seeds need to be agitated with the hand all the time to prevent their sticking to each other, and they are dried with only a light coating. This process is carried out over and over again until 100 grams of seed become very many kilos of stars.

The rolling and grading of stars in the Japanese style and the consequent production of stars of the same size requires much precision and dedication. The drums tend to be large and slightly apple shaped and in order to keep the stars rolling, the bulk of the large drums are empty. Where cut stars are made into round stars the drum tends to be rounded but also has a flat base.

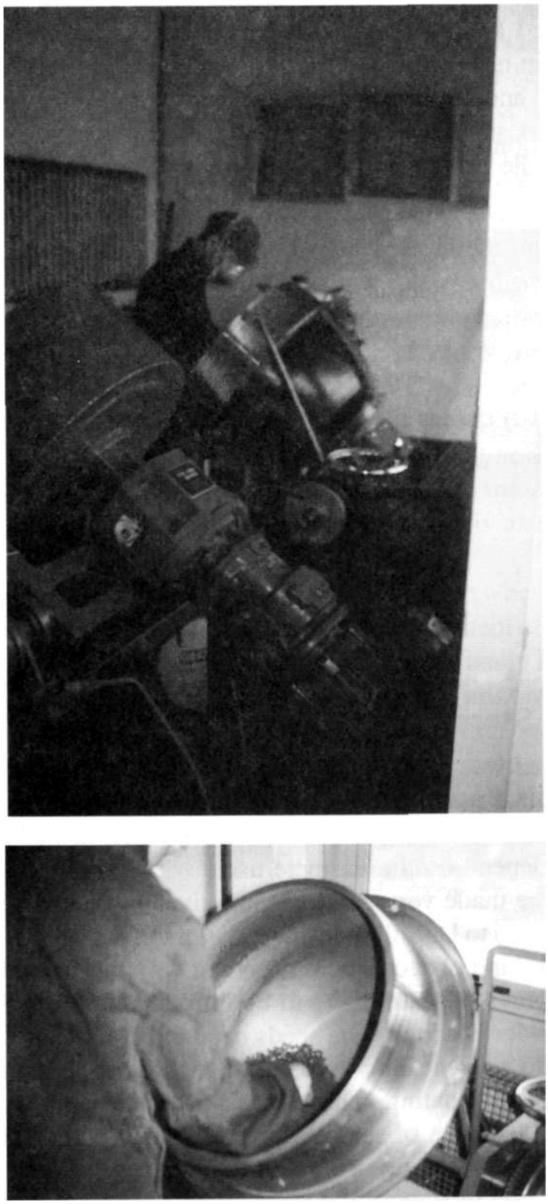


Fig. 10.3 Star making. Courtesy of Kimbolton Fireworks

Dr Shimizu points out in Chapter 6 that there are distinct advantages in the use of glutinous rice starch for making these stars not only as a binder but also because the final product is more waterproof than when dextrine is used. This makes it easier to add layer after layer which is so necessary for colour changing stars.

In the West it has been more common to use single coloured stars and so it is not quite so necessary to take the same degree of care. Spherical drums are preferred by some, but others prefer the circular disc shaped drums which have a flat base and 90° side. Stars of variable diameter are quickly made in these drums using only powder and water. It is again important to coat, dry, sieve and recoat rather than to try and make big stars too quickly.

Needless to say, dense powder rolls better than light mixtures and at all times the drum will be at least a third full to create the weight needed in rolling.

Star pans are usually made of copper, aluminium, or stainless steel. If possible, it is better to have the turning machinery outside the building but flameproof motors are also used.

Modern stars tend to be made with perchlorate and so are less sensitive than they used to be. However, care needs to be taken in the sieving process and dusk masks should be used.

The drying of stars needs to be carefully controlled. There is much to be said for drying in the open and out of strong sunlight, certainly where organic solvents are used. But it is important to dry additions of about 2mm rather than try to make big stars with moisture left in the centre. Indoor driers need a warm air current and, in some areas, a de-humidifier.

11

COLORED FIRES, BENGALS, LANCES, PORTFIRES, TORCHES

Colored flames are made with almost the same compositions as those used for stars, except that fuels which are used to make stars burn rapidly (charcoal for example) are usually omitted. On the contrary it is usual in these items to add materials which will retard the burning rate. Colored fires, torches and bengal illuminations which are sold to the public are usually required to burn quite slowly, and normally have the burning rate reduced by adjusting the fuel. The use of coarsely ground materials, or the cutting down or increasing of the amount of fuel can have this effect, but it is also usual to add retardants such as sawdust, woodflour, starch or flour. The addition of these materials also makes the composition cheaper of course, but care must be taken with materials such as woodmeal since they can contain a good deal of water.

According to the older text books, extensive use seems to have been made of tableau fires in the past. This is not very common now, mainly perhaps because piles of loose composition burn very rapidly and the same effect can be obtained from a smaller quantity of material in the appropriate container. Nevertheless it has been a feature of English firework displays to burn heaps of red or green fire behind bushes. Smoke enhances colored flames since it tends to reflect light, and unless the colored fire is to be used indoors, no attempt should be made to cut out all the smoke. Some who have tried to do this have discovered that part of the effect was also sacrificed at the same time.

Weingart and others have set out compositions containing picric acid in color production, but this is highly dangerous with chlorates, quite Pointless and expensive.

Containers for colored lights are normally made with a thin wall so that the tube will burn away with the composition in order to gain the best color effects. With these slow-burning compositions, the tube need only be dry-rolled and pasted at the edge; lances for instance are made in this way, but if the filling operation exerts any pressure it may be necessary to use a wet rolled tube; wet rolled tubes with thin walls can be quite strong. When thick walled tubes are used for colored fires they must be quite short (e.g. two to three inches long,) or else it will be found that the color deteriorates as the fire moves down the tube. The color is also destroyed by the yellow flame color of the burning tube. The best color effects are thus obtained with wide bore tubes 18 mm in diameter and upwards, and with thin walls.

It is well known that the human perception of color can be erratic and care must be taken when colors are produced in variety at close range. The human eye is more perceptive to reds than to greens for instance, a fact well illustrated when color changing lances change from green to red for then the change-over is easily noticed. Yet, if the color order is reversed with a change from red to green, the green cannot be seen until it has been burning for some time. In addition a red flame appears to be orange or yellow if it is observed for a period of time at close range. For these reasons it is best to arrange colored lights so that the observers see the reflected light but not the source itself. Aerial fireworks utilizing greater distances do not present the same problem though care must be taken with magnesium colors, for these do not always mix well in close formation. Red and white, green and white and possibly red and green magnesium colors will mix, but yellow must be used on its own, and to mix all four magnesium colors together would destroy the colors. Blue magnesium colors are not reliable, for the combustion temperature and the magnesium destroy the color, quite apart from the fact that the usual blue chemical combinations with magnesium are unstable.

It has to be remembered that the copper chloride molecule can only exist in low temperature flames, and so aluminum and magnesium will destroy the molecule. On the other hand very beautiful high temperature flames can be produced in red and green. Chemically the displacement reactions of the electrochemical series also decree that copper will react with aluminum and magnesium which have higher positions. Having said this, copper oxide is quite insoluble and so some interesting effects can be obtained without having to worry about chemical reaction; the fact is however that a good, deep, high temperature blue may be beyond our reach.

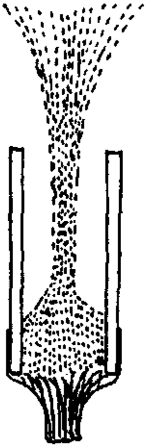


Fig. 11.1 Composition being poured into a tube

Colored Fires

The following compositions may be burnt as heaps of loose composition or gently tamped into short squat tubes. As it has already been stated, any length of tube can be used, provided that the tube will burn away with the composition; in this case the wall thickness, of the tube would be about 1.5 mm. A short squat tube should be 18 mm inside diameter, 75 mm long with a 2 mm wall. The composition should be charged into the tube with a drift and hand pressure only, or a funnel and wire could be used. Many of these mixtures burn more easily and reliably when they are gently compacted or even just shaken down. (Fig. 11.1)

	Blue			Green		
	A Weight (%)	B Weight (%)	C Weight (%)	A Weight (%)	B Weight (%)	C Weight (%)
Ammonium perchlorate	46	30	—	—	50	—
Potassium perchlorate	26	40	60	—	—	49
Basic copper carbonate	10	15	—	—	—	—
Red gum	15	15	—	12	15	15
Stearine	3	—	—	—	—	—
Copper (II) oxide	—	—	10	—	—	—
Barium chlorate	—	—	—	55	—	—
Potassium chlorate	—	—	—	33	—	—
Barium nitrate	—	—	—	—	35	31
Lactose	—	—	20	—	—	—
Chlorinated hydrocarbon	—	—	10	—	—	5

	Red			Yellow	
	A	B	C	A	B
	Weight (%)	Weight (%)	Weight (%)	Weight (%)	Weight (%)
Potassium perchlorate	—	66	68	75	75
Strontium nitrate	66	—	—	—	—
Strontium carbonate	—	20	11	—	—
Cryolite	—	—	—	10	—
Accaroid resin	—	14	11	15	—
Shellac 60 mesh	17	—	—	—	15
Woodmeal	—	—	10	—	—
Sodium Oxalate	—	—	—	—	10
Potassium chlorate	13	—	—	—	—
Charcoal 150 mesh	4	—	—	—	—

	White		Silver
	A	B	A
	Weight (%)	Weight (%)	Weight (%)
Potassium nitrate	74	13	15
Sulphur	8	—	—
Orpiment	18	—	—
Barium nitrate	—	—	45
Potassium perchlorate	—	64	—
Antimony powder	—	13	—
Aluminum dark pyro	—	—	15
Aluminum 30/80 filter	—	—	20
Accaroid resin	—	—	5
Copal gum	—	10	—

Bengal Illuminations

This special type of flare candle is used for illuminating public buildings and is extensively used in Europe for castles which particularly lend themselves to this type of illumination. In order to fulfill the necessary conditions, the composition should produce maximum color, burn efficiently but as slowly as possible, (i.e. 40 to 60 seconds per 25 mm), and not emit too much smoke.

The candles are made in various sizes, but the large ones are about 50 mm in diameter 30 cm long and have a wall thickness of about 1.5 mm. The end of the candle is fitted with a wooden plug and a screw eye for attachment to the holder. The candle is fixed so that it burns in a horizontal position so that the dross will not run down the side of the thin wall and accelerate the burning time. Lastly, the candle is placed behind some kind of shield so that the onlookers do not see it burning. (Fig. 11.2).

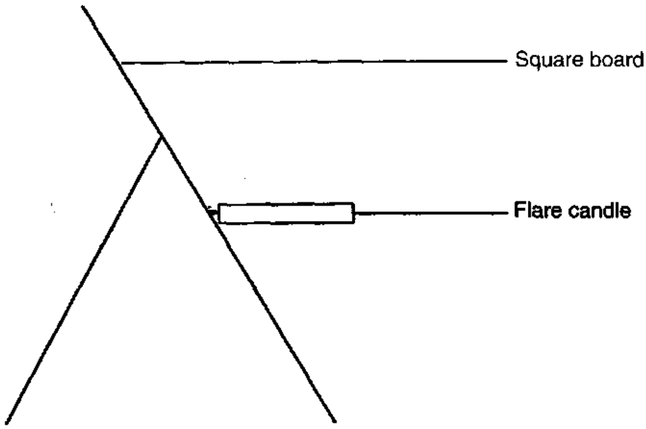


Fig. 11.2 Bengal illuminations

The following compositions are typical. Paraffin oil is added sometimes as a retardant, and to give some protection against moisture which can be a problem in strontium nitrate mixtures which are not heavily compressed.

	Red		Green	
	A Weight (%)	B Weight (%)	A Weight (%)	B Weight (%)
Strontium nitrate	65	63.5	—	—
Barium nitrate	—	—	68.5	70
Potassium chlorate	20	—	—	16
Potassium perchlorate	—	16	15	—
Shellac 30/200 mesh	15	—	—	—
Accaroid resin	—	9.5	15	13
Sawdust	—	9.5	—	—
Lampblack	—	1.5	—	—
Antimony metal powder	—	—	1.5	—
Paraffin oil	—	—	—	1
Approximate burning time in sec/25mm	45	30	20	40

It is always the case with firework manufacture that there are very many snags which practical workers discover only by experience. Strontium nitrate mixtures sometimes shrink if they contain water which subsequently dries out, leaving a gap between the composition and the tube. This naturally increases the burning time.

Strontium nitrate mixtures are very unreliable if they are charged in paper tubes. The issue is even more severe in damp climates. The above

Red mixture A is particularly liable to shrink if it has been kept for a short time. Dr Shimizu has pointed out in (Chapter 6) that this is likely to be caused by the use of shellac, and so red gum would be a better option.

Lances

Large quantities of these items are manufactured every year for use in making set pieces, as fire pictures, mottos, motifs, all made with these little tubes of colored fire. Lances are usually 8 mm or 10 mm in diameter and about 10 cm long. The paper is usually an 0.004 bond or poster paper cut up into pieces 95 mm X 125 mm, and they are dry-rolled on a former which is countersunk at one end. The papers are placed on top of each other with just the outside edge and side uncovered. A pasted sheet of paper is placed on the bench and the former is laid along the paper about 6mm from the end. The paper is brought up and over the former and there rolled up to make the tube. The pasted edge which is left over-hanging the end of the former is then pressed into the countersunk base of the former. This completely closes the base of the lance in a neat fashion, thus preventing the powder from trickling out. The following diagrams in Fig. 11.3 will help to make this clear. The following compositions are typical of those used for lances:

A funnel and wire are used to charge the composition, but the base of the funnel has a nozzle which goes about 10 mm into the lance tube. In this way, the lances can be filled to within 10 mm of the top. The

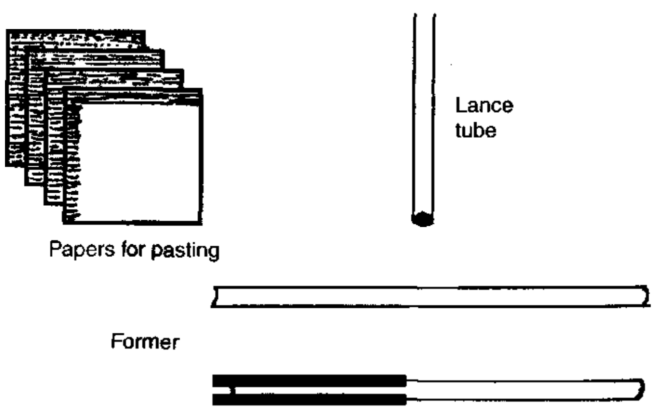


Fig. 11.3 Apparatus for manufacturing lance tubes

next operation is to add the topping composition in a similar way, to a depth of 8 mm. The old manufactures used to use the white lance composition as a topping, but it is not wise to funnel and wire a sulphur mixture onto a chlorate or perchlorate and it would be very hazardous with barium chlorate. A simple mixture of potassium nitrate and accaroid resin serves the purpose quite well. The lance is finally primed with a paste of mealed gunpowder, dextrin and water.

Lance compositions	Red	Green	Blue		Amber	White
			A	B		
	Weight (%)	Weight (%)	Weight (%)	Weight (%)	Weight (%)	Weight (%)
Potassium perchlorate	75	25	64	27	73	—
Barium chlorate	—	36	—	—	—	—
Barium nitrate	—	25	—	—	—	—
Strontium carbonate	12	—	—	—	—	—
Cryolite	—	—	—	—	14	—
Copper carbonate	—	—	—	11	—	—
Ammonium perchlorate	—	—	—	47	—	—
Paris Green	—	—	32	—	—	—
Red gum	13	14	—	15	10	—
Lactose	—	—	—	—	3	—
Copal gum	—	—	4	—	—	—
Potassium nitrate	—	—	—	—	—	65
Sulfur	—	—	—	—	—	20
Antimony metal powder	—	—	—	—	—	10
Mealed gunpowder	—	—	—	—	—	5

As Dr. Shimizu points out on page 347, lances are sometimes a problem mainly because the flame is disturbed by the dross or they produce a long chimney-like ash which obscures the color and the brightness. In view of this, a good lance can only be tested at about 50 meters distance when it should be observed burning in a horizontal position. A lance 9 cm long should burn about 50 to 60 seconds. Lances made with potassium perchlorate are less likely to chimney than those made with the chlorate, and some care needs to be taken with the choice of paper. Spirally wound lance tubes have appeared on the scene now but they are greatly inferior to the hand rolled variety.

Portfires

Portfires, which are used for lighting fireworks are made in exactly the same way as lances, except that the tube is usually longer and has a slightly thicker tube. Portfires are normally 9 mm inside diameter and about 38 cm long. The paper for the 38 cm size would be 18 cm x 38 cm. Portfires usually burn three or four minutes, but they must not burn too slowly or they are apt to go out. The following compositions are satisfactory:

	A Weight (%)	B Weight (%)	C Weight (%)
Potassium nitrate	60	63	—
Sulphur	20	16	—
Meal Gunpowder	20	11	—
Antimony sulphide	—	10	—
Potassium perchlorate	—	—	50
Barium nitrate	—	—	35
Red gum	—	—	4
Copal gum	—	—	11

Unfortunately portfires drop hot dross during burning, and this frequently lands on the ankles: Many people use a color mix to avoid this, e.g. composition C.

Blue Lights Star Lights

These little items seem to have almost disappeared from the market now. In effect they were small lances 5 mm inside diameter, 15 cm long with a wall thickness of 1.5 mm. The compositions were quite slow burning and produced either golden spur fire or molten sparkling drops of the type mentioned by Dr. Shimizu on page 360. The following compositions were used:

	Blue Light A Weight (%)	Blue Light B Weight (%)	Star Light Weight (%)
Meal gunpowder	51	13	6
Potassium nitrate	35	62	62
Sulphur	14	19	19
Orpiment	—	6	9½
Lampblack	—	—	3½

The potassium nitrate was sometimes a mixture of fine powder and the more coarse crystalline powder. These fine tubes were not always charged with a funnel and wire; the composition was merely poured over the open ends of the tubes and shaken down in a similar way to the method used for filling English-crackers (see page 297). Again, not surprisingly, many compositions filled in this loose manner function better than those which are carefully charged.

Torches

Weingart wrote a great deal about these items but they are seldom used now in Europe. The reason for this could be that they are comparatively expensive, or that they are liable to deposit dross, make a lot of smoke, and are liable to cause accidents in crowds. The most commonly used torches today are made of a piece of Hessian or sackcloth which is rolled around a former and then dipped in molten paraffin wax. It is quickly removed from the former and subsequently fitted with a suitable handle. These torches are non-pyrotechnic, but are cheaper and safer. Pyrotechnic parade torches and railway fusees are 18 mm-24 mm in diameter and 20-50 cm long. The tubes are normally wet rolled with a piece of thin kraft paper which makes about four to five turns on the former. Lance compositions are quite suitable for colored torches and, if need be, these can be made cheaper by the addition of 5-10% woodmeal or 5% starch or wheatflour. The following compositions are also quite useful:

	A Weight (%)	B Weight (%)	C Weight (%)
Potassium perchlorate	52	—	25
Strontium nitrate	—	45	—
Aluminum 150 mesh "bright"	24	—	—
Aluminum Flitter 30/80 mesh	20	—	—
Aluminum dark pyro	—	18	—
Dextrin	4	—	—
Barium nitrate	—	76	—
Sulphur	—	4	—
Petroleum jelly	—	2	—
Shellac 30/200 mesh	—	—	14
PVC	—	—	6
Linseed oil	—	—	1
Magnesium Grade O	—	—	9

Parade torches are usually furnished with a wooden handle which is glued into one end, while the other end is primed with a modified gunpowder and touchpapered. (Fig. 11.4) Signal torches are frequently primed with a mixture of potassium chlorate and fine charcoal which has been mixed into a paste with dextrin and water. A small wooden

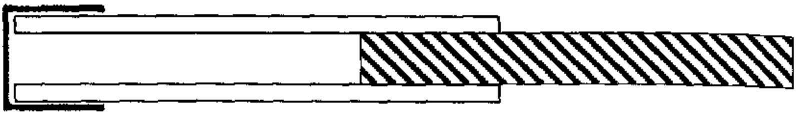


Fig. 11.4 Torch or hand flare

striker on which is pasted a slurry of red phosphorus is also provided for ignition. More sophisticated signals have striker ignitions embedded in polythene units, ignition being achieved by pulling the wire to release the striker.

Flares

In some circumstances, illumination can be achieved almost as well with aluminum as with magnesium. The following compositions can be charged into wide bore tubes with thin walls, but care must be taken when charging mixtures of barium nitrate and aluminum, for these mixtures are more sensitive than one might think. It is in fact much wiser to press them into tubes on an Arbor press.

	A Weight (%)	B Weight (%)	C Weight (%)	D Weight (%)	E Weight (%)
Barium nitrate	56	—	—	22.5	50
Strontium nitrate	—	60	42	—	—
PVC	21	15	12	15	—
Magnesium grade O	—	—	30	35	—
Potassium perchlorate	—	—	9	22.5	—
Polyester	—	5	7	5	—
Magnesium grade 4 or 5	16	20	—	—	—
Aluminum dark pyro	—	—	—	—	35
Potassium nitrate	—	—	—	—	15
Montan wax	7	—	—	—	—

Formulas A, C and D are from BIOS (12) sources and Ellern (5), the two latter being from the American patent literature.

Compositions containing barium nitrate and aluminum are also somewhat difficult to ignite and it is always necessary to add a suitable ignition mixture such as those mentioned on page 213 or a hot burning antimony white star mixture would work equally well.

Magnesium flares are rather more complex to manufacture, mainly because they depend so much on the correct preparation of the materials and they require pressing under heavy pressing loads. Ellern and others have printed many typical formulations.

Waterfalls

In view of the fact that waterfall compositions are closely related to the rest of the fireworks described in this chapter, they will be described here.

The general principle of formulation is to ensure that there is an excess of aluminum present, in order that the burning material will fall to the ground with the appropriate sparks. The tube is usually a wet rolled tube consisting of four or five turns of an 0.010 kraft paper on a 18 mm-24 mm former. The tube is 15 to 30 cm and naturally must burn away with the composition or else the essential dross will not fall to the ground. Old formulations were made with potassium chlorate

	Weight (%)
Potassium chlorate	72
Aluminum"Bright"	28

This was damped with a 10% solution of shellac in alcohol, mainly to control the aluminum dust, but the small amount of well distributed fuel also improves the burning and holds the composition together. Naturally it is much safer to use potassium perchlorate, and in this case a slightly larger proportion of aluminum is required.

	Weight (%)
Potassium perchlorate	50
Aluminum "Bright"	25
Aluminum Flitter 30/80 mesh	12.5
Aluminum Flitter 5/30 mesh	12.5

The usual method of charging is to cover one end of the tube with a thin paper "drum head" or a piece of muslin. A small quantity of igniter composition is placed in the tube first, followed by successive increments of composition which are lightly tapped down with a mallet and drift. Bundles of tubes with a maximum of 7 kilos of composition are damped at one time. The tube is finally closed with a disc.

Many people prefer to use barium nitrate as an oxidizer, and while this is safer it is also inferior, for there is a tendency to get a large glare at the mouth of the tube and a weaker drop effect. Dr. Becher (10) gives the following composition which is fairly typical.

	A Weight (%)	B Weight (%)
Barium nitrate	52	52
Potassium nitrate	8	8
Aluminum dark pyro	16	22
Aluminum flitter 5/30 mesh	21	14
Meal gunpowder	3	—
Aluminum Flitter 30/80 mesh	—	5

In this particular instance, the increments of composition should be pressed dry with a hand press and not charged with a mallet. The igniter composition is also quite essential with this particular mixture. It is also necessary to adjust the aluminum to fit the particular grades used; a bright powder can be used equally well instead of pyro, but this will necessitate the adjustment of the flitter.

All the shower sticks are finally primed on the outside of the drum head with mealpowder, capped and prepared for use as waterfalls. Some people insert a piece of wooden dowel into the end of the shower stick and then nail this on to a length of board which is fixed so that the shower sticks burn in a horizontal position. In England it is common to fasten a piece of thick string on the end of the shower and use this to fasten the showers on to a board. In this way the showers actually move during burning. (Fig. 11.5)

Good waterfall effects can also be obtained by using a bank of iron or titanium gerbs of 24 mm bore, fixed to burn in a horizontal position. It has already been mentioned elsewhere that some mixtures are very

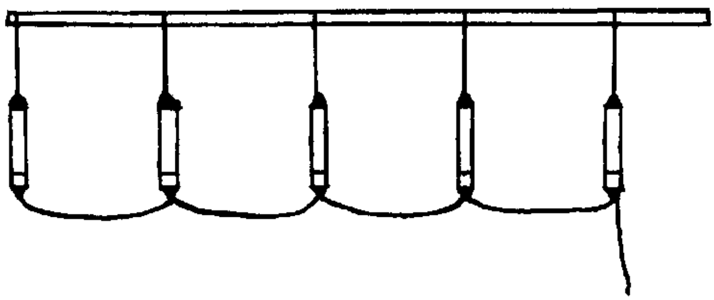


Fig. 11.5 Waterfall

difficult to ignite and may need a special igniter composition. Mixtures of barium nitrate and aluminum in stars and waterfalls are a case in point.

It is usual to use an igniter which produces a hot slag such as:

	Weight (%)
Potassium nitrate	40
Silicon 300 mesh	40
Gunpowder	20

Sulfurless gunpowder can be used with mixtures which contain a chlorate. With a binder, the mixture can also be used for stars.

12

ROMAN CANDLES, COMETS, MINES

Roman Candles

There can be no doubt that it requires much practice to make really good Roman Candles, and the best ones are still made by hand. So many factors play a part in the performance of the candle with the inevitable result that there is always something to go wrong. Each of the factors will therefore be examined in turn and the possible snags pointed out.

Firstly, the tube is all important, and for the purposes of this chapter, only one size of Roman Candle will be referred to, the tube being 16 mm inside diameter, at least 30 cm long and having a wall thickness of about 6 mm. The wall needs to be of this thickness or else the tube will catch fire during the performance of the candle. The best tubes are hand rolled and it is quite essential that the inside lap of paper is completely stuck down or else the powder will creep down the loose paper, cause a "blow-through" and eject the stars like machine-gun bullets. The stars are made in a 14 mm former which means that they just comfortably slide down the inside of the tube. In addition, as would be expected, stars made in a 14 mm former shrink very slightly during the drying process, just as a wet rolled tube on a 16 mm former also shrinks during the drying process, with the result that both factors might play a part. Stars which are too tight are ejected so fast that they are frequently extinguished because they are projected too rapidly. Similarly, stars which are too slack often land on the floor still burning, since they were projected only a few inches into the air.

The quality of the paper of the tube is also quite important. A good quality kraft paper for example, rolled with a good casein glue, provides a tough tube which hardly burns away during the firing of the candle. If a good quality grain powder were used for such a tube, the stars would be ejected with increasing force as the fire proceeded down the tube and would probably be extinguished. The reason for this is not far to seek because the tube is not burning away at the top and a high pressure is thus maintained. On the other hand, the use of a cheap paper could mean that the tube burns away at the top, allowing the gas to escape, with the result that the stars are not projected quickly enough. Clearly the manufacturer uses a good quality grain for poorer quality papers and vice versa. In practice it is usual to use the cheaper paper. The 14 mm stars are usually about the same length, but the burning rate of the composition depends on the way the stars are placed in the tube, for there are two methods.

The better method uses very fast burning stars, such as the ones on page 201, and surrounds each star with a small amount of gunpowder to make sure that it will be ejected immediately. Since the star is ejected so rapidly, it is essential that it should be fast burning or else it will be extinguished.

The second technique places no powder around the star but uses a much slower burning star which actually burns for a second or two in the tube before it is ejected. Gas is lost up the side of the star, which is not ejected as high as those made by the first method. The latter method also produces candles which are more erratic in their performance, for a good Roman Candle should eject all its stars regularly to the same height, the stars burning out just as they turn over to come down again.

The roman candle delay also plays a part, for its burning characteristics are directly related to the grain powder charges under each star. Manufacturers naturally tend to have their personal preferences, some maintaining that it is essential to granulate the composition by damping it with water and subsequently drying it. If this granulation takes place for a definite purpose, such as making the composition dust free and therefore cleaner to handle, or easier to manipulate in the measuring boards for mass filling, this is fine, but it is otherwise unnecessary. Some argue that the fuse should contain a large proportion of gunpowder or sulphur or both, though it is not always clear why this view is held. The most significant factor would appear to be the need of a reasonably dense fuse which consolidates well, a condition mainly satisfied by the presence of sulphur, potassium nitrate, gunpowder and not too much charcoal. The fuse ideally should produce a good show of golden sparks but this is not necessary, of course, and there is always a tendency to produce too much smoke as would be expected.

The following composition is quite a satisfactory one, since it combines most of the characteristics mentioned:

	A Weight (%)	B Weight (%)
Potassium Nitrate	50	55
Meal gunpowder	22	15
Charcoal 40/100 mesh	11	8
Charcoal 30/60 mesh	11	8
Sulphur	6	14

The manufacture of a 30 cm Roman Candle, for example, would take place as follows. The tube, (see the dimensions at the beginning of the chapter) is placed on a small nipple and a charge of clay is placed inside. Using a drift which slides easily down the tube, the clay is firmly consolidated. A charge of English 4FA or FFF grain powder is next placed in the tube, followed by a star. A small charge of gunpowder or fine grain powder is then placed on top of the star and the tube is tilted backwards and forwards so that the powder will trickle down the side of the star. A scoopful of delay fuse is now placed in the tube and this is consolidated lightly with a mallet, and it should be noted that this is where the skill really lies. If the delay is rammed too lightly or too firmly the candle will not function properly, with the result that the stars are ejected too fiercely or in quick succession. Only experience will teach the operator just how hard to strike the drift.

The fuse and clay scoops are usually semi-cylindrical, being beaten out of a sheet of copper. Grain scoops are smaller, but are made in a similar way. A 16 cm X 30 cm Roman Candle takes about six stars. The quantities are roughly as follows:

Fuse scoop holds approximately 4 gm
Grain scoops hold 0.45, 0.55, 0.60, 0.90, 1.20, 1.50 gms
About 0.50 gm of gunpowder is placed on each star.

The smallest grain charge goes in the bottom of the tube on top of the clay and then the charge increases as it gets nearer the top. Fig. 12.1 shows a Roman Candle in cross-section.

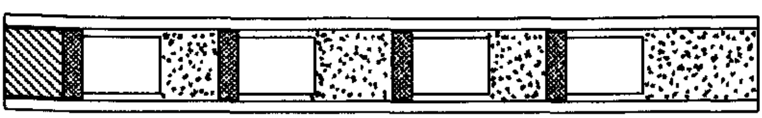


Fig. 12.1 Roman candle

In practice, these candles are not filled singly of course. Display candles are usually filled in small bundles, while commercial items may be charged a hundred or more at a time. American practice appears commonly to employ gang rammers, but this is unusual in Europe where the candles are rammed singly or six at a time. The European method no doubt springs from a fear of the mixture of chlorate in the stars and the sulphur in the fuse plus friction from the gang rammers.

There is a considerable history of accidents charging Roman Candles and widespread agreement that most of them were caused by chlorate/ sulfur contacts. Traditional fuse is made with sulfur - as much as 26% in one UK mix - and one can imagine what would happen if a chlorate star got stuck halfway down the tube and was then forced into position. One UK accident was caused by an operator who added the chlorate stars and then forgot to add the delay fuse before he started the ramming operation.

It is much safer to use a delay fuse without free sulfur such as the following:

	Weight (%)
Potassium nitrate	52
Soft grain gunpowder	22
Charcoal 40 mesh	21
Red gum	5

Good quality grain should always be used for making Roman Candles. Home made gunpowders are fine for so many things, but in good candle manufacture consistency is required.

In mass-filling the grain and the fuse are added by means of the measuring boards described by Weingart. Thick boards made of wood or synthetic resin are drilled with suitable holes just large enough to admit the required quantity of fuse or grain. Another similar board is then placed underneath with corresponding holes which will allow the powder to trickle through into the tubes. If the two boards are arranged so that they will slide over each other, the powder can be contained in the holes of the top board or allowed to run through into the tube by merely sliding one board over the other. The principle is not unlike the one used by organ builders for making the wind available to ranks of pipes. The diagrams will explain the method more easily than a detailed description, and greater detail is pointless since every manufacturer will modify the method to suit his own purposes. (Fig. 12.2).

A good Roman Candle is easily recognized. The fuse will burn rapidly and steadily and each of the stars will come out at regular intervals

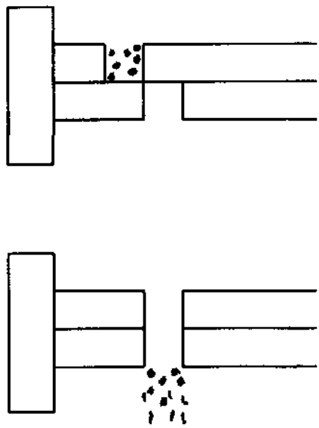


Fig. 12.2 Sliding boards for changing powder

with a sharp little crack, gain a good height and just turnover before it is extinguished.

The reader is referred to an article by the author in Pyrotechnica XIV (29).

A wide variety of Roman Candles are made, with inside diameters as small as 10 mm and as large as 60 mm. Most of the candles eject stars such as colors, glitters, aluminum and lampblack stars, but more sophisticated versions eject pressed magnesium stars, whistles, humming stars, flash and sound, serpents and large comets. The special larger bore candles usually have to be filled singly and require great care in their manufacture since they are such expensive items.

In recent years more sophisticated Roman Candles have been made with felt wads as delays instead of the old candle fuse. The wads are very effective and clean to handle but considerably more expensive. Economically this method should only be used for tubes of approximately 25 mm ID upwards since candles of this bore would require large quantities of candle composition which in turn generates volumes of smoke and sparks. Densely pressed virgin wool felt makes the best wads, but much cheaper re-constituted scrap wool felts are used also. A 30 mm candle would need a felt washer about 20 mm high. The diameter of the wad must be about 3 mm larger than the diameter of the tube so that it is a tight fit when it is forced down the tube, thus producing excellent compression. In the center of the wad is a small hole containing a delay mechanism which fits tightly and comfortably.

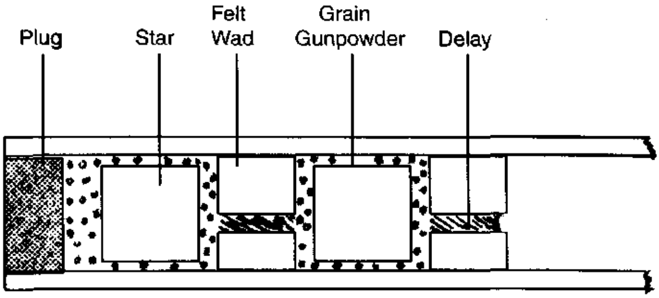


Fig. 12.3 Section of a 30 mm candle

The easiest form of delay is a self-consuming pellet such as a 14 mm nitrate based white star. The star works very well, is easily and cheaply placed in the wad and should be a tight fit. The slight drawback is that this pellet needs a hole of about 12 mm and so there is some loss of gas, and stars can be ejected a little erratically. It has to be said honestly that the overall performance of this method is much more consistent than when loose candle composition is used.

The best delay to use is a short plastic tube charged with powder like a shell fuse. It need only be 4 mm or 5 mm ID and so there is much less loss or gas. Bickford can be used but it is not satisfactory because it needs cross-matching for 100% performance; this is difficult to do on both sides of the wad and the ramming of the wad can upset this cross-matching and cause a misfire. In Spain plastic cups with a molded fuse hole have been made for candles but they are not 100% efficient.

These large candles are most useful for comets or bombettes and are made as large as 60 mm and used for multiple firing of bundles of effects such as whistles and serpents, etc. Such powerful candles need good tubes and while the temptation is to use spiral wound tubes for economy, they frequently disintegrate and need to be of exceptional quality; convolute tubes are much better.

The Chinese produce small cheap candles which are quite efficient, and use granulated clay between the stars. A length of standard Chinese fuse goes down the inside of the candle. A charge of grain is placed in the bottom, then a star and thirdly a charge of granulated clay to make the delay time. The tube is continually charged in this way until it contains eight or more stars. The method works well and the price is good.

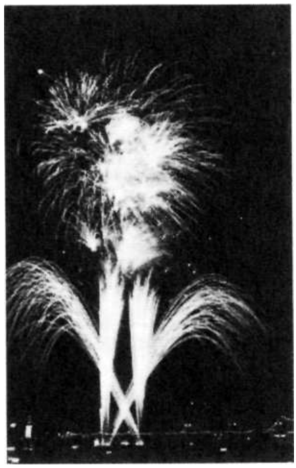


Fig. 12.4 Roman Candles for Thames Day in London

Comets

Comets are single Roman Candle stars in their simplest form, but they are usually gunpowder type compositions since they are ejected at great speeds. The compositions are damped with dextrin and water or accaroid resin and spirit and then consolidated in a single star pump. Large star pumps are made of brass or a mixture of brass and copper and so arranged that they can be charged with a mallet or placed in a press. The smaller comets of about 24 mm in diameter can be adequately charged with a mallet, but the larger comets should be pressed in order to get greater consistency. When comets are being manufactured, it is usual to press more composition than is necessary, eject the excess and then cut off this excess with a knife. (Fig. 12.5)

The majority of the smaller comets are placed in cylinder bombs but they can also be effectively used when fired from the ground in large numbers in quick succession. Comet batteries consist of steel plates on which are welded a dozen or more steel tubes about 20 cm long. Holes are drilled in the base of each tube to allow a piece of slow fuse to be threaded through each one. A charge of grain powder, possibly about 10 gms, is loaded into each of the tubes and then a comet star is placed on top of the charge. Lastly a tight fitting wad is rammed on top of the star. The "wad" need only be a sheet of paper which can be consolidated with a wooden drift. Naturally care must be taken not to ram the tube too tightly or else there is a danger of bursting the tube. Large bore tubes should never be rammed in this way. (Fig. 12.6).

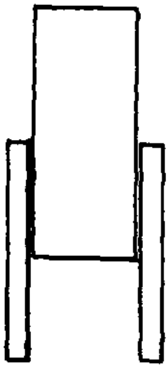


Fig. 12.5 Pump for comet stars

Huge numbers of comet batteries are now reaching the west from China. Strawboard tubes suitably closed are threaded with Chinese fuse and then glued and wired into differently shaped batteries i.e. a square of 16 or 25 tubes or maybe a circle of 90 tubes etc. Some of the 'cakes' as they are usually called may extend to hundreds of shots and vary in diameter from 12 mm up to 75 mm or more.

Appearing with unusual names which in many cases seem to be literal translations of Chinese names, they may have a greater significance than we realise in the West.

Larger comets of 4 or 5 cm in diameter are either solid or filled with colored stars. The star is formed with a chamber in one end of the star so that a colored star or stars can be placed into the cavity which is formed. (Fig. 12.7).

The stars are finally covered with a pasted paper coat. The paper covers one end and three quarters of the length of the star. Solid stars are not normally covered. Crossette stars or splitting comets usually have a small charge of flash powder instead of colored stars. These

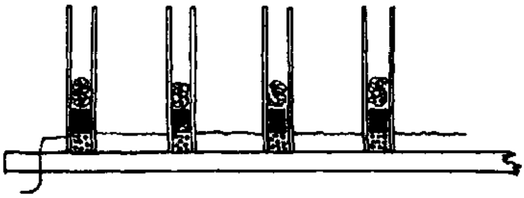


Fig. 12.6 Comet Battery

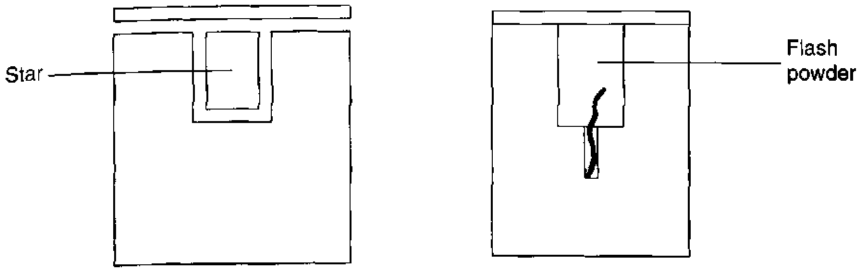


Fig. 12.7 Comet Stars

stars are very effective as the streaming comet suddenly bursts into many fragments.

Effective comet bombs can be made by pressing a star in the bottom of a paper tube and then filling the remainder of the tube with stars or other effects. The result is a spiral of fire terminating in a star burst. These items need to be carefully manufactured otherwise they are liable to "blow through" in the mortar. (Fig. 12.8)

Mines

The ordinary mines are simply a charge of gunpowder and stars at the base of a strong tube which acts as a gun. The "Bags" of commerce, or Pot a Feu as they are sometimes called, consist of about three turns of a medium kraft paper dry rolled on a former which is about 12 mm

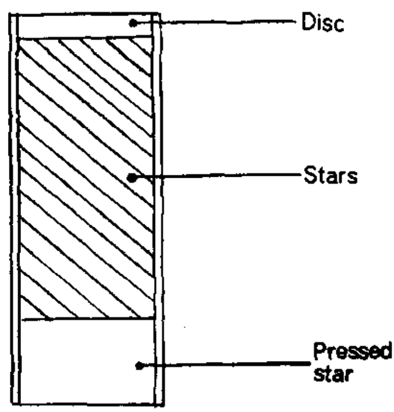


Fig. 12.8 Small Comet Bomb

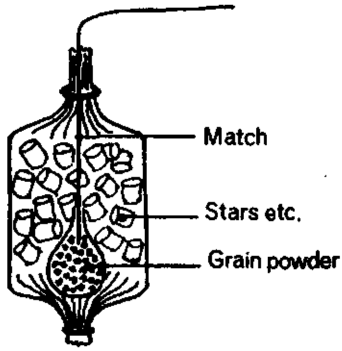


Fig. 12.9 A "bag" or mortar mine

less than the diameter of the mortar. A 11.5 cm bag for example is 100 mm in diameter and about 15 cm high. The paper for this bag would be about 1 m long for the roll up and about 30 cm wide. A gunpowder charge of about 50 gm of grain powder is placed in a small bag which is then tied to the end of a length of piped match. This bag is then placed into the bottom of the main bag and stars, tourbillions, flash charges, comets etc. are then loaded on top of the powder charge to a depth of about 15 cm and the bag is tied off above the stars. Figure 12.9 will explain the method more easily.

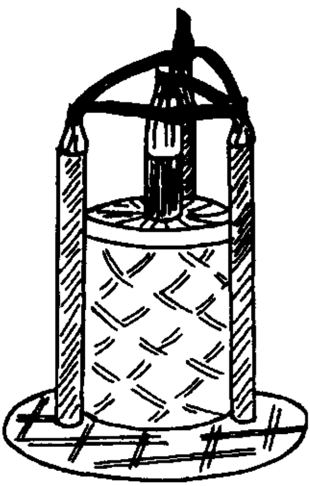


Fig. 12.10 Devil among the Tailors

Fig. 12.11 Devil Among the Tailors. Early 20th Century. Brock's Fireworks

Commercial mines are usually made in wide bore tubes about twice the height of the diameter. The tubes are fitted with a strong base of paper or wood which is securely glued into place, and a weakly fitting lid which will blow off easily. Sizes vary from quite small tubes 24 mm in diameter up to quite large ones 12.5-15 cm in diameter. Mines of this type are normally fitted with a central delay fuse which consists of a long narrow tube which contains no clay at the base, but is merely primed so that the fire can transfer to the powder charge. Roman Candles are also used as delays. Special mines called "Devil Among the Tailors" consist of a mine with a central roman candle and three other candles fixed to the outside of the tube. The device thus produces a fine display of colored stars which terminate in a mine burst of crackers, stars, serpents. (Fig. 12.10, 12.11)

13

NOISEMAKERS

FLASH AND SOUND

Explosive fireworks more than anything else have been the cause of serious accidents and they have probably done more damage to the firework industry than anything else! Flash crackers in their various forms were on sale to the public for far too long and happily have been forbidden in many European countries. Gunpowder "bangers" are still sold to the public but they are mostly of interest only to schoolboys who frequently make a nuisance of themselves by throwing them at people.

It is also a tragic fact that many young people cannot resist the urge to create explosions, and in their enthusiasm they choose unstable and highly sensitive mixtures which they charge into unsuitable containers in highly dangerous ways. Fatalities caused by sodium chlorate mixtures being charged into containers made of metal (of all things!) must be legion.

There can be no doubt that even among firework manufacturers, compositions vary very much in their sensitivity, but so much depends on what is required of the mixture.

Flash compositions of some types will cause explosions in the lightest of containers-even sometimes in just a few turns of paper-but it also happens that these compositions are extremely brisant and sensitive. Horrifying mixtures of potassium chlorate, pyro aluminum, sulphur and barium nitrate have been employed and should be avoided at all costs. Mixtures of the perchlorate, sulphur and bright aluminum are safer and appear to be used extensively in the USA and Japan (page 365) but even these would be considered dangerous by many of us in Europe. In fact the more common European technique is to use a strong paper tube with a composition consisting simply of potassium perchlorate and dark pyro aluminum, e.g.:

	A Weight (%)	B Weight (%)
Potassium perchlorate	66	70
Pyro aluminum	34	30

Sometimes barium nitrate is used as the oxidizer, e.g.:

	Weight (%)
Barium nitrate	68
Pyro aluminum	23
Sulphur	9

		A Weight (%)	B Weight (%)	C Weight (%)
USA Mixes	Potassium perchlorate	67	63	60
	Aluminum	17	27	25
	Sulphur	16	10	—
	Antimony sulphide	—	—	15

Magnesium flash is usually:

	Weight (%)
Potassium perchlorate	38
Graphite powder	5
Fine Magnesium	57

These mixtures are not quite so easy to ignite, but normally do so with Bickford fuse and they easily ignite with quickmatch and gunpowder primes.

It must also be pointed out that dark pyro aluminum is a dark grey impalpable powder with no visible silver particles, in fact it does not even look like aluminum powder. Very many so called pyro powders are much coarser than the European dark pyro powders.

The original flash compositions were made with potassium chlorate and aluminium and barium nitrate was occasionally added. These mixtures in themselves were very sensitive to impact and friction and a quantity of less than 1 gm could be quite devastating.

Prior to World War II the so called fine 'bright' flake powders were used but they were not always as ignitable as one might expect. Flash crackers made for general sale usually had a piece of black match in the tube to prevent the surprisingly large number of failures.

In Europe it has been usual to make the flash composition with the dark pyroaluminium powders. German pyroschliff has always been of good quality though it is more than likely that the powder is also being made increasingly outside Europe for both economic reasons as well as stricter controls on manufacture. In at least one case, European manufacture was stopped by bureaucrats who considered it to be too great a risk, with the result that jobs were lost and the material was imported.

In the USA, atomized aluminium is used in some flash mixtures but it also seems that the USA has better grades of these powders. It would certainly not be possible to use atomized powders made in the UK.

Many of the amateur firework organisations in the USA have demonstrated the extreme brisance of flashpowder by detonating something like 500 gms in a small wooden shed. It is a sobering experience to see it detonate, unconfined. Even if a human was to survive inside a workshop, the effect of the pressure on ears and lungs, etc., is devastating.

The smallest amount should be mixed at one time and 250 gms should be regarded as the maximum in a covered container with the smallest amount exposed.

Mixing is a serious issue and is probably best done by using free flow potassium perchlorate newly sieved, adding the metal powder on to the perchlorate on a sheet of paper and rolling the two together by lifting opposite corners of the paper. The mixture can then, if required, be placed on an earthed sieve and passed through by tapping the side of the sieve. It must never be pushed through the sieve.

The bench should be covered with an earthed sheet of carbon conductivity matting and, if desired, the wrists of the operator can be earthed. Some companies who make large quantities of flashpowder mix the powders in small mixing drums made of this carbon material, the machines being earthed.

The whole issue of sensitivity to static electricity is a complex and highly specialized field, but there should be an earthing system in all danger buildings. So much depends on the climate. Arizona is not the same as the UK.

Nevertheless it is a sobering fact that while accidents do not often happen under careful control, familiarity does breed contempt. What is more, it is not usually one factor that leads to an accident, it is fate which sometimes brings as many as three or four factors all together In one moment in time.

It is clear that if such small quantities of flashpowder are to be handled, there must be a very high cost factor involved in bulk manufacture and there must be some way around this. In practice, containers are filled with two different sets of charging boards. A measure of sieved free flow oxidiser is placed in the tube first, followed by a measure of metal powder and the tubes are sealed. The filled tubes are then taken to a gentle tumbling machine which turns them end over end at the other side of a concrete barrier. The mixing is not so efficient, but it works.

The explosions are normally made out of a paper tube 1 mm thick and upwards which is closed at each end with clay or corks. A piece of Bickford or other fuse penetrates the tube in some manner and is firmly glued in position. The containers are filled about one half or two thirds full of flash powder which is charged loosely and not compressed. Tubes made of metals or brittle materials should never be used because of the danger of flying debris. The barium nitrate mixture is less fierce than the perchlorate composition and, in this case, the tubes are filled quite full. Magnesium compositions are also sometimes used, but naturally they are less stable and rather more sensitive.

Maroons are sometimes filled with FFF grain powder but they need strong tubes. In former times, and occasionally still, the cores were wound with strong twine and then glued on the outside.

Photoflash mixtures made with potassium perchlorate, barium nitrate and atomized aluminum have much slower burning speeds and require a very strong tube to produce a loud noise.

Whistles

The oldest whistles were made with potassium picrate. Picrate whistles are very shrill and can be very entertaining in Roman Candles with their black tails.

Potassium picrate is not normally manufactured by the picric acid manufacturers since there is little use for this material, though the principal English manufacturer did in fact produce small quantities for the firework trade. Dr. Shimizu describes the manufacture on page 369.

Picric whistles are not popular with the firework makers mainly because no-one cares to work with them. The salt stains the fingers and clothing a bright yellow, and the taste is bitter and unpleasant.

It is well known that picric acid and its salts are sensitive to impact and great care needs to be taken when charging potassium picrate. In fact it is much wiser to consolidate the material with a small hand press. Lead picrate is particularly sensitive; therefore lead covered surfaces must be avoided.

Strong narrow bore tubes (e.g. 6 mm inside diameter, 32 mm long and with a 6 mm wall) can be charged quite full, though the material needs to be well consolidated or else it will explode. If neat potassium picrate is used without any additives, the tube must be full to the top and not primed. Priming causes explosions as well. The material purchased in the UK could be charged into whistles without any additional material. On the other hand, material made by the author has been known to explode. As the material is not used anymore, the reason is academic but it may well be the way it is neutralized. The short, full tubes should therefore have about 3% stearine or asphalt added to the potassium picrate, the former being pleasanter to handle.

Other types of whistles operate in such a manner that it is essential to have an empty space over the composition, since the empty tube acts as a kind of resonator. Potassium picrate, as it has already been stated, will work in short tubes without any additive, but in long tubes it must be diluted. Up to 20% of potassium nitrate or up to 15% of stearin or powdered asphalt can be added for this purpose.

Whistles should only be lightly capped with no more than two turns of thin kraft paper or they are liable to explode.

Picric whistles are suitable for rockets, Roman Candles and ground pieces, but they should never be placed in shells lest the lifting charge detonates the picrate.

Many people regard potassium picrate as an exceptionally hazardous material, but there can be no doubt that very many accidents have been caused with the principal alternative, a mixture of potassium chlorate and gallic acid.

A mixture of three parts of potassium chlorate to one part of gallic acid is normally used for these whistles, though it appears that American formulations include a small percentage of accaroid resin. Potassium perchlorate cannot be used with gallic acid. The mixture is extremely sensitive and the greatest care should be exercised during mixing and charging, for explosions have taken place during mechanical mixing and fires have occurred during sieving and charging. The mixture is charged into tubes from 6 to 10mm. in diameter, to a depth 24mm. in about four increments. The top 35 mm of the tube should be left empty. Two pieces of quickmatch are inserted into the empty space before the tube is capped. An additional disadvantage of this mixture is the high Price of gallic acid.

In recent years there has been a tendency to make whistles with a mixture consisting of 70% potassium perchlorate and 30% sodium salicylate. Again, in the USA. they add a small percentage of accaroid resin, and this is not necessary. In fact, this mixture is hygroscopic and whistles should not be kept for long periods, particularly in unheated magazines over the winter. Oddly enough, the addition of accaroid resin to this mixture seems to increase the tendency to absorb water, but the reason for this is not clear. Polyester can be added to the salicylate composition but it does not give complete protection from moisture. Potassium benzoate can also be used in place of sodium salicylate. This type of whistle can be pressed or hand charged, but the potassium perchlorate and most of the sodium salicylate must pass a 120 mesh sieve. The exact particle size is something of a problem and batches of sodium salicylate vary somewhat in their performance.

Work on whistles was originally done by Maxwell (49) but from a firework point of view, great credit goes to a Turkish pharmacist Selcuk Öztap. Two excellent articles in Pyrotechnica (XI, XIII) give a wealth of information on the kind of articles which can be produced with this mechanism which is related to the strobe effect (see Chapter 6).

Mr Öztap originally worked with salicylates and was original in that he also added vaseline or oil to the mixture and a small amount of iron(III) oxide. The following mix is representative:

	Weight (%)
Potassium perchlorate (170-200 mesh)	76
Sodium salicylate (170-200 mesh)	20
Vaseline or paraffin oil	3
Red iron oxide fine powder	1

The ingredients are mixed by warming to 40-45°C.

Sodium benzoate has been employed in whistles but as a general rule potassium benzoate is the favorite in commerce. The Chinese seem to prefer potassium hydrogen terephthalate, see page 115. Variations in tone can be produced with these whistles. Benzoate whistles with a central spindle shaped hole (but no choke) like a rocket, make an extraordinary rattling noise and have been commercially available in Europe for some years. As with rockets, the mixture needs to be carefully charged and the spindle not too large or the items are likely to explode.

This strange rattling noise generally described as a 'croaker' 'screecher' or 'knatter' is being used for general entertainment at firework displays or for scaring birds. Titanium can also be added to the mixture or to the ordinary whistles for a silver tail. It must be borne in mind however that adding titanium increases the sensitivity. All these

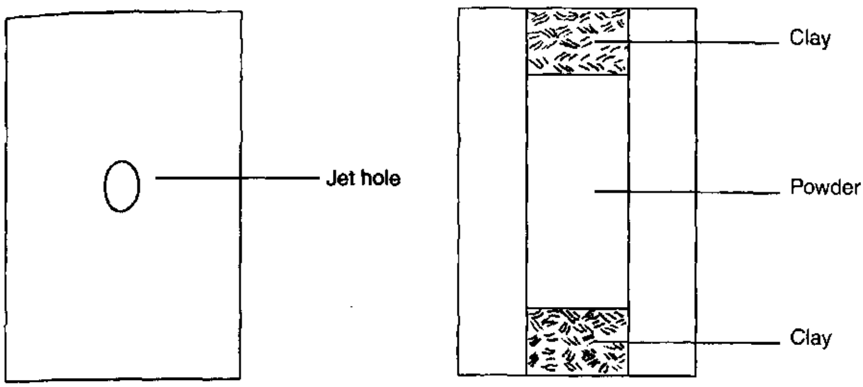


Fig. 13.1 Firework hummer

mixes are fiendishly explosive particularly when pressed in moulds and should be pressed behind a barrier.

The Chinese are using these mixtures pressed into tubes in similar ways to the hummer described below to obtain either a screecher or a humming effect. In tubes with clay chokes the sound can be positively flatulent.

Humming Fireworks

Humming Fireworks are constructed in a manner which will allow a jet of gas to issue out of a tube at such a speed and at such an angle that the tube will be caused to rotate on its own axis. In the air this causes a humming noise.

The smallest hummers are made out of narrow bore tubes about 8 mm internal diameter and with walls 6 mm thick. The tubes are about 32 mm long and must be blocked with clay at each end. Inside the tube, between the clay plugs, a very fast burning mixture of gunpowder and aluminum is carefully charged. (Fig. 13.2).

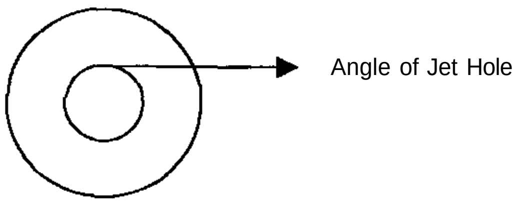


Fig. 13.2 Angle of the jet hole of a firework hummer

The purpose of the aluminum is merely to slow down the mealpowder to prevent an explosion and also to produce some silver sparks. 7% to 10% of fine titanium or silicon can be used for the same purpose.

Larger hummers 16 mm inside diameter often employ a little charcoal in addition to the gunpowder and aluminum and frequently have two holes.

The gas jet issues out of the tube from a small hole pierced through the wall in the center. The size of the hole is, of course, related to the burning speed of the powder.

It will be observed from Figure 13.2 that the angle of the hole is such that the tube will be made to spin in flight. Needless to say it is better to pierce the hummer tube since drilling is rather hazardous. For ignition, a piece of quickmatch is placed in the pierced hole and then secured with a piece of tape. It is possible to drill the empty tubes first and then charge a piece of match into the composition during the filling operation.

The best hummers are made with a long steady stream of gas. This is ideally done with a polymerized Bakelite resin containing potassium perchlorate and some aluminum. This was the subject of a patent by R.G. Hall of Brock's, and a further development of trials in Germany during the WWII. The Bakelite resin in the form of a syrup is mixed with the manufacturers recommended quantity of accelerater. Potassium perchlorate is added to produce a putty-like extrudable mass which can be extruded into the tubes. The mass dries into a hard solid which burns with a steady production of gas.

The main snag with these resins is that the formaldehyde is given off over quite a period, and the skin needs protecting while working with the material. In the end one is tempted to say that blackpowder is easier to handle.

14

ROCKETS

Rockets are one of the oldest pyrotechnic devices. Their history can be traced from the Middle East, where they were used as weapons, to India, and to China where, it is believed, they were first used for display purposes. The manufacture of rockets was well known in Europe during the early middle ages, and the origin of the word is thought to be based on the similarity in appearance of a rocket on its stick, to the round piece of wood used to cover the point of a lance in mock combat. This was known as a "rockette" an Italian diminutive of "rocca" a staff.

All rockets, from the smallest firework to the giant satellite carrying Saturn, have four basic components in common. They are:

- A case or rocket motor
- A "choke" or Venturi
- A propellant charge
- A flight stabilizing device

Rockets are reaction motors. On ignition, the propellant charge produces gas at a high temperature and so the internal pressure of the gases in the rocket body is raised. By allowing the gases to escape through a narrow opening, the pressure at this opening, or nozzle, falls and the velocity of the gases is increased. At any time, the momentum of the rocket must equal the momentum of the escaping gases so that, very simply, we have the following equation:

mass of rocket and unburnt propellant X velocity of rocket

= mass of escaping gas X velocity of gas.

Rocket bodies or cases may be made from a variety of materials.

Simple firework rocket bodies are almost exclusively rolled from a good quality Kraft paper. After cutting to size, the paper is pasted and tightly rolled on a cylindrical former and allowed to dry. It makes little difference whether this operation is done by hand or by machine, except that when the cases are machine-rolled a slightly inferior quality of paper may be used, as the tighter machine rolling gives greater mechanical strength to the finished case. Care should be taken to ensure that the inside surface of the finished case is smooth and regular, and that the inside edge of the paper is firmly pasted down. This is important since it is possible to dislodge this edge during the charging operation and to turn it over into the composition. This would seriously affect the consolidation of the propellant charge and would most likely lead to the bursting of the rocket on ignition. The cases should be thoroughly dried. That is, they should be allowed to reach an even moisture content in equilibrium with the atmosphere in which they are to be charged. Failure to observe this simple precaution can cause swelling or shrinking of the case after charging and the subsequent malfunctioning of the finished rocket. For signal rockets, which have to stand more vigorous handling and storage conditions, the cases may be made from phenolic resin impregnated papers. After rolling, the resin is cured or polymerized in a heated oven and this process gives a rigid case of great mechanical strength. Metal cases of steel, or aluminum alloy, are also used and these are often varnished on the inside surfaces to give greater adhesion between the propellant and the case wall and sometimes to prevent undue heat transfer along the case. Good quality, thin paper linings, which may or may not be varnished, are also used for the same purposes.

The "choke" or venturi is an important part of the rocket. The pressure energy of the propellant gases is converted to kinetic energy by this device. In firework rockets the "choke" is quite crude and is often formed by constricting the rolled case whilst it is still damp. The constriction, which may be from 25-35 mm from the end of the case, is then tied with string to prevent its opening out on drying. A slightly more refined "choke" is formed by placing the dried case on a metal step which has a nipple of the required "choke" dimensions.

A scoopful of dry clay is poured into the case and pressed or rammed into the case until it is solid. The case and its clay "choke" is then removed from the nipple. Nipple sizes and dimensions will be given later. In signal and line carrying rockets, the "choke" may be no more than a cylindrical hole bored in a metal plate which in turn is roll crimped or riveted to the rocket body. This is a common form of "choke" where black powder type propellants are used. When more sophisticated propellants are employed, the nozzle and venturi should be so designed that the maximum thrust is given by the burning propellant charge. Economic factors and the desirability of mass production of *nozzle* units invariably force the designer to compromise and the result, while satisfactory, is not always the best which is technically possible. A full mathematical treatment of nozzle and venturi design is to be found in the many technical books on rocketry (22).

The traditional propellant charge for the firework rocket is either:

- Gunpowder
- A mixture of mealed gunpowder and charcoal
- A simple mixture of potassium nitrate, sulphur and charcoal.
- A mixture of mealed gunpowder and calcium carbonate

To obtain consistent results with any of these compositions, a few simple but very necessary precautions should be observed. When grain gunpowder is used alone, the grains should be small, regular and free from dust. They should be quite dry and show no signs of white crystals on the surface when examined under a powerful lens. The potassium nitrate and sulphur should be of a good commercial quality and the particle size should be closely controlled. Samples passing 120 British Standard Sieves (B.S.S.) and retained on 160 B.S.S. are ideally suited for the mixed type of composition. The moisture content of the ingredients should be as low as possible and this level should be consistent. Any drying out of the composition after charging would invariably lead to cracking of the charge and to increased pressure build up and bursting of the rocket on firing. Charcoal is the most difficult ingredient to control. It is imperative that the charcoal be kept in a dry, warm store, if the regularity of the burning rate of the finished composition is to be maintained. The particle size should be sufficiently large to give a good glowing "tail" when the rocket is fired. A charcoal passing 40 B.S.S. and retained on 80 B.S.S. is useful for small rockets, and a charcoal containing 10% passing a 15 to 20 B.S.S. and retained on 40 B.S.S. gives a good display in larger rockets. The ash content of the charcoal should be consistent from batch to batch and the type of wood from which the charcoal is made should also be specified. Generally, hard wood charcoals give compositions which burn more slowly than similar compositions made from soft wood varieties.

When a particular formula has been found to give a satisfactory rocket subsequent batches of composition can be checked for consistency by column test. A weighed amount of composition is pressed in equal increments, into a gun metal tube about 10 mm diameter until the column of composition is about 50 mm in length. This length is controlled by a mark on the ram.

The measurements given are purely arbitrary and any reasonable measurements can be used but, once the weight of the composition, the number of increments, the diameter of the tube, and the length of the composition has been decided by the manufacturer, they should be strictly adhered to. The column of composition is fired by a piece of quick match and the burning time is checked by a stop watch. A variation in the burning time of 1.5% is allowable. The gun metal tube is washed in warm water, dried, and is ready for the next test. This test is quick, reliable, and easily carried out. Any discrepancy in mixing or in the purity of the ingredients shows up in increase or decrease of the burning time.

Modern propellants for signal rockets may be of the double or triple base nitro-cellulose powders. These are mixtures of nitrocellulose with nitro-glycerine, or of nitro-cellulose with nitro-glycerine and nitroguanidine. More frequently plastic/perchlorate propellants are employed, since these allow the use of simply designed motors. These propellants are capable of being molded to any desired shape in order to give the correct burning characteristics. Typical formulations would contain polyisobutene, ammonium perchlorate, ammonium picrate (13).

There are three basic types of solid propellant rockets. In the first type, the composition is pressed into the case in a solid mass and is ignited at one end only. The propellant is said to burn in a "cigarette" or "end" burning manner.

It will be seen that only a limited burning surface is available for gas production, and therefore, a fairly quick burning composition is needed in order to sustain an adequate internal gas pressure. In firework rockets, these compositions are usually compounded of mealed gunpowder and fine charcoal. The charcoal is usually present in proportions varying from 20% in rockets of 18 mm bore to 10% in the smaller 12 mm diameter rockets. Fine grained gunpowder is also used and such rockets are quite powerful for their size, but they lack a spectacular "tail" and in the author's opinion are not so interesting as those rockets containing charcoal. In these rockets the "choke" is of clay as already described and the diameter usually varies between 2 mm and 4 mm depending upon the diameter of the rocket and the type of composition used. This end burning type of rocket is usually pressed with the case supported in a metal mold in order to prevent collapse of the paper case. The composition is put into the case in four to six equal increments and each increment is pressed at 300-500 pounds on the ram.

The weight of composition may vary between 5 gms and 25 gms per rocket depending upon the diameter. It is not possible to be more specific, since the ingredients vary in moisture, particle size and so on, from place to place and from different suppliers. Indeed most manufacturers devise their own formula to suit the particular type of case and charging pressures, and stick to this as closely as possible. In the end, firework rocketry is largely a matter of trial and error. Most signal rockets are of the end burning type, but the burning surface is frequently modified in shape to give better burning characteristics. As the charge burns away the chamber will, in effect become larger and this will cause a fall in gas pressure. In order to overcome this disadvantage, the end of the charge is shaped in such a manner that the burning surface will increase, and so tend to keep the chamber pressure constant. Cruciform or concentric channels are the two simplest and most favored designs for this purpose.

The second type of rocket has a charge which is perforated along its long axis. The perforation takes the form of a long thin cone, and this is usually formed during the charging process. The choked rocket case is placed over a tapering hard steel spindle which normally extends into the case for $^{3}/4$ of its length excluding the choke. (Fig. 14.1)

The diameter of the base of the spindle is about $^{1}/12$ of its length and this should be the dimension of the rocket choke. The base of the spindle is supported by a solid concrete or steel post. For rockets of 24 mm diameter and above, the composition is divided into 14 equal

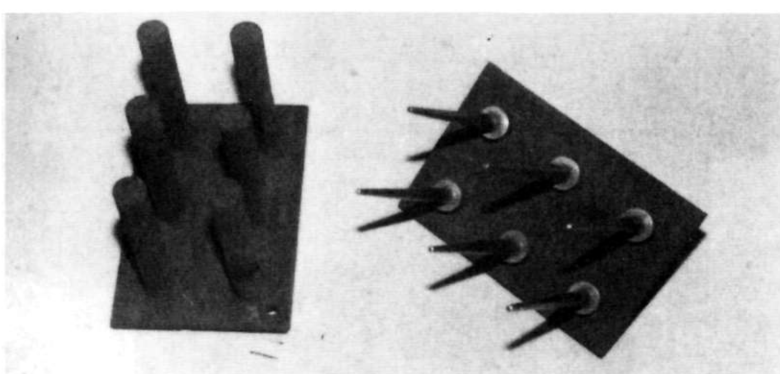


Fig. 14.1 Rocket spindles and drifts

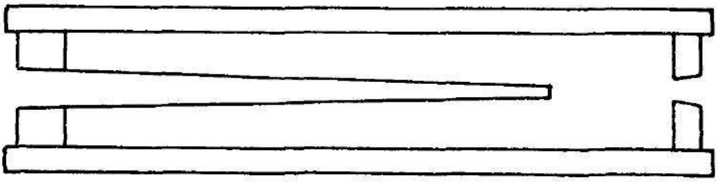


Fig. 14.2 Section of charged rocket

increments, each increment is poured separately into the case and consolidated by means of a hollow drift or ram which is subjected to a pressure of 2 tons. The case should be supported in a mold or tube to prevent collapse.

When the column of composition has reached the top of the spindle the remaining increments are pressed with a stepped drift to form a plug with an axial hole. The finished rocket will have the appearance of Fig. 14.2 in cross section.

Smaller rockets of 18 mm diameter and under, should have the composition charged in 8-10 increments. Very small rockets may be filled lightly with powder, and then bored by machine. This operation also serves to consolidate the composition.

Compositions for this type of rocket are of the sulphur, charcoal, potassium nitrate mixture type. The proportions vary widely, 60-70%

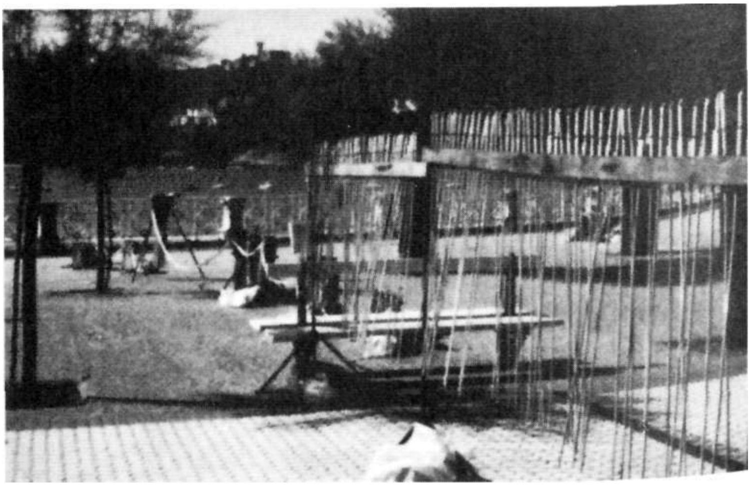


Fig. 14.3 Multiple firing of rockets in Spain

potassium nitrate, 15-20% charcoal, and 15-20% sulphur. It is not possible to be more specific in view of the problems mentioned above, but as a guide, rockets of 24 mm diameter and over usually require composition containing 63-67% potassium nitrate and this percentage increases as the rocket diameter decreases.

Rockets should be kept in a dry atmosphere, moisture absorption causes the composition to crack, and so gives rise to an increased burning surface, and explosion on ignition. Both types of rocket are ignited by means of a length of match inserted through the choke, or by means of fine grained gunpowder which is caused to adhere to the choke by means of a small quantity of thin shellac varnish. With both types of rocket, the flash of ignition should be sufficient to cause instant ignition of the burning surface, otherwise slow "take off" and erratic flight will result.

Stabilization of firework rockets is achieved by means of a stick. Many rules for stick dimensions have been given over the years, but the author has found that it is only necessary to ensure that the center of gravity lies a little to the rear of the head. The stick holds the rocket in a stable position during take off, and tends to counteract deviation during flight. Sticked rockets will always tend to turn into the wind due to unequal pressure on the stick.

Finned rockets are usually used for signal purposes. Here, the rocket is usually given sufficient forward velocity, to maintain stability during take off, by means of a small charge contained in the launcher. Fin design problems are covered fully in the technical literature. Line carrying rockets are stabilized by the harness and line and are also launched by a powder charge.

Firework rockets may carry a payload of stars, hummers or other pyrotechnic articles. The load is usually carried in a lightly rolled paper case attached to the head of the rocket. A flash from the propellant charge ignites a few grains of powder which ejects and lights the effects. The payload weight should be in the ratio,- 5 load to 3 propellant for a well constructed rocket.

In the first edition of this book R. G. Hall, retired Technical Director of Brock's Fireworks kindly wrote this section on rockets. It is clearly the work of a man of experience, and anyone in the trade accepts that there is little sense in committing anything more precise to paper. Once a manufacturer has decided on the physical dimensions of his rocket and chosen a formulation with the material at his disposal, s/he must get the best result by either changing the powder or the dimensions. At this point s/he must carefully check the burning speed of the powder in future batches. Ron Hall has made this crystal clear. However, since that first edition we have had so many complaints about the fact that precise details were omitted, that it has been decided to give some additional general details not withstanding the fact that burning speeds of powder still need to be carefully controlled.

Rockets with a Perforation Down the Center (Fig. 14.2)

Tube ID 19 mm OD 30 mm Length 145 mm
Spindle diameter at base 10 mm at top
3 mm Length 120 mm
Thickness of clay about 14 mm

		Weight (%)
Composition	Potassium Nitrate	61
	Sulphur	5
	Charcoal 150	20
	Charcoal 40	14

The composition needs to be sieved twice through 30 mesh and twice through 20 mesh for uniformity and then pressed in about eight increments using drifts with increasingly smaller central holes until the top of the spindle is reached. One diameter is pressed on top of the spindle. Let us assume that there is not enough gas pressure. The rule therefore to increase the percentage of potassium nitrate and possibly reduce the charcoal. If the rocket is too fast then the reverse would apply. The percentage of sulphur is less critical but should not be less than 5%. Rockets which are too slow can, of course, have the spindle lengthened by reaming out the composition at the top of the spindle. Needless to say, there must be enough pressed composition there. One way is to press too much on top, and then bore a hole into this from either or both ends. This is frequently done with rockets that are "long headed".

Some manufacturers add a small percent of Gum Arabic to the composition and charge the powder slightly dampened. The powder consolidates and sets into a solid mass which does not easily 'blow through'. This is often done in warm climates but in more temperate zones the drying out period creates problems for testing. In one remote part of Spain, the author saw rockets being made in this way and charged solidly in the first instance. The filled tube was then placed in a modified lathe and a hole was drilled through the clay into the powder.

The method is quite neat for small rockets and a few tests with each batch quickly determines how long the hole should be. The cutting edge needs to be on a narrower shank in order to allow the loose powder to escape. The writer shuddered at the sight of loose composition everywhere and hoped that there would be no foreign matter about to cause an ignition. Loose increments are quite a problem as they are liable to make the rocket explode. Great care must be taken when pressing large numbers of rockets at the same time. The 18 mm rockets mentioned in this article were pressed 6 or 8 at a time. It was the custom in the UK to charge numbers of tubes up to about 16mm. with 'pulled in' chokes by simply constricting the tube with a choking machine (page 194). The rocket was then spiked with an arbor press or a machine. In general this is fine, but if loose composition breaks away in the venturi the rockets frequently explode. Bad handling of such rockets is a problem, and in badly made specimens it was sufficient just to bang them against a table to make them explode. Chinese rockets were made this way with a red fire composition that contained magnalium. They should have ascended in the air with a red tail. By the time they reached the UK, they had turned into flash crackers of great ferocity that almost smashed the bottles in which they were fired.

The variation in the burning speed of commercial blackpowder and the fierceness of the powder means that rockets made with this material and spindle type perforations are even more delicately balanced. The blackpowder is slowed down with either charcoal or precipitated calcium carbonate, but careful manufacture is essential.

End Burning Rockets

The traditional rockets with the central hole may look beautiful, and gain great heights, but they do take a long time to charge and there are these unfortunate composition variations to cater for. At the end of World War II, Germany introduced the commercial blackpowder rockets with great success. These rockets do not look as attractive as traditional rockets since the gold tail is reduced, neither do they go as high, but they are easier and cheaper to make. This type of rocket can also carry a good payload, and provided that the head is well constructed they can look better than some small shells. Small rockets are often made with paper tubes and clay chokes, but the majority are pressed in an aluminum tube. The use of precision aluminum tubes makes it easier to use molds and press large numbers at a time. One end of the tube is sealed with an aluminum plug containing a central hole. A typical example would have an ID of 24 mm and a venturi of 7 mm.

While there is no central hole, in practice there is a slight indentation into the powder of about 18 mm in order to give the initial thrust. The blackpowder used contains a little graphite. Some signal rocket motors have also used blackpowder and calcium carbonate.

The aluminum tube conducts heat, of course, but the motor is normally forced into a paper tube after pressing, and this makes it easier to add a star pot and fix a stick. This type of rocket also has the advantage that a different type of composition (silver for example) can be pressed on top of the blackpowder. It is, however, better to start with blackpowder.

15

Drivers, Saxons, Tourbillions

Drivers

Wheels and moving fireworks are operated by rockets or more commonly by drivers. Drivers are stout tubes from 12 mm to 40 mm internal diameter, choked down to about $^{1}/3$ of a diameter and charged with a fierce composition containing a high percentage of gunpowder. The composition is charged solidly in small increments and does not contain the central spindle which is characteristic of rockets. The tubes are choked with a clay washer or by "pulling in" the tube in a choking machine.

Small wheels are turned quite adequately with tubes which are 12 mm or 16 mm in diameter and about 100 mm long. A 16 mm tube for example would be placed on a nipple with a central spiggot about 5 mm in diameter. A small amount of clay is first charged around the spiggot to produce a washer, and then increments of composition are added and charged with several light blows. With fierce compositions, many light blows are better than a few heavy ones, and increments of composition should be sufficient to occupy one diameter in height. A charge of clay is finally rammed into the tube to close it up, though not all tubes are clayed, for some are just fitted with a paper cap to enable fire to be transferred to a new driver where relays are required.

The following compositions are suitable for small drivers:

	A Weight (%)	B Weight (%)	C Weight (%)	D Weight (%)
Meal gunpowder	60	55	88	70
Charcoal 150 mesh	—	—	12	—
Charcoal 40/100 mesh	7	7	—	—
Potassium nitrate	25	23	—	—
Iron Turnings 60 mesh	—	—	—	30
Sulphur	8	6	—	—
Titanium 20-40 mesh	—	9	—	—

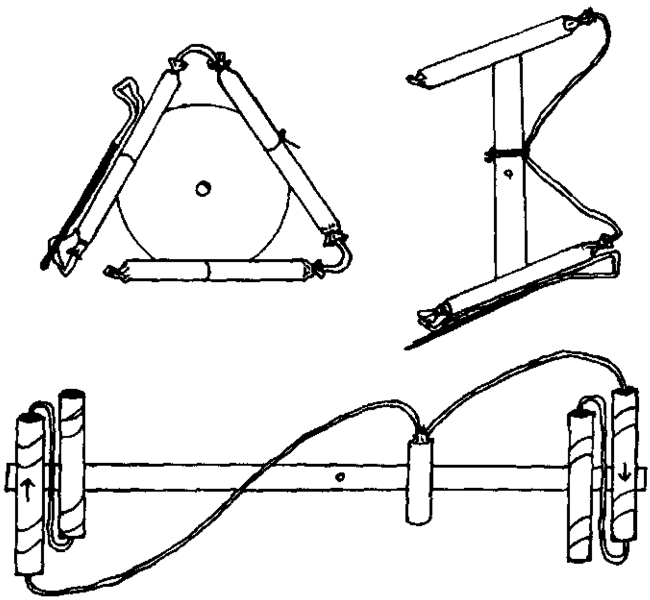


Fig. 15.1 Small wheels

The smaller drivers are used for a variety of different types of wheels as the diagrams in Fig. 15.1 show. The older wheels were made with a central boss, three or four spokes and a beech hoop, but these have been replaced in more recent times with constructions made out of plywood and hardboard.

Large drivers are used for the bigger display wheels from 2-5 meters in diameter. The tubes are 24 mm or 40 mm in diameter and about 23 cm long. Compositions are a shade slower and often contain more charcoal than the smaller sizes, e.g.:

	A Weight (%)	B Weight (%)	C Weight (%)
Meal gunpowder	74	65	60
Potassium nitrate	10	5	15
Charcoal 40/100 mesh	6	—	5
Charcoal + 150 mesh	6	—	4
Sulphur	4	5	7
Iron Turnings 20 mesh	—	25	—
Titanium Turnings 40 mesh	—	—	9

Saxons

These fireworks are used in combination with a small color case to produce small colored wheels which are usually part of a larger design.

Thick walled tubes are charged with composition, but the tube is closed with clay at both ends, and the fire issues from a hole which is cut into the side of the tube at right angles to the axis of the tube. The hole is near to the clay plug which closes one end, but the size and position of this hole depend on the strength of the composition. The hole is often bored 12 mm or so from the clay plug so that the composition burns all around the hole when the tube is ignited, thus giving an extra large thrust at the beginning to get the wheel started. Unfortunately it is a common sight to see sluggish saxons which do not seem to have enough power to get started, or else they become stuck with a piece of match piping wrapped around them or have a nail which is too tight. Another snag with saxons is the fact that the hole in the tube gets larger during the burning process with the inevitable slowing of the piece. Thick walled tubes about 16 mm in diameter with a 4 mm wall or 12 mm in diameter with a 4 mm wall are used, and they are about 25-30 cm long.

Compositions should not be too hot, i.e. they should not contain too much potassium nitrate and sulphur or else they are liable to burn the jet hole away too much with the resulting loss of force. Old mixes were rather hot burning, e.g.:

	Weight (%)
Meal gunpowder	50
Potassium nitrate	25
Sulphur	25

but the following are more typical and useful:

	Weight (%)
Meal Gunpowder	50
Potassium nitrate	30
Charcoal 40/100 mesh	10
Sulphur	10

A little titanium can be added to this mixture of course. Saxons are made in various forms, but are mostly double. A tube about 30 cm. long has 12 mm of clay solidly rammed into one end and then is charged with 125 mm of composition. 24 mm of clay is then charged, followed by 125 mm of composition and final 12 mm of clay. The tube is now full. A hole to receive the nail is bored through the middle of the tube, through the clay, and then the jet holes are bored near the ends, but on opposite sides of the tube as in Fig. 15.2.

Saxons can be fired simultaneously from both ends or they can be arranged to fire successively by inserting a piece of quickmatch in the base of the composition of one end and so transferring the fire to the

Fig. 15.2 Double ended saxon

opposite end as shown in Fig. 15.2. Some manufacturers make the saxon in two separate units, joining the two together in the center with a paper tube or a piece of wooden dowel. Single saxons are also made. A small spacer tube should be fixed between a saxon and the timber work to prevent the saxon from striking the woodwork during the performance. Color cases are usually fixed on the side of the saxon to produce the fire rosette. They are timed to burn the same length of time as the saxon and require careful fixing with glue and paper or else they are liable to fly off during the performance. (Fig. 15.3).

Tourbillions

The French word "tourbillion" or "whirl wind" is still used to describe these fireworks which have appeared in many forms and sizes. The older and larger forms were in effect a fierce type of saxon which first of all spun around on the ground and then lifted up into the air by means of two or four holes bored in the underside. (Fig. 15.4).

A curved stick, roughly the same length as the tourbillion itself, was nailed to the center of the tube, but at right angles to the tube. The process of boring the six holes in a large tourbillion is quite a tricky one and needs to be carefully done. The holes in the side and base also need to be exactly at 90° to each other or else the performance will be

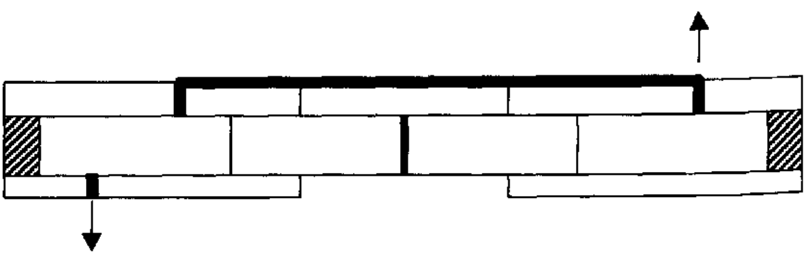


Fig. 15.3 Two single saxons attached to a piece of wooden dowel.

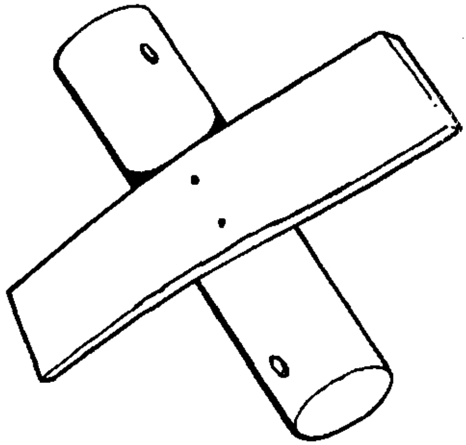


Fig. 15.4 Tourbillion

erratic. A useful way of making the tube is to slip it inside a hollow metal or paper tube which already has the holes drilled in the correct positions, thus using this external tube to mark the position of the holes prior to drilling. It is also unwise to drill tubes which already contain composition a much better method being to drill or punch the holes in the empty tube and cover them with a piece of paper or adhesive tape which can be removed after filling. This also applies to saxons of course.

The larger sizes are made with a tube which is approximately 24 mm. diameter, 20 cm. long and with a wall thickness of *6* mm. The holes are about 4 mm. depending on the strength of the composition, but they also must be carefully spaced so that there is roughly the same quantity of composition on either side of each hole. The following composition is a good one though some adjustment may need to be made with the diameter of the jet hole.

	Weight (%)
Potassium nitrate	45
Meal gunpowder	35
Sulphur	5
Charcoal 40/100 mesh	15

Sticks are usually made out of a piece of beech hoop of the type used for sieves and large wheels, and are fixed to the tube with a copper nail. The tourbillion is matched in such a way that the match is ignited on the top in the center, transferring the fire first to the two side jets

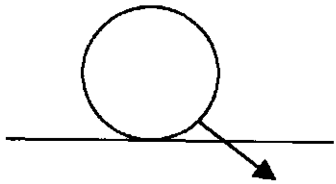


Fig. 15.5 Position of the jet hole

for spinning and lastly to the lifting fire jets at the base. The match is fixed with tape and then covered with paper. Small tourbillions are made with a tube about 12 mm. in diameter, about half full of composition. They are made to ascend with a single jet punched at about 30° or 45° which both lifts the firework and spins it at the same time (Fig. 15.5). These small articles use much fiercer compositions with a larger percentage of mealpowder and as before, the size of the jet hole is related to the burning speed of the composition. Wings are usually made of paper board or plastic.

Closely related to this type of firework is the famous Flying Saucer See Fig. 15.6. This piece has various names such as Geyser, Girandola, Flying Crown and consists of a circular horizontal wheel which spins at great speed on a spike at the top of a pole and then takes off into the air to climb several hundred feet. Some varieties ascend and descend and finally reascend during flight.

This piece is very difficult to produce, but it basically consists of very fierce horizontal drivers which cause the unit to spin on the post and a few fierce vertical drivers or rockets which lift the piece in the air.

No attempt will be made to describe the manufacture of these items for there are many pitfalls which only considerable experience can overcome. Those who attempt to make the pieces will find that either the drivers are not fierce enough to lift the piece or they explode. In addition badly made drivers will burn incorrectly, sending the saucer into the air at the wrong angle and possibly falling into the crowd. The saucer usually carries a small shell which fires at the highest point of the flight. It can also be fitted with fountains or small pot a feu.

Flying Pigeon

The line rocket or flying pigeon is a very popular item at firework displays and frequently consists of a wooden block with a hole through

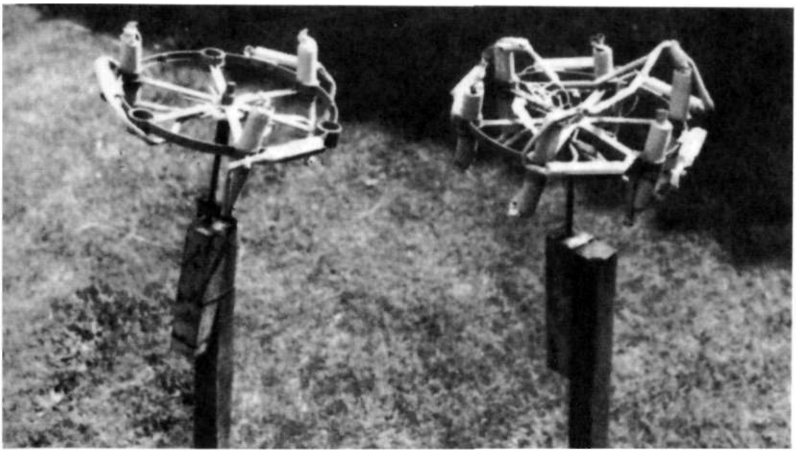


Fig. 15.6 Flying Saucer

the center so that it can slide along a tightly stretched rope or wire. Four 16 mm rockets are fixed to the block and, in addition, there are four fierce drivers attached to a small hoop fixed on the block. See Fig. 15.7.

The first driver rapidly spins the unit on the rope, and as soon as it burns out it ignites the first rocket which transfers the piece to the other end of the rope. The burnt out rocket then ignites the next driver and the process continues, backwards and forwards along the rope. Where ropes are used, the friction is quite high and large rockets of at least 18 mm bore need to be used. Whistles and colors are often added to the pigeon. A tube needs to be placed on each end of the rope to prevent the pigeon striking the post and thus being damaged. A good way of assembling the pigeon is to attach the rope to two firm stakes and then stretch it with two stretchers according to the diagram. The stretcher

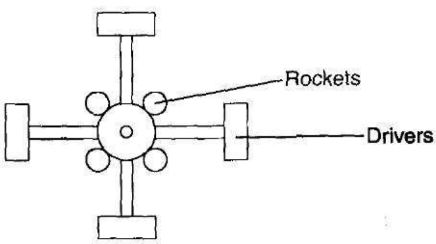


Fig. 15.7 Flying pigeon

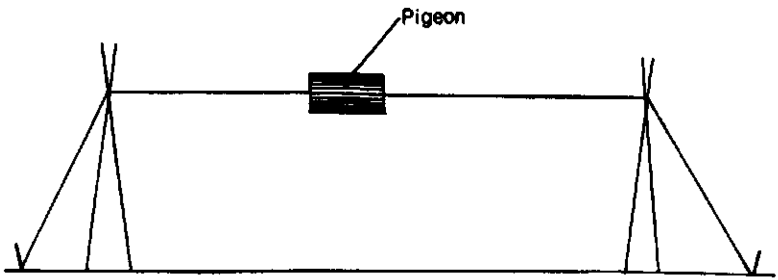


Fig. 15.8 Flying pigeon

consists of two wooden poles loosely joined at the top with a nut and bolt. (Fig. 15.8).

Smaller pigeon type fireworks called rats consist of a relay of very fierce drivers which follow each other down the wire. They are charged with a mixture of gunpowder and iron and the tubes are about 12 mm in diameter.

16
SHELLS

The greatest skill of the firework maker can be exhibited in the manufacture of star shells, or "Bombs" as they are frequently called. Shells are produced in huge quantities every year but the quality varies from, at one extreme, the most ordinary types, which literally drop the stars into the sky in a disorderly heap, to the magnificent pattern shells at the other extreme. The older method of shell construction involved the manufacture of hollow paper spheres about *6* mm thick but this was a costly and time-consuming business. Strips of paper were soaked in paste and then laid in layers in a hemispherical mold. A hemispherical former is used to press the paper into the mold in order to press the strips of paper down. When the shell halves are dry, the rough edges are trimmed with some type of lathe. (Fig. 16.1) When the two perfect hemispheres are ready, a hole is punched in one of them to receive the fuse and the two halves are glued together. The final process consists of pasting strips of paper, which are well soaked in paste, all over the outside. Long strips are used, usually stretching from the fuse hole to the base. Sometimes the paper sphere is made up from four hemispheres, two inner ones and two outer ones. The hemispheres are pressed out of sheets of pasted strawboard cut out in the following shape. (Fig. 16.2).

Ideally, the thickness of the two inside shells should be equal to those on the outside, so that when the halves are in different planes, the shell should break at least into four quarters to produce an even burst.

In practice this even burst is not easy to obtain and instead of all the stars being thrown out evenly from the center, they tend to fall downwards in a kind of bouquet. The old method was even worse, for

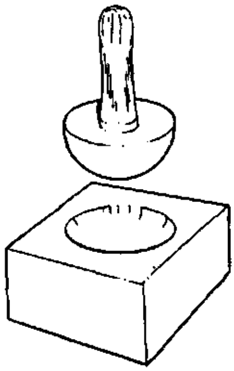


Fig. 16.1 Shell mold and former

in effect the shell broke into two halves and dropped the stars out in a heap.

It will be seen that the formation of the shell wall is quite vital and that the pattern of the burst is entirely dependent on this in relation to the nature of the bursting charge.

The easiest type of shell to make is similar to the Japanese "Poka", page 400. The sphere is loaded with stars and 10 to 25 gms of meal gunpowder is poured loosely amongst them before the fuse is glued in. In some cases a mixture of gunpowder (85%) and fine charcoal (15%) is used instead, employing about twice the quantity one would use in the place of neat gunpowder.

Two methods are used to burst round shells. One method has been outlined already and consists of bursting a shell with a comparatively

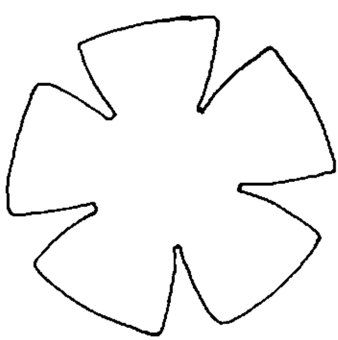


Fig. 16.2 Paper cut out for shells

weak outside wall. The other method is to use the Japanese "Warimono" (page 392) technique which requires the formation of an extremely hard exterior wall consisting of many layers of pasted kraft paper. This is adequately covered by Dr. Shimizu.

The shell maker thus has the choice of three methods of bursting round shells:

1. Employ a small gunpowder charge and a weak exterior wall to obtain the bouquet effect.
2. Employ a much fiercer bursting charge and a comparatively weak shell wall in order to obtain an even burst. The use of a fierce bursting charge involves the risk of destroying the stars or causing ignition failures. Flash powder is sometimes used for this purpose but there are many drawbacks and dangers to the technique.
3. Employ a very strong outside shell wall and use a comparatively slow expanding bursting charge. In the West, various grades of grain powder are used for this purpose but in the east they have their own distinctive techniques outlined in Chapter 23.

Round shells are used in various sizes, the smallest being made to fit a 50 mm diameter tube and the largest 100 cm. The most common sizes are 75 mm, 100 mm, 125 mm, 150 mm and 200 mm, these being fairly universal. 300 mm and 400 mm shells are sometimes manufactured but it is a by-word among firework makers that their effect is frequently no better than a 150 mm or 200 mm shell. Dr. Shimizu reports that two 100 cm mortars are known to exist in Japan. It appears that this unusually large size is not regularly manufactured but has been a feature of a yearly summer display at the city of Nagaoka. It is of interest to note that it has been said of these shells also that they are not as attractive as one might think.

In recent years plastic ball shells have become very common, the molded plastic being made in such a way that the delay and lifting charge are all built into the same unit. They are cheaper and easier to fill, though in some respects paper still seems to be superior.

Some manufacturers describe their shells in terms of circumference instead of diameter. Fortunately the practice is not common and is possibly a device to deceive the uninitiated. 300 mm sounds much better than 100 mm, but what a disappointment when you receive the shell.

After the shell has been filled with stars and blowing, the fuse is carefully glued into place, but care must be taken to see that the fuse is secure or else it may be forced through into the shell by the lifting charge. Lifting charges vary, depending on the size of the shell, the

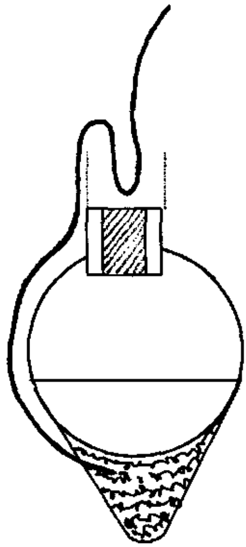


Fig. 16.3 Cross-section of a round shell

quality of the powder, the length of the mortar and the tightness of the fit of the shell. A 100 mm round shell would take about 40 gm. 4FA British powder while an 150 mm shell would require about 100 gm. The lifting charge is usually placed in a cone though any substantial paper container would be adequate. The cone is particularly useful in situations where mortars are to be re-loaded, for the cones fit into each other and do not take up too much room in the tube. (Fig. 16.3). Lastly a length of piped match is tied into the fuse and continued down to the lifting charge so that the two will be ignited almost instantaneously. It is advisable to have two pieces of match between the time fuse and the lifting charge, for a failure in this position could cause the shell to explode in the mortar. The shell fuse itself is usually wrapped with about three turns of cotton cambric to hold the match pipe, for shells are often carried by their leaders and cambric will not tear as paper does. The black match at the end of the match pipe is usually covered with an empty lance tube for safety.

Three types of shell fuse are made. The older type consisted of a very hard tube about 18 mm in diameter, about 30 mm outside diameter and about 40 mm long. A white fire composition such as the following:

	Weight (%)
Mealed gunpowder	65
Potassium nitrate	25
Sulphur	10

was charged into the tube in about eight increments of 3 mm when charged, each increment being rammed with many light blows until it is rock hard. 24 mm of composition burns about 4 seconds. Solid filling is essential or else there is a good chance of getting a "blow through". This fuse burns with a white light and is quite effective.

The second method uses tubes about 8 mm or 10 mm in diameter and about 65 mm long. Meal gunpowder, or better still a soft unpolished grain powder, is charged into the tube in the manner described above until there is about 24-30 mm of solid powder. The remainder of the tube is filled with lengths of quickmatch which project about 12 mm outside the tube. The match is held in place through wedging it by breaking down the inside wall of the tube with a piercer, or tying it into a piece of cambric which is glued on to the end of the tube. (Fig. 16.4)

The shell moves in the air at great speed and turns end over end and these narrow bore fuses have been known (surprisingly) to burn out without igniting the shell. This particularly happens in completely air tight plastic shells. To avoid this an indentation is made into the end of the fuse so that it will 'spit' backwards into the shell.

A third way of making fuses is simply to employ a piece of Bickford or other safety fuse. These fuses burn at the rate of about 3 seconds per 24mm. and vary in thickness from 6mm. to 9mm. In England it was usual to glue two lengths of Bickford into a small wooden plug. The Americans tend to use one piece of 9mm. Bickford fastened to the center of a mill board disc. The ends of the Bickford require to be primed with gunpowder paste, or better still pierced and threaded with a short length of quickmatch, to ensure ignition. (See Fig. 16.5)

The firing tubes or mortars for the shells consist of strong steel polythene or paper tubes. The length of the tube varies with the type of shell, but mortars are normally 30-50 cm for round shells or short

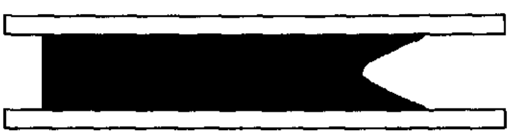


Fig. 16.4 Shell fuse

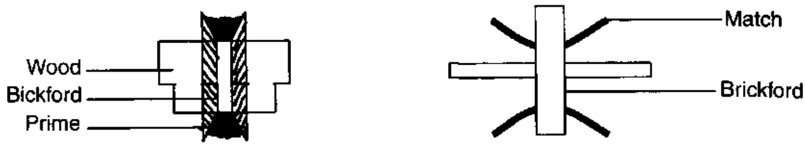


Fig. 16.5 Left: Bickford in wooden fuse. Right: Bickford in cardboard disc

cylinders, and 75 to 125 cm for long cylinder shells. Paper tubes are adequate up to about 125 mm diameter and should be stout, straight rolled tubes about 12 mm thick, fitted with a strong wooden base firmly nailed in position. Spirally wound tubes can be used but are less satisfactory. Cylindrical shells should always be fired from steel tubes but maroons or salutes should be fired from paper tubes in case they explode in the tube. Steel mortars are made out of ordinary steel tube fitted with a firm steel base which is carefully welded in position. It is a good idea to countersink the mortar base and fill the space with weld. Cast iron used not to be recommended but it would be hard to find now. In the late Sixties the author pioneered the use of polyethene mortars for firing single break shells and is still using some of the very same tubes after thirty years! They have many commendable characteristics.

(a) They are lighter than metal and do not corrode.
(b) They are easily washed out and unaffected by rain.
(c) They do not shatter.

A 75 mm salute in one of these tubes blew a hole in the side of the tube after 'belling' the center of the tube but it did not shatter. PVC, of course, is entirely different and must not be used because of the sharp fragments it can produce.

Mortars for small shells are frequently placed in long wooden boxes which must be very securely held with stakes to prevent them from falling over during the firing operation. Larger tubes are buried in the ground or secured in drums of sand. A thick wooden board should be placed under mortars, for they tend to dig themselves in the ground and can be very difficult to remove from the wet earth or clay. Beware also of the dangers of using such a board. If you have a particularly heavy kick from a shell bursting in the tube, this can cause the wood under the mortars to act like a 'spring board' and throw all of them out of the trench. It is sensible to drill a hole through the top of mortars that are subject considerable recoil. A steel rod pushed through the holes makes the mortar much easier to lift. Mortars also get held in wet clay. A steel bar to push down the outside and get air under the tube also facilitates removal, particularly in heavy clay.

Sensitive compositions should have been eliminated by now, but where they are used, it is a wise precaution to place sandbags between the mortars and the operator or crowd for detonations have caused serious accidents. Flash charges containing chlorates and sulphur or sulphides in large cylinder shells are particularly liable to detonate and (in the opinion of the writer) should be illegal in all countries.

Articles in Pyrotechnica (29) have described the manufacture of cylinder shells and it must be said that some of the best effects are produced by them. Unfortunately they are also the most expensive items because of the tremendous amount of hand work which goes into the more effective ones.

To make a cylinder shell, a former and some cardboard discs are required, the diameter being about 12 mm less than that of the mortar. A sheet of medium unglazed kraft is then cut so that it is about 65 mm to 80 mm longer than the length of the completed shell and sufficiently long to go about three times around the former. Sometimes, a thicker sheet of paper the length of the finished shell is wrapped inside also. The paper is rolled around the former and pasted just on the outer edge to form a bag. A disc is placed in the bottom of the bag and the bottom 40 mm of paper is cut into 18 mm strips which are then turned over as in (Fig. 16.6). The bag is then filled to within 40 mm of the top with stars or other effects, carefully consolidating the stars but not breaking them. Gunpowder is next poured into the stars to fill up the spaces so that the bag is quite full. This is a necessary operation since the

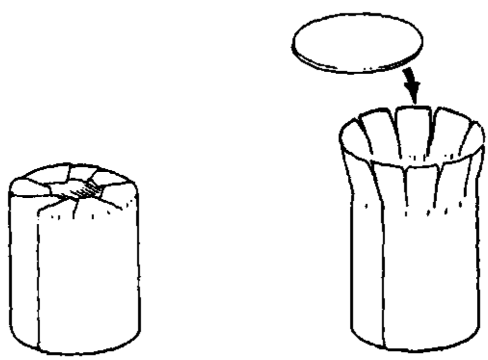


Fig. 16.6 Shell bag

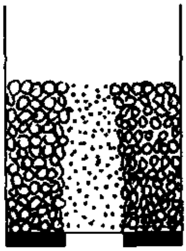


Fig. 16.7 Filling the stars and powder

shell wall is flimsy and gains its strength only from the filled interior. In special shells, the powder is only placed in the center. In this case the stars are filled around a hollow brass or copper tube in the center. Powder is then placed in the center of the tube which is slowly withdrawn, leaving the powder in the middle. (Fig. 16.7).

The next operation is to add the fuse which has been previously glued into the center of a disc. This disc is placed in the bag on top of the stars and gently tapped down. The shell wall is then cut into strips as at the beginning, turned down and held in position with another disc. (Fig. 16.8)

Stringing takes place next. The thin string is soaked in paste and wound around the shell first down the length of the shell and secondly around the sides so that the whole shell is covered in squares with a side of anything from 6 mm to 24 mm depending on the type of shell. The stringing must be even and quite taut to produce an even burst. (Fig. 16.9)

The final operation consists of covering the outside of the shell with two or three layers of pasted Kraft paper. Small shells require only a small quantity of paper but larger ones take more. The shells are then completed by adding the lifting charge and leaders.

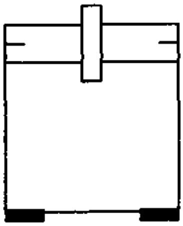


Fig. 16.8 Filled bag

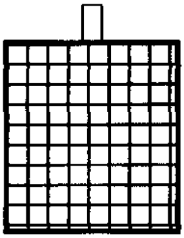


Fig. 16.9 Shell after stringing

Fig. 16.10 Shell manufacture.

Cylinder shells are the best ones for carrying smaller tubes such as whistles, hummers, tourbillions, and flash charges, for they are more economical of space. It is usual practice to place the special effects in the bottom of the shell with a charge of stars on top. Shell tourbillions are usually about 12 mm in diameter, 100 mm long and drilled with two holes, but of course they require no stick. Flash charges are usually thick tubes with wooden end plugs, one plug being furnished with a length of Bickford fuse. Sometimes a number of small shells are placed inside a large shell, so that after the initial burst of stars, the smaller ones burst in a ring below. Shells are also charged sometimes with short quick firing Roman Candles.

Cheap cylinder shells are sometimes manufactured out of cannisters fitted with cap ends and two discs. (Fig. 16.13) The effect is not so good as the more complex cylinder shells, but is quite useful for ordinary work.

The older methods employing tough cylinders with wooden ends are not commonly used now; they are too complex and expensive.

Repeating shells are somewhat more complicated but are made basically in the same manner as ordinary cylinder shells though there are two techniques. One technique involves making short cylinders all of the same diameter and height and marrying them to each other so that the fuse of one projects into the section above. The sections are all strung together, this being a vital operation for success.

The sections of repeaters are usually fitted with two second fuses.

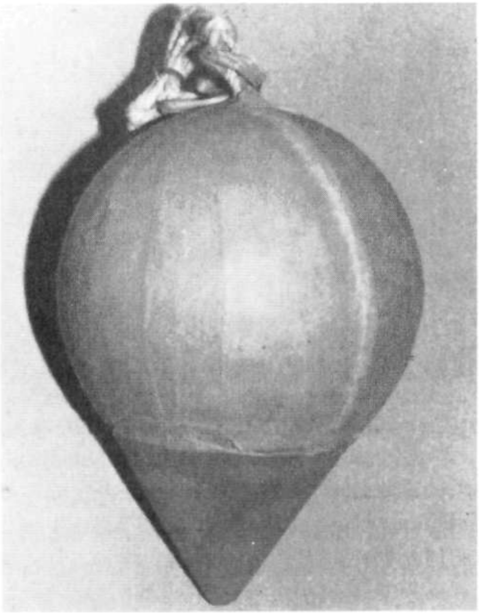


Fig. 16.11 Round shells.

Fig. 16.12 Cylinder shells

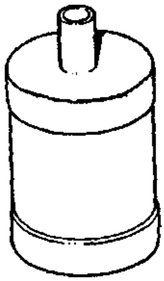


Fig. 16.13 Cylinder shell with cap ends.

The first fuse may also be of two seconds if the shells are to burst on the way up; otherwise it is four of five seconds where the shell reaches its fullest height before the initial burst. Needless to say, the lifting charge increases with the number of repetitions and shells bursting on the way up require larger lifting charges than the others. (Fig. 16.14) The second technique for repeating shells is the one more commonly used in Europe and involves the placing of one bomb inside the other. The last section to burst is frequently a flash maroon which is carefully made and strung prior to being placed in the bottom of the bag of the second section. Section two, when complete, then goes into the bottom of the bag of the first burst. (Fig. 16.15) Careful packing and stringing is essential or else the inside shell is destroyed by the main shell burst. It also means the use of many different sizes of discs and formers. (Fig. 16.16) shows a set of repeating shell. Further detail on shell manufacture is pointless because every shell maker has to adjust his technique to fit the materials in hand and the unreliability of fireworks makes

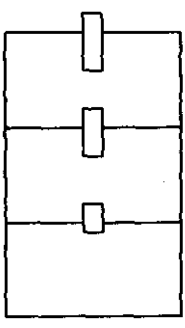


Fig. 16.14 Repeating shell

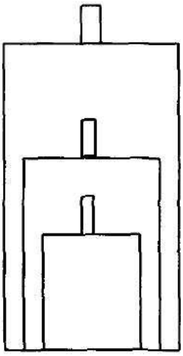


Fig. 16.15 Repeating shell

her/him adhere to those methods s/he has tested in her/his own experience. Again, a list of types of shells is pointless since the numbers of permutations are limited and obvious.

Perhaps the 915 mm Japanese shell is the most unusual of shells and we are grateful to Dr. Shimizu for this photograph of such a shell being loaded for the Nagaoka festival by the Kashiwazaki Fireworks Co. (Fig. 16.17)

The comet shell is an interesting variation. A large pressed comet

Fig. 16.16 Set of repeating shells. Courtesy St. Michael's Firework Factory. Lija, Malta

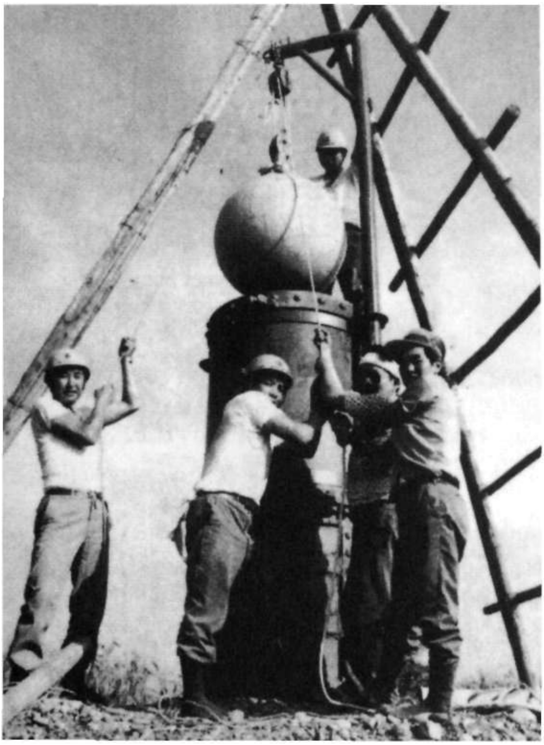


Fig. 16.17 Loading a 915 mm shell (Courtesy of Mr. Seiji Kase Nagaoka-Shi, Japan)

is fastened on to the end of the shell so that it will produce a spiral of fire as it rises in the air. The Japanese glue a small comet on to the outside of some of their shells, but they also sometimes coat the whole of the outside of a shell with a streamer composition.

A smaller version of the comet bomb is to press a star into the bottom of a tube about 35 mm in diameter and then place stars on the top of it. (Fig. 16.18) Small units like these are also fired out of Roman Candles.

Parachute shells are made in much the same manner as other shells, though the bursting charge has to be cut down and the parachute needs to be protected with sawdust. A good way is to tie the flare into the small bursting charge which is in turn tied on to the inside of the fuse. The rest of the shell is filled with the parachute and sawdust. (Fig. 16.19)

Parachutes for ordinary work are normally made of cotton cambric or good quality tissue paper 0.38 cm of twine is tied on to each corner,

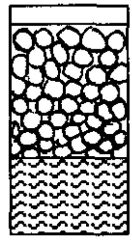


Fig. 16.18 Small comet bomb

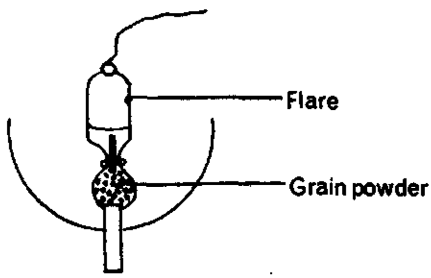


Fig. 16.19 Parachute shell

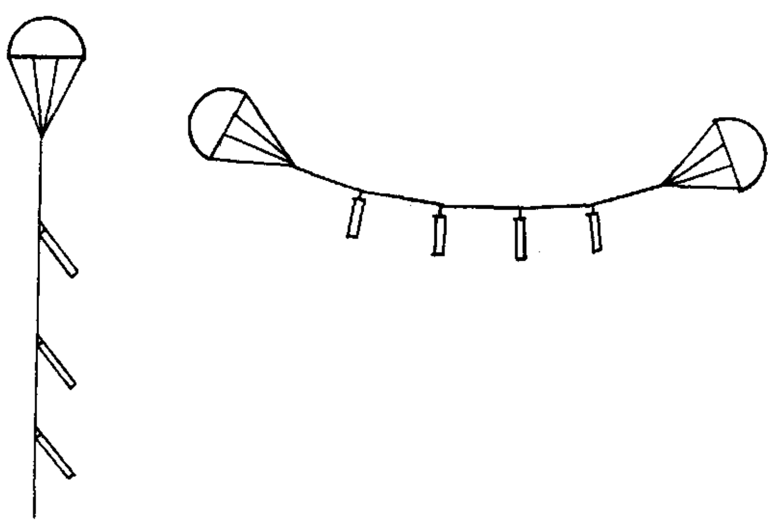


Fig. 16.20 Parachute chains or festoons

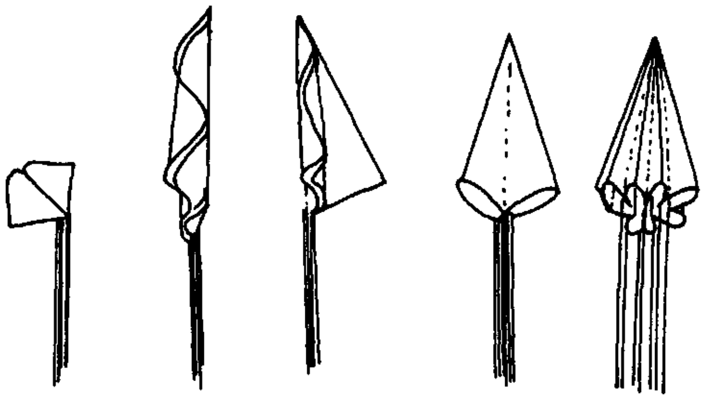


Fig. 16.21 Method of folding parachutes

and these are tied together at their ends and fixed to about 30 cm wire or asbestos string. This last 30 mm needs to be wire or asbestos so that it will not be burnt by the flare. When it is required to make a string of lights, there must be as much as a meter of string between each light; otherwise they appear to be close together in the sky. Sometimes festoons are made by attaching parachutes to both ends of a string of lights. (Fig. 16.20)

Parachutes must be specially folded so that they open correctly. The following diagrams illustrate the procedure and it is wise to sprinkle the chute with talcum powder before folding it up. The folding procedure applies equally well for rockets and shells. (Fig. 16.21)

17

GERBS, FOUNTAINS, RAINS, SQUIBS, CONES

Gerbs

The French word "gerbe", meaning a spray or sheaf of corn, is still used for firework fountains, particularly for those which produce force in choked tubes. A wide variety of fountains can be found within the firework range but generally speaking there are two basic types; those of the long narrow variety and the short squat fountains. The mixtures naturally vary immensely with the type of tube and method of filling. The long narrow "Fix" used for "feu croisée" in set pieces for instance, requires fierce compositions which need to be carefully charged, while at the other extreme, some short squat fountains are so slow burning that the composition requires little more than being poured into the tube and shaken down.

Fountains

Tubes for fountains are usually about 25 cm long and from 12-25 mm in diameter. There are also other sizes which are smaller or larger than the ones mentioned. The wall thickness is sufficient to prevent the fire bursting the side of the tube. Long narrow fountains are either choked with a clay washer to one half or a third of a diameter or just "pulled in" as described in Chapter 9. Pulled in tubes are sometimes essential; some glitter fountains for example will not function correctly in clayed tubes, mainly because the solid burning products do not seem to be able to get past a clay choke, with the consequent "coking up" of the tube. Machine choked tubes also present problems with very fierce compositions. It seems that the tube relaxes when the pressure is released after pressing, and sometimes loose powder at this point causes an explosion. This is overcome by charging the first increment with a slow composition.

The so-called display "Fix" are 12-16 mm inside diameter and 25 cm long. They are choked to half a diameter and charged by hand or pressed in about eight increments. The compositions are quite fierce for they are required to produce two or three feet of concentrated fire for set piece pattern work. The following compositions are used for this purpose:

	A Weight (%)	B Weight (%)	C Weight (%)
Meal gunpowder	84	73	64
Charcoal 150 mesh	16	—	—
Potassium nitrate	—	—	8
Sulphur	—	—	8
Iron 60 mesh	—	27	20

Fountains of 18 mm to 75 mm inside diameter require less fierce mixtures but if they are not strong enough they will "deteriorate" lower down the tube owing to blockage from dross. These compositions are usually cheaper because they contain less gunpowder, but they are invariably dirty because finely powdered materials are required. The following mixtures are fairly uncomplicated

	A Weight (%)	B Weight (%)	C Weight (%)	D Weight (%)
Potassium nitrate 150 mesh	72	40	44	27
Sulphur	8	8	9	14
Charcoal 40/100 mesh	16	—	—	9
Charcoal 28 mesh	4	—	—	—
Charcoal 150 mesh	—	8	8	—
Meal gunpowder	—	16	9	40
Coated iron 20 mesh	—	24	30	—
Titanium 40 mesh	—	—	—	10
Aluminum flitter 10/30 mesh	—	4	—	—

The old English "Flower Pot" is produced from a combination of red orpiment and lampblack. The burning is very drossy with the result that bits of dross are forced into the cool air where they sparkle with their characteristic golden coruscations. The following compositions are typical, but it needs to be emphasized that only certain types of gas black will function correctly and the material has to be chosen by trial and error.

An excellent article in Pyrotechnica XVII well illustrates the problems of the Flower Pot effect and the reader is also referred to Dr Shimizu's comments in Chapter 6.

The traditional English Flower Pot gerb was a long tube of about 16 mm inside diameter, 200 mm long. It was fitted with a clay choke with a hole of about 9 mm. The composition was not rammed, but charged with a funnel and rod. A good composition was:

	Weight (%)
Potassium nitrate	54
Sulfur	24
Mealed gunpowder	8
Red orpiment	8
Gas black	4
Charcoal + 150 mesh	2

A smaller fountain used to be sold in the shops under different names such as Zodiac or Orion. The tube was about 35 mm inside diameter, and only about 40mm high. It was choked with a stout cardboard washer which was forced into the top. The washer had a central hole about 7 or 8mm and was closed at the base with another disc. Again the composition was similar to the above and was something like:

	Weight (%)
Potassium nitrate fine crystals	55
Sulfur	25
Gas black	14
Red orpiment	6

The mixture was frequently adjusted by adding fine potassium nitrate and reducing the gas black.

A bubbling cone was also made (Lava Cone). It really looked like a volcano pouring out red lava and producing the characteristic gold corruscations. For some the effect is not exciting, but for those of discernment it is great.

	Weight (%)
Potassium nitrate	57
Sulfur	25
Gas black	9
Iron 20-40 mesh coated	9

But everything depends on the Gas Black or Lampblack

Silver fountains are made with titanium or aluminum. Titanium is uncomplicated, but aluminum powder varies tremendously from one manufacturer to another. Fountains made with aluminum often start off well and then get blocked up with molten dross lower down the tube. As a general rule it is necessary to use two or more grades of aluminum in the one composition and keep the quantity as low as possible.

	Weight (%)
Meal gunpowder	72
Potassium nitrate 150 mesh	7
Charcoal 40/100 mesh	7
Aluminum dark pyro	7
Aluminum 80/120 mesh	7

A rather more difficult fountain *is* a silver one using barium nitrate as the oxidizer. The tube is about 18 mm in diameter and 15 cm long. The choke must be of clay (about half a diameter) and the wall of the tube must be very strong for the temperature is very high indeed. Mixtures of barium nitrate and aluminum are of course sensitive and so they should not be charged with a mallet and drift, but pressed. Again, everything depends on the aluminum for success. The following mixture represents a rough guide only

	Weight (%)
Barium nitrate	45
Potassium nitrate	5
Meal gunpowder	5
Aluminum	45

The aluminum here is a mixture of dark pyro, bright polished and flitter grades.

Glitter and flitter gerbs are modifications of the corresponding star mixes. Yellow glitter is made with sodium oxalate and white glitter is made barium carbonate or strontium oxalate. As a general rule, they perform well in unchoked tubes but it is not always straightforward in long narrow choked tubes where clay chokes should be avoided. The heat opens up a paper choke, thus preventing 'coking' up towards the bottom of the tube. For the best results, manufactured gunpowder needs to be used and there is an advantage in using a mixture of mealed gunpowder and soft grain powder. The following is typical:

	Weight (%)
Gunpowder	68
Antimony sulfide	14
Sodium oxalate	10
Aluminium	7
Boric acid	1

The aluminum can be flake 'bright' powder +120 mesh or fine atomized aluminum.
Compositions for unchoked tubes about 125 mm long

	A Weight (%)	B Weight (%)	C Weight (%)	D Weight (%)
Mealed gunpowder	67	38	66	76
Potassium nitrate	—	28	—	—
Strontium carbonate	—	—	—	10
Antimony sulfide	—	—	—	8
Charcoal 40-100 mesh	—	—	20	—
Charcoal +150 mesh	8	—	7	—
Aluminium dark pyro	8	—	—	—
Aluminium atomized +120 mesh	17	—	—	—
Aluminium atomized + 350 mesh	—	—	—	6
Sulfur 40-80 mesh	—	27	—	—
Titanium 20-40 mesh	—	7	—	—
Iron 60 mesh coated	—	—	7	—

	Weight (%)	Weight (%)	Weight (%)
Meal gunpowder	42	17	15
Potassium nitrate 150 mesh	—	46	45
Charcoal 40/100 mesh	—	17	—
Sulphur	7	3	6
Charcoal 150 mesh	10	—	9
Iron coated 60 mesh	—	—	8
Antimony sulphide	20	—	—
Sodium oxalate	14	—	—
Aluminum "Bright"	7	—	—
Charcoal 28 mesh	—	17	—
Lampblack	—	—	12
Aluminum flitter 10/30 mesh	—	—	5

Rains

Gold and silver rains consist of long narrow fountains of small bore which are fierce enough to produce a good show of sparks. The tubes are about 6 mm to *9* mm in diameter and from 7.5 cm to 12.5 cm long. As they are cheap items they are invariably dry rolled, being merely pasted at the edge of the paper. Tubes are charged with a funnel and wire or other means, but it should be pointed out that dry compositions containing more than a few percent of aluminum should not be used

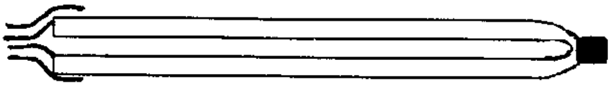


Fig. 17.1 Gold or silver rain

in a funnel and wire apparatus. (Fig. 17.1) shows a drawing of a Rain. The following compositions are useful:

	A Weight (%)	B Weight (%)	C Weight (%)
Meal gunpowder	75	75	80
Charcoal 40/100 mesh	25	23	5
Aluminum dark pyro	—	—	5
Aluminum "Bright"	—	1	5
Aluminum 80/120 mesh	—	1	5

Short rains for rockets and shells are occasionally charged as short lances.

Squibs are no longer manufactured in Britain, but they were in effect golden rains with a small gunpowder "bounce" at the end. They also had a practical use, for they were sold to householders who placed them inside coal-burning oven "flues" to discharge collections of soot from places difficult to reach by other means.

Flying Squibs

In effect these were fierce little drivers, but they are no longer sold to the public because of their erratic and consequently dangerous behavior. Tough little tubes about 8 mm diameter with a "pulled in" choke were firmly charged with a fierce driver composition of gunpowder and charcoal (Fig. 17.2). When ignited, they scurried along the ground and could be both amusing and irritating. They are, on the other hand, very effective in bags, mines and rockets, and are still used for this purpose.

Fig. 17.2 Flying squib

Compositions:

	A Weight (%)	B Weight (%)	C Weight (%)
Meal gunpowder	64	91	—
Barium nitrate	—	—	60
Potassium nitrate	8	—	5
Sulphur	4	—	—
Charcoal 150mesh	24	6	—
Titanium	—	3	—
Aluminum dark pyro	—	—	25
Aluminum 30/80 flitter	—	—	10

Composition C requires a starter fire such as composition B.

Cones

Cones have been included in this chapter because they are really fountains, though they are not usually charged very solidly.

The cases are not too easy to roll, and are normally wet rolled, on a cone shaped brass or aluminum former, from a number of semicircular pieces of paper cut out like Fig. 17.3.

The narrow end of the cone is then covered with touch paper or a plain paper circle pasted over the end, and they are placed narrow end downwards in a type of egg rack with holes large enough to support each cone in the center. The composition is poured into the cone, lightly consolidated by hand pressure, and then filled with sawdust to the top. Finally a disc is firmly glued in place or, in some cases, the bottom of the cone is spun over on to the disc.

Some cones are fitted with a washer inside the cone itself to give a secondary effect, but this is not common (Fig. 17.4).

Fig. 17.3 Paper cut for rolling cones

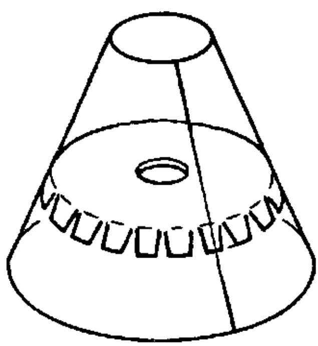


Fig. 17.4 Cone with secondary effect

Tough textile cones are quite effective for fireworks, though the author is unimpressed by the huge cones seen on some markets, for a close examination reveals only about 50 mm of composition at the narrow end!

Cone varieties are many and various, though as a general rule one is limited to the usual fountain effects - gold, silver, iron, gold and silver. Some cones commence their performance with colored fire, but this should always be perchlorate if it is to be followed by a mixture containing sulphur. In fact it is not even wise to mix perchlorate and sulphur; the articles get knocked about on the market and it is preferable to leave the cones as simply colored fire in this case.

Cone compositions are as follows:

	A Weight (%)	B Weight (%)	C Weight (%)	D Weight (%)
Potassium nitrate	55	54	55	—
Sulfur	11	9	8	—
Charcoal 40-100 mesh	—	13	—	—
Charcoal 20-40 mesh	19	—	11	—
Sawdust 20-40 mesh	6	—	4	—
Titanium 20-40 mesh	9	—	—	—
Iron 60 mesh coated	—	24	10	—
Mealed gunpowder	—	—	10	—
Aluminum flitter 30-80 mesh	—	—	2	10
Potassium perchlorate	—	—	—	63
Aluminum Flake 'Bright'	—	—	—	18
Shellac 60 mesh	—	—	—	9

B is taken from Weingart and works very well. D is charged after damping with alcohol and needs a starting fire of red fire or something similar without sulfur.

Chip Gerbs

Fountains and cones have always been made with micro stars which were made from either small pieces of coloured star composition or silver granules. These were mixed with a gold charcoal mix and, needless to say, stars made with chlorate were hazardous. There was also a second problem in that the stars often burnt out inside the tube before they reached the outside.

The silver granules were made with barium nitrate, aluminium and sulfur but these have become more or less obsolete as the Chinese system using nitrates and magnalium work so much better. The nature of these micro stars is such that they light after a short delay and this gives them time to get out of the tube. However, the compositions need to be lightly charged to avoid breaking the stars and to get fast clean burning.

The reader is referred to Dr Shimizu's notes in Chapter 6.

18
PINWHEELS AND CRACKERS

Pinwheels

There are several ways of making pinwheels, but good ones are not easy to manufacture. The usual British method employs a long narrow pipe about 5 mm in diameter, dry rolled against the grain, and pasted at the edge only. The length of the tube depends on the size of the pinwheel of course, but could be 30 cm to 50 cm long. The narrow bore tubes are not easy to fill, but they can be charged in bundles by funnel and wire or the composition can be shaken down the tubes. In England the wheels are filled on automatic funnel and wire machines operating on a bouncing principle.

If the composition is filled by hand bouncing, a sheet of paper is wrapped around a bundle of tubes so that it extends the open ends (one end of the tube having been previously closed with touch paper or sealed off in some other way). Fig. 18.1 will make this clear.

The composition is then poured on to the open ends of the tubes until they appear to be full. The whole bundle is then lifted and dropped sharply on to the bench several times, so that the composition is consolidated in the pipes. The whole operation is then repeated until the pipes are full.

Some manufacturers conduct this operation inside a container with a close fitting lid to reduce the dust hazard.

After charging, the pipes are placed inside damp cloths so that the paper will become sufficiently damp to avoid breakage during the coiling operation. When the tube is sufficiently damp it is neatly coiled around a cardboard or plastic disc, fixed with sealing wax or tape, and set aside to dry (Fig. 18.2).

Compositions are a little more complex than might be expected. In

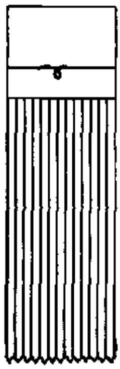


Fig. 18.1 Bundle of tubes ready for charging

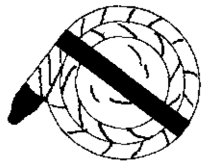


Fig. 18.2 Pin wheel

fact the mixtures need to run down very narrow pipes and therefore contain a high percentage of grain gunpowder, coarsely ground sulphur and potassium nitrate crystals. They also need to be fast burning and they do contain a higher percentage of gunpowder than most printed formulations would seem to indicate. The following basic formulation is typical, but manufacturers naturally adjust the particle sizes of the ingredients according to their technique and granulate the composition.

	Weight (%)
Meal and grain gunpowder	74
Potassium nitrate	13
Sulphur	13

Silver wheels can be made with gunpowder mixed with about 12% of bright aluminum powder.

Some silver spinning wheels of this type employ a mixture of barium nitrate, special kinds of dark pyro aluminum, potassium nitrate and aluminum flitter, similar to the silver gerb composition, but there are many snags to the manufacture of this firework. The composition is very hot, of course, and so it is essential to have a thicker and larger bore tube than the smaller pin wheels or else it will burn through all the coils of tube on ignition. In the second place, such a mixture is also virtually a flash composition and so it will explode if there are air locks in the filled tube; this can be partially overcome by rolling the tube between heavy rollers after charging. A third drawback is that it would be dangerous to funnel and wire such a mixture, but it is very dirty to bounce it. The fourth problem is the type of aluminum to use. If the aluminum is too fast burning, explosion is likely, but if the aluminum is too slow the wheel will not turn. These wheels are a problem, but the Germans make good ones.

Crackers

English crackers are made in exactly the same way as pinwheels in that the grain gunpowder is poured over a bundle of pipes and then shaken down. The pipes are made of brown kraft paper, dry rolled. Manufacturers vary in their tastes as to which type of grain to employ but often use FFF or F or mixtures of these and other grades.

When the pipes are full of grain they are rolled several times between heavy rollers so that the grain is crushed and the pipes are flattened.

The extent to which the pipes are rolled is a matter of experience and can only be determined by trial and error.

After charging and rolling, the pipes are damped in the same manner as pinwheels so that they can be easily bent backwards and forwards into their characteristic form.

Weingart and others have described the method by which the pipes are bent backwards and forwards as in Fig. 18.4.

Finally the tubes are held in place by a tie of twine or adhesive tape (Fig. 18.5).

Fig. 18.3 Finishing Pin Wheels. Early 20th Century. Brock's Fireworks.

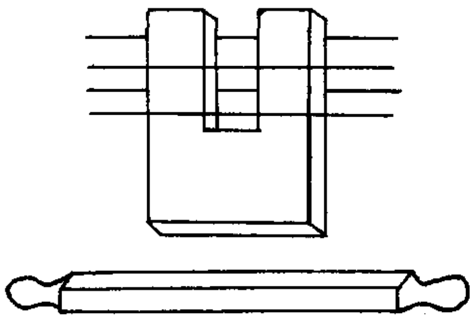


Fig. 18.4 Cracker bending tools

Some manufacturers use machines to bend the pipes, but others feel that the time taken to load the machine is almost as long as it takes to bend the pipes manually.

Large bore English crackers were rolled and charged on a manually operated machine which is fed with a continuous strip of paper and a hopper of gunpowder. A continuous length of charged cracker piping can be made in this way.

Many European manufacturers use an entirely different method for making crackers. The method is roughly as follows. The long narrow strip of paper for the tube is laid on the bench and pasted down one of the long sides; in fact several sheets are usually fanned out and pasted at the same time. The sheet of paper is then dry-rolled around a cylindrical brass former, but only half the paper is rolled on to the former. At this stage a specially long narrow scoopful of meal gunpowder is carefully placed onto the paper alongside the paper-covered former and the tube is finally rolled up and stuck down at the edge. The special gunpowder scoop naturally needs to be the same length as the

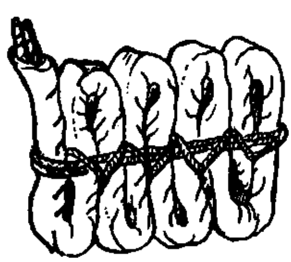


Fig. 18.5 Cracker

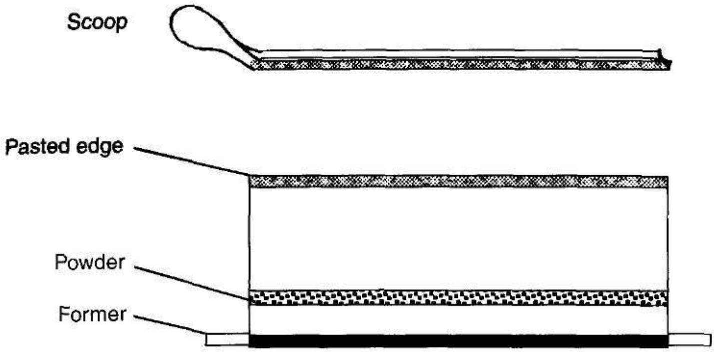


Fig. 18.6 German Method of Cracker Manufacturer

cracker pipe itself. Finally, the former is removed from the pipe which is then rolled and completed in the usual manner. The tools are shown in Fig. 18.6.

The narrow bore English crackers and the other wider bore crackers are somewhat different in performance. The former type tends to fizz in straight portions of the tube and then crack at the bends in a rather

Fig. 18.7 Filling Pin Wheels. Early 20th Century Brock's Fireworks.

Fig. 18.8 Finishing Crackers. Early 20th Century. Brock's fireworks.

leisurely manner, but the wide bore crackers usually produce a quick succession of cracks rather like a burst of machine gun fire.

A rather cheap and less successful method of making crackers is to enclose a length of thick, good quality match in a close fitting length of match pipe, and complete it in the usual way.

Torpedoes, Throw Down Crackers and Amorces

These specialist items are outside the normal range of firework manufacture for they employ impact sensitive materials which are very dangerous to handle. Silver fulminate is much too dangerous to handle commercially and mixtures of potassium chlorate and red phosphorus are quite lethal. Although the quantities used in amorces and torpedoes are quite minute and safe to handle, the actual process of manufacture is frighteningly dangerous and should only be attempted by the specialists who have problems of their own in any case.

19

INDOOR FIREWORKS

The manufacture of indoor fireworks tends to be somewhat specialized and is frequently undertaken by manufacturers who restrict themselves to these alone. They also have the advantage of being able to operate under less restrictive legal provisions.

The following represents a brief summary of the more usual types of indoor firework, but this sphere of activity is outside the direct experience of the author, who can do little more than comment in certain cases on confidential industrial information.

Fern Paper

This unusual effect is obtained by soaking brown ribbed kraft paper in hot water containing a mixture consisting of 5% potassium bichromate and 2-1/2% potassium nitrate. When the paper is dry, a sheet about 7.5 cm X 10 cm is folded backwards and forwards like the bellows of a concertina and fastened at one end to a cork or block of wood. When the paper is touched at the top with a burning cigarette, it smolders away to leave a beautiful and unusual fern-like ash. (Fig. 19.1).

Fire Pellets

A compressed tablet of metaldehyde or hexamine will burn with a steady smokeless flame. The addition of lithium, or copper in some form, and magnesium powder will create quite attractive variations in color and effect. It should be noted, nevertheless, that the fumes produced by burning metaldehyde are objectionable in quantity, and in

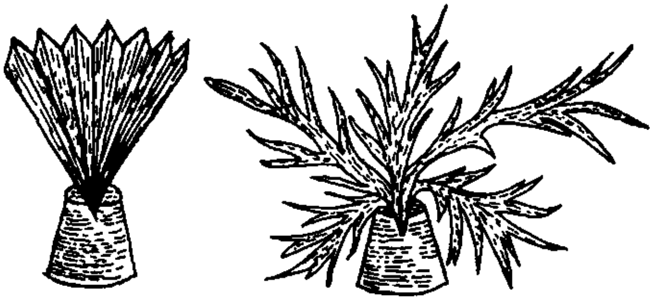


Fig. 19.1 Fern paper

fact poisonous. Patents have been taken out for these fireworks in the past.

Fire Pictures

In Chapter 23, Dr Shimizu has also mentioned these items. A sheet of semi-absorbent paper can be used for the picture which is drawn with a solution of potassium nitrate. The result is invisible when dry, but if any part of the picture is touched with a burning cigarette, the rest of the picture is gradually burnt out. Sometimes the papers are also printed in ink with additional detail. For example, a man may be depicted firing a gun. The trajectory of the bullet is invisible until it is burnt on the saltpeter trail, and it culminates in the ignition of a paper amorce fixed at the end.

Flash Paper

Sometimes unsized paper is nitrated with the usual nitrating mixture of concentrated nitric and sulphuric acids. When it is thoroughly washed and dried, it burns with a brilliant flash. It is well known though that such nitrations need careful control and the products can be very unstable unless they are carefully washed and expertly made.

Fountains

Indoor fountains are almost odorless and smokeless, being made principally from nitro-cellulose. The addition of iron, magnesium and aluminum along with salts of lithium and copper produces some very pleasant effects. The main problem is knowing where to obtain powdered nitrocellulose with the correct percentage of nitrogen and the correct, and very necessary, stabilizer. Sometimes when the conditions are not right, the fountains produce gas but no flame.

Matches

The manufacture of match heads has been well covered elsewhere (5), but the so-called Bengal Matches do come within the scope of fireworks even though they are normally made by the match manufacturers. It is well known of course that the choice of adhesives, the viscosity and the temperature of the slurry are all important when the splints are dipped, for this affects the way in which the matches dry. Some pre-war German formulations set out in the B.I.O.S. Reports (12) were as follows:

Red	Strontium nitrate	2,500
	Shellac	500
	Potassium chlorate	300
	Fine charcoal	250
Green	Barium nitrate	3,000
	Shellac	500
	Potassium chlorate	300
White	Potassium nitrate	3,500
	Sulphur	1,125
	Shellac	1,000
Blue	Potassium chlorate	900
	Paris Green	300
	Resin	135

Storm matches are simply bengal matches producing flame but not color. They were used extensively at sea for the older signals which had to be ignited by ordinary methods, and are still used for lighting portfires at firework displays.

Exploding matches are usually book matches which have a tiny dab of fulminate and adhesive at the base of the match head so that they produce a sharp report soon after ignition.

Smokes

Firework smokes are frequently used in the theatre, but naturally they must be as innocuous as possible. Sometimes a smoke puff is produced by the combustion of a flash powder made with aluminum, magnesium or zinc; larger quantities of smoke can be made with the insecticidal types of smoke (see Chapter 21).

Colored smokes are made with the usual combination of dye, potassium chlorate and sucrose or lactose. An interesting colored smoke stick can be made by forming the composition into a slurry with adhesive and dipping the sticks in the same way as for sparklers.

An amusing little non-pyrotechnic smoke seen on the market utilizes celluloid to give the illusion of a toy monkey smoking a cigarette.

Snakes

The best snakes are the black ones which are made out of pitch. This curious German discovery is said to have been made by G. Vorbringer in 1867 and since then has given an immense amount of pleasure. Recent research by Adrian Shell of the UK has confirmed that there are two main types of snakes but that many substitutes have been tried throughout the ages, including one recipe using cigar ash and a cough sweet. The snakes are quite remarkable and those made of naphthol pitch will produce an ash 25 mm in diameter and over a meter long. This pitch is the residue after the distillation of naphthol and appears to be a mixture of many compounds including naphthol and its dimers. The material is not readily available and the producers naturally make no guarantees for what is a waste product; samples have to be obtained and tested. Weingart and Davis (6) (7) have written at some length on the manufacturing procedure and so there is no need to repeat this except to add a few caveats omitted by them. Davis maintains that a mixture of roofing pitch and Syrian asphalt is a good substitute. Some manage to use ordinary coal tar pitch.

The actual nitration is an unpleasant procedure, best carried out in an aluminum or glazed earthenware bowl. Pitch, linseed oil, and nitrocellulose powder are mixed together and the acid is slowly added. The reaction is very vigorous and copious clouds of nitrogen dioxide are evolved. Ordinary concentrated nitric acid will not work and fuming nitric acid is too strong; a small amount of water is therefore added to the fuming nitric acid which enables the reaction to proceed smoothly.

Weingart and Davis do not make it clear that the oxidation process is incomplete. The addition of too much fuming nitric acid frequently causes the mass to catch fire, destroying the whole experiment. On the other hand, insufficient acid for the completion of the reaction causes the mass to be sticky due to the presence of too much oil. The correct quantity of acid leaves a hot molten mass with no excess acid present, due presumably to the usual breakdown of nitric acid in the presence of hot carbon. Washing is thus unnecessary, though as a precaution a

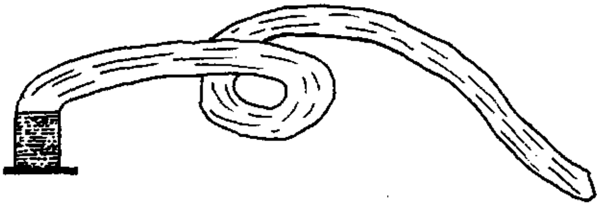


Fig. 19.2 Firework snake

tiny percentage of barium carbonate is sometimes incorporated into the final operation.

After the mass has cooled and solidified, it is ground and pressed into pellets with the addition of a small amount of a lubricant such as graphite. Picric acid has been used to burn the pellets to produce the ash but it is quite useless commercially as it stains the fingers and clothing, and has a bitter taste. Nitrocellulose is best and can be incorporated into the nitration. It appears that the Japanese have used ammonium perchlorate.

When it is ignited, the snake pellet burns with a sooty orange flame and a smooth snake with a metallic lustre winds out of the flame. The shiny outer skin has small carbon particles on it, inside is a mass of bubbles (vesicular). The snake is composed of an aromatic polymer system swollen to many times its original size by gaseous decomposition products (Fig. 19.2).

The Snake-in-the-grass is an interesting variation which consists of green Cr_2O_3 from the thermal decomposition of ammonium dichromate $(NH_4)_2Cr_2O_7$. A small cone made of aluminum foil is filled with a mixture of ammonium dichromate mixed with a small amount of fuel and oxidizer. At the base of this a pinch of loose black snake composition is added before the cone is sealed off. On ignition it produces a spray of green chromic oxide followed by the black snake. (Fig. 19.3).

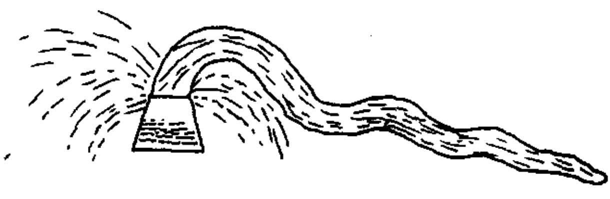


Fig. 19.3 Snake-in-the-grass

Smaller white snakes called Pharaoh's serpents used to be made with Mercury (11) thiocyanate (sulphocyanide) and were apparently discovered serendipitously and independently both by Berzelius and Wöhler in 1821. This obscure salt is insoluble in water and can be made by adding potassium thiocyanate solution to Mercury (11) chloride solution to which a small amount of Iron (111) chloride has been added, until the first permanent red color remains on stirring. When the precipitate has been washed and dried it is made up into tiny pellets with a solution of gum arabic and water; a little potassium nitrate is added. This snake is less exciting, more brittle and has the disadvantage of being poisonous as a certain young Prince O, discovered in 1865 when he ate a snake pellet mistaking it for a sweet; he survived the poisoning, but it killed off his tape worm!

The pellet burns with a blue flame, giving off mercury vapor and expands (intumesces) to approximately 50 times its original length. The composition of the snake is quoted as $C_6H_3N_9$ and is orange/white on the outside and grey/black inside. It is said to consist of a mixture of melam, mellone, mercury sulphide and mercury. The pellets were at one time placed in wine corks and into porcelain caricatures so that pigtails/curly tails emerged once lit!

Outside the pyrotechnic world it is well known amongst the chemical fraternity that a snake can be made from 4-nitroacetanilide. To achieve the snake heat a 1:1 mole ratio of concentrated sulphuric acid with (3g at most) 4-nitroacetanilide in a beaker. This gives an intumescence of 100 times the original size. The snake consists of a polyaniline-like polymer swollen by gas. It is black and almost metallic in color but more wart-like than the smooth naphtha snake.

Snow Cones

These little cones are made in exactly the same manner as the snake-in-the grass. Circles of aluminum foil are cut out with a radial cut as shown in Fig. 19.4 and after forming into cones they are placed in a board with a series of cone shaped holes of the same size. When the cones are filled in this way, they retain their shape and are easily closed up at the base by simply bending the foil over on top of the composition.

The snow cone merely burns magnesium powder with the production of large flocks of white magnesium oxide, though quite why any person should wish to allow such a thing to happen indoors is anybody's guess.

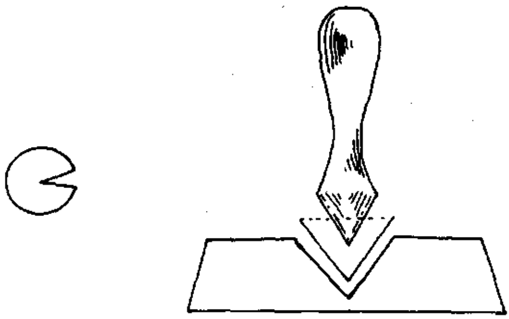


Fig. 19.4 Tools for snow cones

The composition is basically;

	(%)
Fine magnesium powder	40-50
Potassium nitrate	5-10
Flour or woodmeal	about 40

Small tablets of metaldehyde also produce a snow-like effect when placed on a cigarette due to the sublimation of the metaldehyde.

Sparklers and Fire Sticks

The well known sparkler is basically made of barium nitrate, aluminum and steel.

	Weight (%)
Barium nitrate	50
Dextrin	10
Steel	30
Aluminum powder	8
Charcoal 150 mesh	$^1/_2$
Neutralizer	1 - $^1/_2$

The materials are ground with suitable adhesives and water to make a thick slurry. Wires are fixed into wooden frames to space them suitably before dipping into the slurry. Sometimes the sparklers have to be dipped twice. As might be expected, the drying process is quite important and usually takes quite a long time to prevent the mass cracking. The iron is usually coated in good quality sparklers, though judging by the appearance of many commercial products, this is frequently not the case.

Other fire sticks are made also, but of course they should not be burnt indoors as the compositions suggest. The following composition is from an earlier American patent number 1,936,221(1933):

	Weight (%)
Potassium chlorate	46
Barium nitrate	17
Strontium carbonate	12
Shellac	11
Cryolite	8
Dextrin	6

The outside of the composition is coated with magnesium/aluminum alloy grit. Weingart (6) gives other compositions but these have not been tested by the author.

Table Bombs

Table bombs are in effect little mines filled with toys and other items. The lid is fixed quite lightly so that it will not blow off violently, and instead of blackpowder, a nitrated cotton is used to eject the toys. The cotton is ignited with Bickford fuse.

Theater Fires

Smokeless fires are sometimes required, but it is not possible to produce good colors without smoke or smell. The following compositions are sometimes used, but they must be kept dry.

	Weight (%)		Weight (%)
Strontium nitrate	68	Barium nitrate	56
Potassium chlorate	24	Potassium chlorate	26
Shellac 30/120 mesh	8	Shellac 30/120 mesh	18

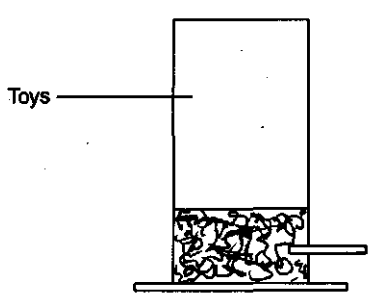


Fig. 19.5 Table bomb

Throw Down Crackers

These consist of small twists of tissue paper containing sand and a small amount of silver fulminate. They crack sharply when thrown onto the pavement. Large quantities are manufactured in Brazil. Packaging of these items is quite an important manufacturing procedure!

20

FUSES, QUICKMATCH

SAFETY FUSE

In the early days of mining there were many accidents associated with the blasting operations which used mainly blackpowder. These powder charges were ignited with quills which were filled with gunpowder. It was an extremely hazardous and unreliable operation due to the fact that some quill fuses flashed off irregularly, and in other cases breaks in the powder train leading to a dangerous misfire. The matter was further complicated by moisture and there were many instances where miners returned to misfires too quickly only to get blasted by the explosion which followed.

William Bickford was born in Devonshire in England in 1774 and was baptized in Bickington. Earl (26) tells us that he later moved to Tuckingmill near Camborne in Cornwall where he became a leather merchant in the heart of the mining area. Earl makes the point that he was a humane man who was particularly distressed by the mining accidents and set about trying to make the ignition systems more reliable. While visiting a friend who was a ropemaker he conceived of the idea that it might be possible to pour gunpowder through a funnel into the center of a rope as it was being spun. A Methodist, Bickford further discussed the matter with another Methodist friend who was a worker miner called Thomas Davey and after some trials they were delighted to find that their method of making fuses worked.

The first fuse to be made was simply a continuous core of powder which was surrounded by a number of flax yarns. The yarns were twisted as they were pulled down around the continuous core. The next stage was to place a second layer of yarns around the first stage but in the opposite direction when twisted. The final stage was to pass the fuse through a bath of tar to hold the fuse together, promote even burning and to keep out the moisture.

The first product was called The Patent Safety Rod' and was 10 mm to 13 mm diameter. The British Patent No 6159 was taken out in 1831. Unfortunately Bickford was taken ill in 1832 and died in 1834. Bickford made an enormous contribution to safety with his invention and set up a business at Tuckingmill which remained with many changes until July 1961.

The Bickford family had some problems in protecting their valuable invention but many changes were made and in time the manufacturing method was turned into a continuous process. Earl tells us that in the beginning they were making about 72 kilometers a year. However in 1930 they were making 167,272 kilometers per annum and that did not include the material made by competitors.

The biggest change in the process came in 1840 and after that the method has remained pretty well unchanged until the present time. Quoting Earl (26), machines were made up from cast iron framework, a brass powder funnel being fixed at the top. The powder from this fell into the middle of the flax, later jute yarns, which were brought together to form a tube in a cone shaped hole 'die' machined to the diameter needed for the first spin cord. The die was arranged vertically and coaxially in the center of the circular, rotating, 'plate' which carried the bobbins of flax yarns. Each thread was guided into place in the die by small holes drilled down at an angle through the plate into its central axial opening, ensuring they were evenly spaced as they entered the die. From here the cord, with its gunpowder core, was drawn down and away by a pulley which was geared to turn at the right speed in relation to the spinning plate so that the desired pitch-lay was given to the spinning yarns. The cord so made was then countered by a second plate - the 'Countering plate' - charged with bobbins of yarn, turning in the opposite sense, rotating faster for a given 'draw down' (length of fuse) so as to give a steeper pitch to the threads. Finally the semi-fuse rod so made was 'struck in' to a varnish mixture as in the original method. An outline of this process is given in the French patent taken out by Bickford, Smith and Davey during 1842, when Davey's factory at Rouen was going into production. By this time the fuse was world famous.

There were two kinds of fuses in production, Common Fuse and Sump Fuse. The latter was for use in wet places or under water and was much the same as the Common Fuse except that it had extra cover and varnish. A rather larger diameter fuse of 10 mm diameter has been made in the USA even in recent times and this has been particularly useful for the firework trade for making shells. However, the fuse did reduce in diameter over the years and was normally about 4.5 mm in diameter. Earl makes the point that in the early days, the fuse cost three pence per fathom. Post decimalization of the UK currency, this would be 1.25 pence per 1.83 meters. In 1990 it could cost 30 pence per meter.

In the older Bickford, the powder charge was 11 to 12 gm per meter and Earl quotes two compositions as follows:

	Common Fuse Weight (%)	Sump Fuse Weight (%)
Potassium nitrate	73.0	77.0
Charcoal	15.5	13.5
Sulphur	11.5	9.5

Inevitably the main problem with manufacture was the possibility of having gaps in the powder core which would cause the fuse to 'hang fire'. This problem was overcome by introducing two central identification cotton strands into the center of the powder stream and by making these cotton strands slightly damp, the powder actually stuck to them.

The burning time of the fuse powder was determined by charging the powder into a lead pipe about 300 mm long and about 6 mm diameter. This was then repeatedly rolled out until it was just over three times its length and finally a length of 0.9144 m was timed by burning it on a sand tray.

Even though the fast burning or 'running fuse' had its problems for the makers, the time came when there was a demand for an instant fuse and this was available in the UK until the Second World War. Large quantities of old stock of this material was used up in the post war years as the first fuse for lighting the lifting charge on firework shells. This fuse was developed in the Davey plant at Rouen and it was colored orange to distinguish it from the other fuses. This fuse was made by spinning three strands of quickmatch into an impervious cover. This technique provided an airspace between the quickmatch and the outer cover with the result that an increase in pressure caused the fuse to explode. The manufacture of this type of fuse after the early 1950's Was discontinued because of the new detonating cords.

The firework maker primarily requires fairly short lengths of fuse which provide delay times up to about 10 seconds at the most. Bickford serves this purpose well and has the additional advantages that it is reasonably waterproof, the fire is not communicated laterally, it is easily cut and pierced, and is tough enough to block up narrow bore tubes in addition to acting as a delay.

Bickford is normally about 4.5 mm in diameter. This narrow bore is commonly used in small explosive fireworks and ignites quite easily from a gunpowder charge. To ensure ignition the fuse is often cut at 45° and then primed with gunpowder paste.

The best way to be certain of ignition is to punch a hole through the center of the Bickford from one side to the other and then thread this with a length of quickmatch. The small diameter of the British product does not readily lend itself to this technique, but the larger 9 mm sizes made in other parts of the world are excellent for this purpose. (Fig. 20.1).

In addition to making the larger size of Bickford, the Americans also make a self-consuming type of Bickford fuse which is useful for firework purposes where it is intended to ignite a succession of items. This Red Visco, as it is called, has only a small amount of yarn on the outside and is finally coated with a layer of red nitrocellulose dope.

More recent times have seen the introduction of plastic Igniter Cords. Again according to Fordham (13) the fast cord burns at a rate of about one second per 30 cm and consists of paper or textile yarns coated with blackpowder at the center. This is then covered with a plastic incendiary composition beneath an external coat of waterproof polyethylene. The slow cord is made in a similar manner except that a copper wire replaces the blackpowder center of the fast cord. The copper wire conducts heat from the burning front into the unburnt composition thereby controlling and speeding up the rate of burning. The slow cord burns at the rate of about 10 seconds per 30 cm The British plastic incendiary compositions are usually made from potassium nitrate or potassium perchlorate,

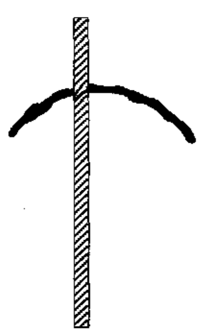


Fig. 20.1 Bickford threaded with quickmatch

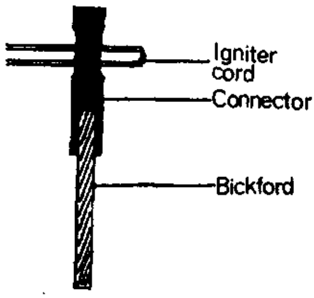


Fig. 20.2 Method of connecting several pieces of Bickford fuse

red lead and silicon with a nitrocellulose binder. Igniter cords are now much more expensive than piped match but have the advantage of being waterproof. On the other hand they are much slower than good piped match and in long lengths burn irregularly, appearing to hang fire momentarily in an unusual manner. A slight disadvantage of igniter cord is that when it is used for lancework it is more likely to be accidentally ignited from dross than paper matchpipe. However igniter cord is very useful for igniting a number of lengths of Bickford by using special Bean Hole Connectors which are also made by I.C.I. The technique is shown in Fig. 20.2. Igniter cords are also clean to handle and do not drop bits of blackpowder when cut.

Firework makers sometimes make their own time fuses with blackpowder. Narrow-bore tubes with strong walls are charged with fine grain powder. Each increment is rammed with about twelve blows of a mallet and there are about eight increments per 24 mm. Much, of course, depends on the powder that is used, but such fuses usually burn at the rate of about three seconds per 24 mm. These fuses can also be pressed.

Occasionally fuses are made with modified gunpowder mixtures,

	Weight (%)
Potassium nitrate	25
Sulphur	10
Meal gunpowder	65

Fuses for small mines and cannon crackers are long narrow bore tubes charged with a reasonably fast composition of the golden rain type, e.g.:

	Weight (%)
Meal gunpowder	75
Potassium nitrate	20
Sulphur	5

The composition is charged with a funnel and wire.

QUICKMATCH

One of the most essential items to the firework maker, quickmatch, is also one of the most unpleasant to make. Cotton strands are passed through a slurry of gunpowder, adhesive and water and then wound on to a drying frame and allowed to dry.

The match is usually made up from four to ten strands of cotton which are run off reels into a bath of alcohol and water, which thoroughly wets the cotton. As the cotton leaves the bath it passes between rollers which remove the alcohol solution prior to passing into the gunpowder slurry. As the cotton leaves the slurry, it passes through a small funnel which removes the excess.

The match is wound on to large wooden frames, about 180 cm long and 120 cm wide where it stays until it is dry. Frequently, the box of slurry moves along a threaded rod which in turn is geared to the winding frame so that the match is carefully spaced on the frame as it leaves the slurry container.

When the frame is full of match it is dusted with fine grain powder while it is still wet. Manufacturers use a good quality powder for match, (e.g. FFF) but they vary in their choice of adhesives. European firework makers tend to favor Gum Arabic or dextrin, but in Britain there is a preference for boiled starch solution. Perhaps the damp British climate is the reason for this preference for there is no doubt that match made with dextrin becomes quite limp in damp weather.

A typical match formulation would consist of approximately 100 parts of grain powder mixed with 100 parts of water which have been boiled with 6 parts of starch. Another formulation used 1 part of Gum Arabic in 4 parts of water to which is added 8 parts of sulfurless gunpowder.

Good match burns steadily and fiercely at about the rate of 5 seconds per 30 cm in the open. On the other hand, when placed in a match pipe it is almost instantaneous.

Match pipes are made from brown kraft or white sulphite paper. The

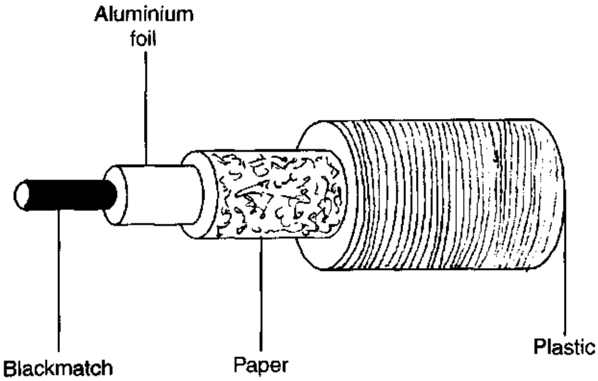


Fig. 20.3 Mexican Protected Match

tubes are dry rolled on a former about 6 mm in diameter; they must be dry rolled since they are bent so much when in use, but the diameter of the pipe is not especially important. Some manufacturers make their match pipe in continuous lengths from rolls of strip paper but there is still a tendency in Britain to roll the pipes in $^1/2$ meter lengths and join them together as required. For this purpose, the former is slightly tapered so that the narrow end of one pipe will fit into the wide end of the next. (Fig. 20.3)

TAPE MATCH

It is not clear whether the U.K. firm of Standard Fireworks were the first to use this type of fuse, but Edward Greenhalgh certainly first made this commercially in the late 1950s. It consisted of a train of grain gunpowder sealed in the centre of a tape which consisted of two pieces of paper which were stuck together. It was extremely useful for conveying fire around units in Roman Candles for example.

A less sophisticated tape is also marketed in the form of a train of grainpowder down the centre of wide 'scotch' tape. Many people use this tape for connecting lances on set pieces, combining both speed of burning and ease of application. It also has some drawbacks in that it dribbles gunpowder, is easily ignited by stray sparks and does not look very elegant.

WATERPROOF AND FIREPROOF SAFETY MATCH

Dr Pablo Hernandez of Articulos Pirotécnicos Mexicanos has kindly provided information on the type of match which they use in their special firework pieces known as Castillos (59).

Firework shows in Mexico are mainly based on this Castillo or castle. It is a structure of 15 to 20 meters in height on which a great variety of wheels, logos and frames are set up and burnt in sequence. It can burn as many as 15 times.

The show must be synchronised and needs to keep a burning sequence which allows gerbs, drivers, lances and special effects to be burnt as they have been programmed.

However, in varying conditions of rain, humidity, and the close proximity of the fireworks it has been necessary to look for other ignition options in order to guarantee harmony and continuity.

It meant that the lances, drivers and quickmatch had to be protected from fire residue, hot ashes from nearby fireworks which would alter the burning sequence. There must also be protection from humidity and rain, both enemies of quickmatch. (Fig. 20.3)

Plastics, aluminium foil, different waxes and paper nosings to protect primes have all been investigated so that quickmatch can maintain its necessary characteristics:

- Flexibility
- Waterproof
- Fireproof
- Minimum ash residue
- Burning speed

FLEXIBILITY

It is essential that blackmatch must have the correct amount of gunpowder and binder so that the cotton strings are completely impregnated. If there is insufficient binder, the blackpowder will become detached and spoil the fire transmission. On the other hand, too much binder will make the match brittle and burn slower.

The paper and plastic pipe is also important as it protects the match. The paper should have a long fibre so that it is strong under tension, this being further reinforced by the plastic cover which helps to prevent rupture.

This flexibility allows the work to be done quickly, but more important, there is no need to fix the quickmatch since the tube does not break easily.

IMPERMEABILITY

The plastic cover affords perfect protection from the weather, but it also enables work to be done more quickly (e.g. using plastic tapes to join up pieces of quickmatch).

FIRE PROTECTION

The aluminium foil pipe around the quickmatch is vital to protect the match from fire residues and hot ashes from the other performing fireworks. It also aids the continuity of the show and prevents pre-ignition of other devices.

In a recent test, a length of blackmatch was wrapped around this safety match and ignited. The safety match did not ignite after ignition and even subsequent cooling.

RESIDUAL ASH

After the safety match has burnt, there is very little residue of any size and very few ashes. This because the protective aluminium foil is in intimate contact with the blackmatch and so prevents the propagating flame from igniting the paper and plastic layers. Since they do not burn there is little ash.

TRANSMISSION SPEED

As it is necessary to have a definite burning speed in terms of meters per second, accurate control is required. It is related to the size of the explosion and consequently the explosion increases with the burning speed.

All drivers and gerbs are fitted with a paper nosing. This protects the prime and allows the fuse to be tied in to give a seal and avoid accidental fire and moisture. Good safety fuse is vital for if it burns too violently the explosion may be so great that it prevents ignition.

21

SMOKE

The extensive use of smoke for screening and signalling purposes during the last two World Wars has produced a very specialized branch of pyrotechnics which is not directly concerned with fireworks. As there is an abundance of specialized literature on the subject, the reader who is looking for greater detail is referred to the following works (4, 5, 9, 12, 22, 34).

Colored smokes are usually made by vaporizing a suitable dye by mixing it with a heating mixture of potassium chlorate and a fuel. In order to make the mixture as cool burning as possible, lactose or a mixture of lactose and sucrose is used as the fuel. In certain types of white smokes thiourea is also sometimes used.

As a general rule with colored smoke formulations, it is necessary to use dyes which have a melting point which is as consistent and as low as possible. The dye should also be free from organic salts and have a particle size which is uniform. Smoke compositions are mixed for long periods to produce uniformity and consistency, for this, along with the particle size, affects the burning rate which is further controlled with other additives.

A simple smoke formulation would consist of approximately 60% dye, 20% potassium chlorate and 20% sucrose or lactose or a mixture of the two. The material is charged into a metal container with hydraulic pressure, leaving a space down the center of the composition rather like the spindle hole in a rocket. The composition must not be too dense or voluminous or else the carbonaceous residue will decompose the smoke before it leaves the container. A metal gauze is frequently placed on top of the smoke composition, which must not completely fill the cannister. The cannister is then closed with a suitable lid which contains holes for the smoke to issue forth, and a suitable ignition. The empty

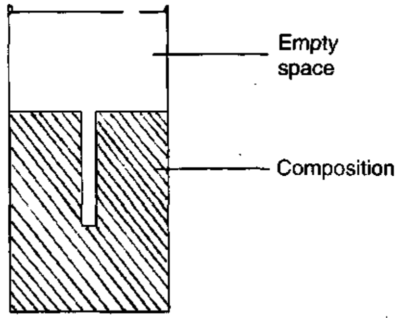


Fig. 21.1 Smoke cannister

space at the top of the container is essential in order to allow cooling to take place. In the absence of this, the smoke will catch fire and merely burn. These smoke containers and ignitions have become highly complex and efficient. A smoke cannister is shown in Fig. 21.1.

Black smokes gain their effect from the production of tiny particles of carbon when oxygen negative mixtures containing naphthalene or anthracene are burnt. These mixtures consist of potassium perchlorate and anthracene or potassium perchlorate, hexachloroethane, and naphthalene. During the last war, the Germans used a somewhat explosive mixture of hexachloroethane, anthracene and magnesium powder, e.g.:

	Weight (%)
Hexachloroethane	60
Anthracene	20
Magnesium-fine	20

Brown smokes have frequently been made with pitch or tar. Hard pitch is ground to a powder and mixed with potassium nitrate and sulphur. Glue is frequently added to control the reaction. The mixture is placed in a cannister similar to colored smoke, but it tends to get very hot. The following composition given by Faber (9) is typical:

	Weight (%)
Pitch	29.2
Potassium nitrate	47.4
Borax	10.6
Calcium carbonate	4.9
Sand	4.0
Sulphur	3.9

A better method is to use liquid tar which is absorbed into sawdust. The mixture has better burning characteristics and can be used in thick-walled paper tubes with a washer at the exit to prevent the smoke burning.

Black Smoke	Weight (%)
Potassium nitrate	60
Sulphur	3
Sawdust	26
Liquid Tar (Coal)	7
Accaroid Resin	4

Grey smokes are invariably of the so-called HC type involving the use of hexachloroethane (HC) and zinc in some form. The grey color is formed because of the production of zinc chloride and carbon particles, but the zinc chloride also forms zinc hydroxide and hydrochloric acid in the presence of moisture. Mixtures containing zinc powder are liable to react with water and it is usual practice to make sure that moisture is excluded before the cannister is sealed. One magazine was destroyed when smoke spontaneously ignited because a worker allowed beads of perspiration to fall into the composition during processing. In view of this hazard, HC smokes are more frequently made with a mixture of hexachloroethane and zinc oxide with smaller percentages of calcium silicide and potassium nitrate. The high vapor pressure of hexachloroethane also means that all the HC smokes have to be sealed in air-tight cannisters.

		Weight (%)
A.	Hexachloroethane	50
	Zinc Powder	25
	Zinc oxide	10
	Potassium nitrate	10
	Colophony resin	5
B.	Hexachloroethane	45.5
	Zinc oxide	45.5
	Calcium silicide	9

A is from Izzo (8) and B is from Ellern (5).

White smokes were invariably made by the old firework makers with ammonium chloride. Strictly speaking, a mixture of potassium chlorate and ammonium chloride is highly unstable owing to the formation of ammonium chlorate. Nevertheless there seems to be good evidence of the stability of such mixtures.

Shidlovsky quotes the following:

	Weight (%)
Potassium chlorate	20
Ammonium chloride	50
Naphthalene	20
Charcoal	10

and Dr. Becher (10) the following:

	Weight (%)
Potassium chlorate	40
Ammonium chloride	45
Montan wax	12
Kieselguhr	3

Formulations of the latter type occasionally employ a little paraffin oil, presumably to help exclude moisture and reduce sensitivity.

More useful white smokes are made with HC and zinc oxide or mixtures of potassium chlorate, thiourea, lactose and the organic chemicals used as insecticides. Mixtures of potassium chlorate and thiourea can be somewhat explosive and they are now somewhat frowned upon. In addition to this, there are now anxieties about the toxic nature of HC smokes, and many of them have been replaced with cinnamic acid. The composition percentages can be changed to vary the burning time. However these can be explosive.

	Weight (%)
Potassium chlorate	29
Cinnamic acid	27
Lactose	29
Kaolin	15

In more recent times, many commercial and military smokes have returned to the potassium chlorate and ammonium chloride mixture with the addition of lactose and colophony resin. These formulations naturally vary with the requirements such as the burning time and the type of container. These smokes however would be based on percentage of 40-50% of the pine resin and about 10% ammonium chloride. The remainder being the heating mixture of potassium chlorate and lactose.

Many of the old smoke mixtures were formulated to simply burn in the open and were often used on the stage though they would be regarded with some caution to-day.

The following would be typical:

	Weight (%)
Potassium chlorate	50
Potassium nitrate	33
Magnesium powder	8
Gum copal	9

An interesting communication from Dr Yuri Frolov of the Moscow Academy writes of investigations at the Institute of Chemical Physics into the use of smoke for fire suppression. It was found that smokes containing alkali metal ions (Potassium and Sodium ions) were particularly effective in buildings such as libraries and museums. Examples are as follows:

1.	Weight (%)	2.	Weight (%)
Potassium nitrate	60	Sodium azide	63.5
Epoxy	25	Sodium nitrate	21.8
Iditol	15	Urotropine	14.7

Iditol is phenol formaldehyde resin $C_{13}H_{12}O_2$.

The earliest types of insecticidal smoke generators were used in the second World War in the form of hand grenades for fumigating dugouts in the jungle and the Far East. Later these were developed, under patent, for use in greenhouses.

Insecticidal smoke formulations are much the same as those for colored smokes which utilize dyestuffs, though in this case the pyrotechnic mixture has to be carefully regulated to give the right amount of heat to vaporize the maximum quantity of active ingredient. The earliest ingredients in these smokes were DDT and BHC.

DDT 1,1,1-Trichloro 2,2-Dl-(4-chlorophenyl) ethane.

Lindane (gamma BHC 7-1,2,3,4,5,6-Hexachlorocyclohexane, the pure gamma isomer later replaced BHC. Later developments utilized azobenzene and tecnazene (l,2,4,5,-tetrachloro-3-nitrobenzene); development since has been extensive.

After ignition of the smoke composition, a dense smoke is produced with particles less than 3μ in diameter which consist of super-cooled droplets of insecticide. As the insects fly around (particularly at optimum temperatures of 21°C.) they collect the insecticide particles on the hairs of their bodies and antennae and soon die. Once again environmental and 'green' attitudes have played their part in the revival of natural substance like Pyrethrum.

Other firework smokes have been discussed by Dr. Shimizu in Chapter 23. Ordinarily, smoke has no direct application in fireworks; on the contrary it can be a nuisance at a firework display on a still night. On the other hand, apart from daylight fireworks, smoke is used commercially because of its penetrating capacity. It is used to detect leaks in drains and tanks, for it not only penetrates all available space, but is visible when it emerges.

Drain testers are simply thick-walled tubes clayed like fountains but with a smaller hole, and charged with a simple mixture of potassium nitrate, sulphur and a small amount of additional fuel. These smokes contain large amounts of sulphur dioxide and are also frequently used to discourage mice and moles. Mole smokes are usually made of roughly equal quantities of potassium nitrate, sulphur and sawdust. They do not often kill the animals, but drive them into the next property instead!

22

EXHIBITION FIREWORKS

Exhibition fireworks do not vary very much from one manufacturer to another in their general arrangements because the number of possibilities are limited. On the other hand, the finer details vary enormously from one country to another though we can see that each individual country tends to follow its own general pattern.

In England displays are usually fairly leisurely affairs striking a balance between set ground pieces, Roman Candles, Rockets and Shells. On the other hand the Italians and Germans prefer fast firing mass aerial effects of shorter but more spectacular duration. Many English people also prefer the latter type of display but the public usually feel that a show should last half an hour if they are to get good value for money. Apparently the English also are more reluctant to spend large sums of money on displays, preferring to buy a few smaller fireworks of their own. Large displays are still very much a feature of European fetes, festivals and carnivals, but they are becoming more common in England. Very large quantities of small fireworks are still sold in England for the traditional festivals on November 5th (Guy Fawkes Day).

Shells

Shells for display work have been fairly adequately covered in Chapter 16. Re-loading is virtually impossible in fast firing displays making it quite imperative to have one mortar per shell. For the smaller sizes, paper mortars in wooden boxes surrounded by sand are quite adequate, but care must be taken not to allow the boxes to fall over. The shells are frequently fitted with automatic delays of the type mentioned earlier, but if these are used, the match pipe must be tied to the mortar, or else

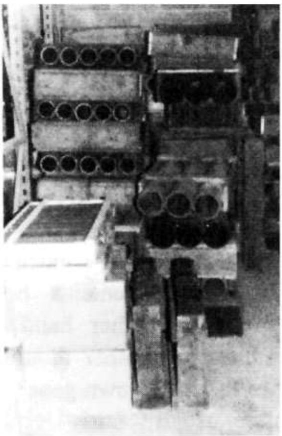


Fig. 22.1 Mortar boxes

Fig. 22.2 Roman candle batteries

a shell leaving a mortar can sometimes drag unfired shells after it. (Fig. 22.1)

Roman Candles

Display candles are usually fired in batteries of five or more. The best effect is gained by arranging the candles in a fan-shaped board or spline. A piece of timber drilled with a few holes to take the tubes is all that is required. (Fig. 22.2). Large candles should be wired to wooden frames. Candles are sometimes fired in bundles but these are less effective.

At this stage, it would be appropriate to mention the manner in which candles and other fireworks are joined together with piped match. The candles and gerbs are usually capped with about three turns of a tough thin paper (e.g., ribbed kraft). The paper is pasted only at the edge and where it comes into contact with the tube. It should overlap the end of the tube by about 40 mm.

When it is necessary to join several tubes together, a length of piped match is used to connect them. The end of the match pipe with about 12 mm of bare match protruding is pushed inside the end of the tube and the capping paper gathered around it. The capping paper is then tied with a clove hitch. The match pipe is then cut further along the pipe near to the next tube with a V shaped snip to bare the match again, and after being inserted into the capping it is tied off as before. The method is illustrated in Fig. 22.3.

The clove hitches are almost always used by fireworkers and are

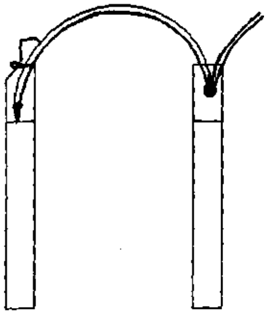


Fig. 22.3 Matching tubes

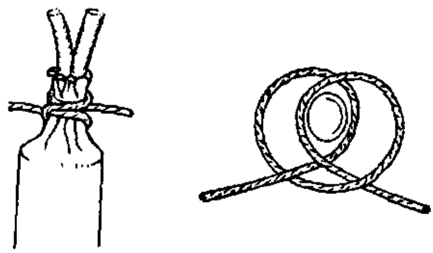


Fig. 22.4 Clove Hitch

tied in two ways (Fig. 22.4). Both methods have to be mastered, for the one method involving the formation of two loops on top of each other, can only be used in those situations where it is possible to slip the loops over the end of the object to be tied. It is also important to note that when the cappings are tied they must be neither too tight nor too slack, for in the former situation the fire does not always get through, and in the latter case the match can be pulled or blown out of the cap without causing ignition.

Rockets

Large display rockets are fired from frames with a double row of screw-eye staples about 75 mm apart. The frame is usually collapsible for ease of transportation and arranged so that the rockets can be fired at any angle. (Fig. 22.5)

For this type of firing, the base of the rocket is covered with a paper drum-head so that the sparks do not ignite other rockets in the frame. Touch-papered rockets cannot, of course, be fixed in these frames. Sometimes the rockets are furnished with thin cappings and matched together for rapid firing.

Mass firing of small rockets is obtained by placing many rockets on to a board drilled with holes, or chicken wire covered with a sheet of paper, or simply in long rows. Each rocket has a piece of match in the vent and in each case ignition is obtained from one of the rockets which produces enough sparks to light the rest. Batteries of rockets of this type require some kind of cover lest they ignite prematurely owing to stray sparks from other items in the display. (Fig. 22.6)

Falling rocket sticks are a potential hazard, of course, but it is remark-

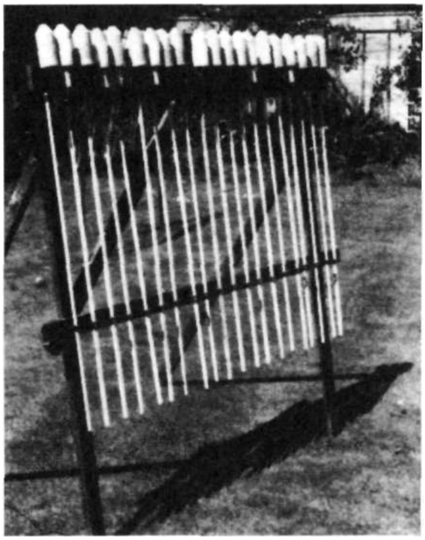


Fig. 22.5 Collapsible rocket frame

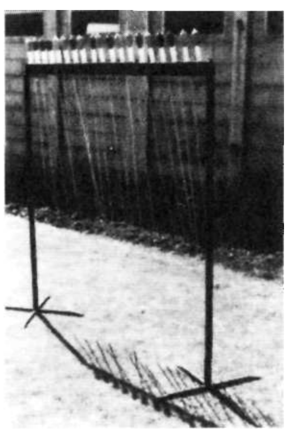


Fig. 22.6 Rockets arranged to fire in quick succession

able how few seem to cause any damage, particularly to people. It is also necessary to exercise some caution in firing parachute rockets, since chutes occasionally fail and drop burning flares to the ground.

Fire Pictures

Prior to the 1939-45 war lance-work was very much a feature of firework displays. Huge portraits of Kings and Queens 6 m X 9 m, Indian Palaces, Triumphal Arches were to be found, involving the use of thousands of lances and many more feet of match. The assembly of these items involved large quantities of timber, posts, ropes and pulleys as well as very many man hours. A whole day or more would be spent setting up these displays with rain clouds hovering menacingly above. Needless to say such displays are now most uncommon; four or five frames 3 m x 1-$^{1}/_{2}$ m is the most one would expect to see.

Lance-frames are usually a standard size of 3 m x 1-$^{1}/_{2}$ m in Britain, being made in 30 cm squares from light laths. The portrait or design is first drawn out on squared paper or graph paper and then reproduced exactly on the 3 by 1-$^{1}/_{2}$ frame using thick cane which is fastened to the frame with wire nails.

The next stage is to fix double pointed nails into the canework at 75 mm intervals. These nails are about 12 mm long and are allowed to project about 6 mm into the cane. (Fig. 22.7)

The unprimed ends of the lances are dipped in glue and then pushed on to the nails, where the glue sets sufficiently to hold the lances temporarily.

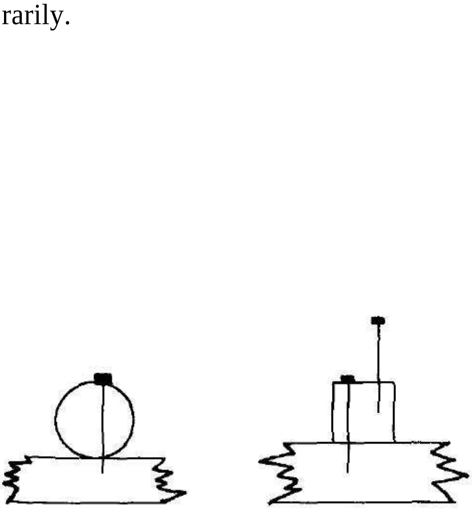


Fig. 22.7 Making lancework frames

Fig. 22.8 Lancework device

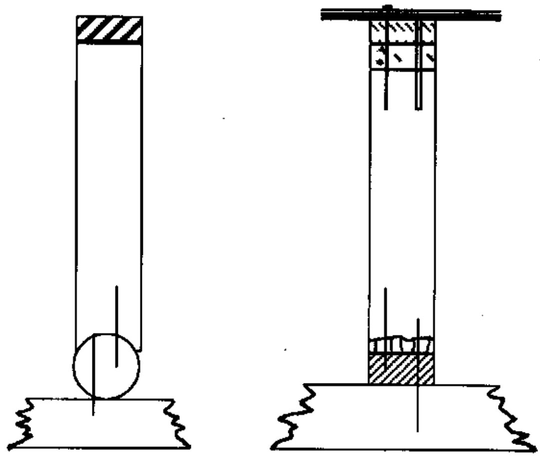


Fig. 22.9 Matching lances

Techniques for connecting the lances with piped match vary somewhat but are all more or less similar. The most laborious method uses a large pin to secure raw quickmatch to the lance. This is then covered between each lance with short lengths of piping which are slid along the match. Pasted paper strip is then used to cover the top of each lance. This method is ridiculously time-consuming but it does ensure that all the lances ignite. (Fig. 22.9)

An easier method is merely to lay piped match across the tops of the lances and drive a large pin through the pipe into the lance. A narrow staple is also used for this purpose but many ignitions have been caused by stapling guns. It is also fairly common practice to make an additional hole through the match pipe into the lance prime, to ensure the fire transfer from the match. The final operation is to cover the top of the lance and the match pipe with either pasted paper or adhesive tape. This operation helps to prevent the pins from being pulled out and is a protection from rain and stray sparks. The lancework can also be protected from rain with a solution of shellac or paraffin wax.

Fountains

Fierce burning fountains, or "Fix," are arranged on light timber to produce geometrical designs or "feux croisées". In situations where it is desirable for fires to touch or cross, the spread of the fire needs to be measured so that distances can be worked out. Saxons and small

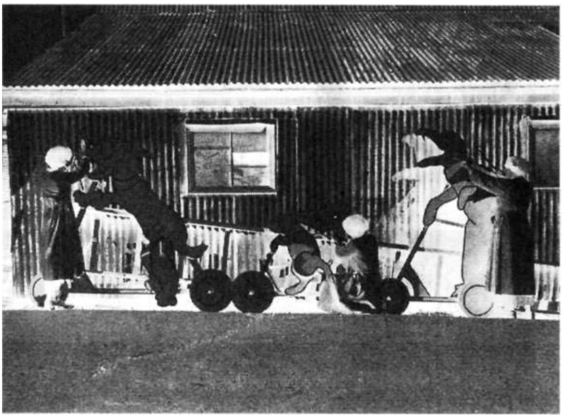


Fig. 22.10 Novelty Set Pieces. Early 20th Century. Brock's Fireworks.

wheels are invariably added to produce variety and movement. It is here where the greatest variations are to be found, each fireworker being able to devise his own pieces. The suggestions in Figs. 22.11, 22.12 and 22.13 are typical.

Wheels

Display wheels vary in size from 1/2 m, up to 5 m in diameter. The smaller wheels (up to about 1-$^{1}/_{2}$ m) are frequently made in the old fashioned manner with a heavy central boss, six spokes and a circular beech or ash hoop around the circumference.

Larger wheels are made so that they can be assembled on the site. In this case, the spokes slot into the boss in tapered sockets and are held in place by a smaller steel hoop and a number of bolts. (Fig. 22.14).

Many horizontal and vertical wheels are made from a long piece of timber with a hole drilled through the center to take the spindle upon which the timber revolves. (Fig. 22.15)

Vertical wheels are often fitted with color pots, whistles, gerbs and even waterfall cases, strings of lights or flash charges. (Fig. 22.16)

Drivers for wheels vary very much with the size and speed of turning. Small wheels about 1m in diameter use 18 mm drivers; up to 3 m take 24 mm drivers; 5 m wheels take large gerbs about 35 mm internal diameter and 25 cm long.

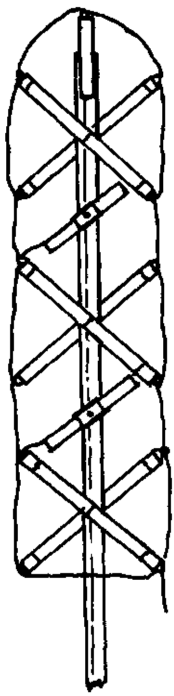


Fig. 22.11 Lattice pole before ignition

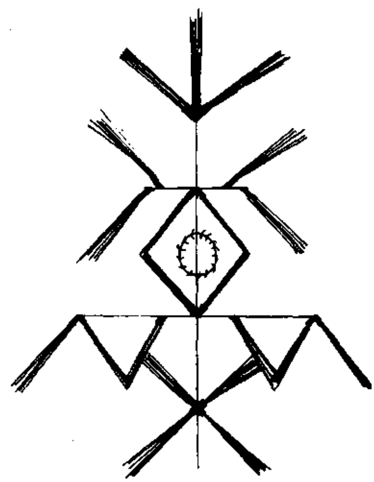


Fig. 22.12 Gerbs forming a tree piece

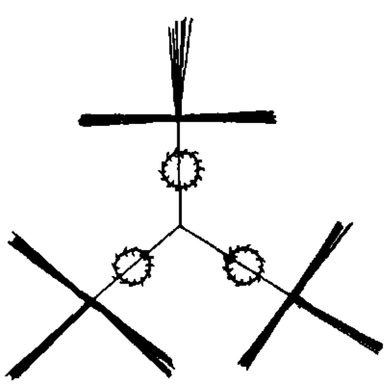


Fig. 22.13 Gerbs and saxons in geometric design

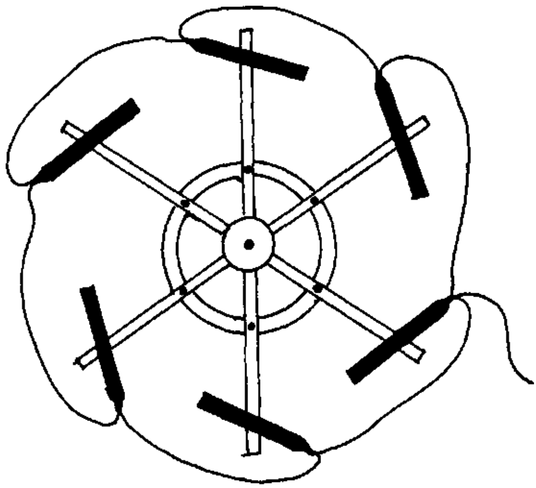


Fig. 22.14 Revolving sun

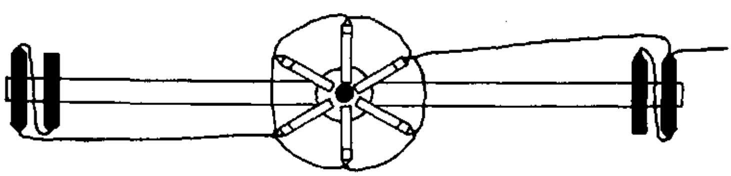


Fig. 22.15 Large vertical wheel

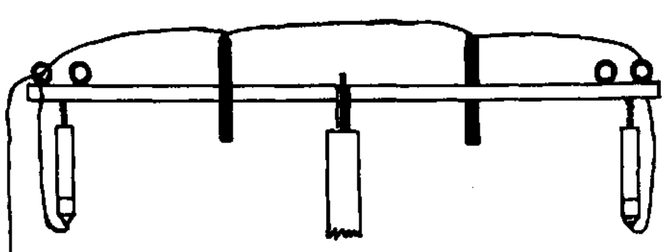


Fig. 22.16 Horizontal wheel

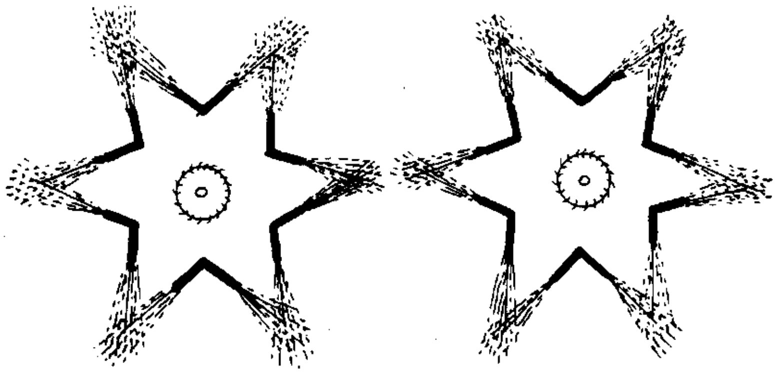


Fig. 22.17 Combination fronts

Combination Fronts

Very large spectacular effects are obtained by combining several identical pieces or a mixture of set pieces and wheels etc. (Fig. 22.17)

Battle scenes also use various combinations. Two ships in lancework, for example, can be made to fire streamer Roman Candle stars at each other to the accompaniment of roman candle whistles, flash charges, thunderflashes and crackers. The possibilities are quite endless.

23

MANUFACTURING PROCESSES FOR FIREWORK COMPOSITIONS JAPANESE FIREWORKS

Takeo Shimizu

These processes are generally very simple and once the manufacture of the most dangerous compositions have been mastered, it is easy to manufacture others which are safer. Compositions which contain potassium chlorate and red phosphorus, realgar, antimony trisulphide, or metal powder are the most dangerous. The best way is to use none of them, but we cannot always find safer compositions of the same character, and we often have no alternative but to use them.

We have two processes, wet and dry.

The *wet process* applies to compositions of high sensitivity, which do not explode in the wet state but explode when the moisture is removed by drying. An example of the wet process is as follows: A quantity of water is added to an oxidizer to make it wet. Then fuel is added to it and the whole is well-mixed into a paste, keeping the mass wet. Compositions of potassium chlorate and realgar, or potassium chlorate and red phosphorus are usually produced by this process. When the process is finished it must be used quickly by wrapping it in small pieces of paper, or some other method of separating the composition into small amounts, before it dries. The composition which is enveloped in each piece is left in the air so that it may dry gradually and gain its sensitive character.

It must be noted that the wet process does not apply to ingredients of high solubility or to ingredients which cause some chemical reaction or create acid in the water. We have had experiences of spontaneous explosions which are thought to have been brought about because the acid concentration became high enough to cause the explosion. Each component has a different solubility in water, and when the wet composition is left to stand for a while, some particles of the ingredients which are heavier than others sink to the bottom, and cause a lack of uniformity. An adequate amount of water and if necessary, gelatine, can be used to moderate the viscosity of the composition.

The minimum amount of water, which ensures safety during mixing, depends upon the composition, e.g. in a composition which contains red phosphorus and potassium chlorate 30 gms of water per 100 gms of the composition will not completely suppress its inflammability and explosive nature, in fact the amount of water should not be less than 50 gm. A water content as high as this makes the composition muddy. A composition, which contains potassium chlorate and realgar, sulphur or antimony trisulfide, explodes even when mixed with 20 gms of water per 100 gms of the composition, but becomes non-explosive with 30 gms of water per 100 gms, so in this case the operation is permissible with not less than 40 gms of water. Care must be taken during the operation that neither the rim of the container nor the operator's clothes are stained with the slurry, which can often dry and ignite without one being aware of it.

The *dry process* applies to compositions which are relatively safe to handle. Sieves are used to mix dried powdered ingredients and this does not change the component ratios like the wet process. (The wet process causes the oxidizer to ooze out of products thus changing the ratios of the components). First the ingredients are ground to a fine powder with a chemist's mortar, wooden roller or ball mill. It is one of the common rules to sieve each ingredient before mixing, so that the particle size is uniform and foreign substances are eliminated. A sieve made of hair is generally used for mixtures of relatively high danger like a potassium chlorate or barium chlorate composition, and for less dangerous compositions a sieve made of copper wires may be used. Apertures of 800-1000μ are usual for mixing sieves. Ingredients which agglomerate easily (for example potassium chlorate, barium nitrate, potassium nitrate, colophony) should be sieved just before the mixing process. (Potassium chlorate can now be purchased as a free flowing powder).

As an example we can cite here the mixing process of the composition H3, a name which comes from the percentage of hemp coal it contains (i.e. the ratio of hemp coal to potassium chlorate is 3:10).

H3 is sometimes used as a bursting charge for shells in Japan. This process also applies in the same way to other less dangerous compositions. A sheet of Kraft paper is laid on a work table. (A sheet of synthetic resin is not recommended for this purpose, because it is too soft to handle). The paper should be used only once and not used for other compositions, so it is best to use something like cheap cement bag paper. The prescribed amounts of potassium chlorate, hemp, coal, and glutinous rice powder are weighed onto the paper. The ratio of the three components is generally 10:3:0.3. A part of the hemp coal and all the rice powder are added to the potassium chlorate and it is well mixed by hand, and then it is passed through a hair sieve once. The potassium chlorate then becomes free flowing and can be mixed easily. The residue in the sieve should be left untouched, and not rubbed with the hands. The rest of the hemp coal is all mixed into the premixed potassium chlorate and allowed to pass through the hair sieve two to three times. In this case the residue in the sieve is also left untouched. The final residue which remains in the sieve after the mixing process is thrown away in a safe place. The finished composition is packed into a suitable container, with a label showing the kind of composition, the formula, the date of manufacture, the name of the worker, and is taken to an expense magazine. It is forbidden to leave explosive or inflammable products in the work room. The quantity of material which can be mixed at one time depends upon the composition. In the case of sensitive compositions it should be less than 5 kg. To correctly mix more than this amount by hand takes a longer time, and causes more danger. In place of hand mixing it is possible to use a V type or cylinder type mixer, but special care must be taken in charging or discharging its content.

In the case of black powder, even when the three components (potassium nitrate, sulphur and charcoal) are mixed together by the above process, the force of the powder is very small. In black powder production as an industrial explosive on a large scale, the three components are brought together by pressing or milling or by beating in a mortar. The manufacture of black powder in small amounts for fireworks is very dangerous, and the semi-wet process is much easier to handle. 7.5 kg of potassium nitrate and 2.5 kg of water are charged into an iron pan and heated to 100°C, stirring constantly. Hot water may also be used to heat the pan. Next the contents are taken out of the pan and charged into a mixer. 1.5 kg of hemp charcoal is then added and the two are mixed for an hour to soak the hemp coal into the potassium nitrate. This process is safe, because there is still some moisture in the mixture. Then the mixture is dried and charged into a ball mill, which is made of wood; an eight angle drum of 33 cm diameter and 35 cm in length. This is placed in a work room surrounded by defense walls. 1.0 kg of sulphur is added to the mixture and then about 100 glassy porcelain balls, each one being 33 mm in diameter and 30 gms in weight; these are charged into the drum which is driven for 24 hours. This three component mixing process serves two purposes, i.e. mixing and milling. It is a dangerous operation and not always to be recommended, but it has been used for a long time in my factory without an accident. The "three component" mixing room should be capable of bursting in one direction and the operator should not enter the room while the drum is revolving. The force of the black powder produced by the above process was compared with that of ordinary hand-mixed black powder by comparing their burning ratios in the atmosphere. If we take the value of the hand mixed powder as 1, then the value of the powder made by the above method in the wet state becomes 12, and "three component" dry mixing gives a value of 6. This proves the superiority of the semi-wet process described above. Never use a porcelain mortar or drum for mixing the three components, because it is very dangerous.

BURSTING CHARGE

The bursting charge is the powder which is charged into a shell to break it by means of an explosion. The purpose is to throw out and spread the contents of the shell, to ignite the contents and to give velocity to the stars. We have two kind of shells, the so-called "Warimono" and "Poka". Warimono is a chrysanthemum shell which needs a fairly large amount of strong bursting charge. It is capable of giving proper velocity to stars so that they form a round flower in the sky. Poka is an ordinary shell with a flag, willow or flare and which does not need so much or so strong a charge as Warimono.

The force of the charge for Poka should be enough only to break the shell, and the commercial black powder or powder made in the factory is generally used for the purpose. The powder is mixed with water to a paste and chaff is covered with the slurry.

The bursting charge for Warimono should have a large explosive force and proper burning rate. When the value for the burning rate is too large, the stars in the shell are destroyed or not ignited. On the contrary when the value of the burning rate is too low we cannot have a good radius of fire in the chrysanthemum.

Potassium Perchlorate Bursting Charge I	Weight (%)
Potassium Perchlorate	70
Hemp Coal	18
Sulphur	12
Soluble Glutinous Rice Starch	2 (Additional Percent)

This formula has already been used for over 20 years and no accident has happened. It is useful in practice and thought to be safer to handle than the potassium chlorate bursting charge. A 2 kg drop hammer test showed that the non explosive point is 37 cm. (In the case of picric acid: 23 cm) By Yamada's friction test apparatus, we obtained a non explosive weight of 75 kg (In the case of picric acid: 56 kg.) The burning rate of this composition in the atmosphere when it is pasted on cotton seeds is 1.0 mm/sec and is rather small. A calculated value of the force of explosion shows 0.71×10^6 dm. This value is twice that of black powder. The values of the heat of explosion, the specific volume (= the volume of the gas created by explosion measured at 0°C, 1 atm.) and the explosion temperature are 690 kcal/kg, 4801/kg and 3000°C respectively. The author proposes the use of the following formula, which is thought to be safer than the former because of the absence of sulphur.

Potassium Perchlorate Bursting Charge II	Weight (%)
Potassium Perchlorate	70
Hemp Coal	25
Lamp Black (Pine Black)	5
Potassium Bichromate	5 (Additional Percent)
Soluble Glutinous Rice Starch	2 (Additional Percent)

Generally it is better to use very fine charcoal to get a high burning rate, i.e. the finer the better. The force of explosion of the above formula seems to be somewhat smaller than that of the former. The values of the non-explosive point and the non-explosive weight, by the same test apparatus, are 60 cm and 75 kg respectively.

Potassium Chlorate Bursting Charge H3	Weight (%)
Potassium Chlorate	77
Hemp Coal	23
Soluble Glutinous Rice Starch	2 (Additional percent)

This is the famous old formula for the bursting charge H3, which is still widely used in Japan. The ratio of hemp coal to potassium chlorate is about 3:10, from which the name H3 comes. Compositions, which come into contact with this formula, increase its sensitivity when they contain sulphur, realgar, red phosphorus or antimony trisulphide, and we must pay close attention to this in production management. Compositions of this kind are thought to be the ones which most frequently cause accidents. Many fireworkers replace part of the potassium chlorate with potassium nitrate, but it is not always certain to be safe enough. The value of the non-explosive point obtained by a 2 kg drop hammer test was 50 cm. By Yamada's friction test apparatus we had the value of the non-explosive weight of 75 kg. The latter is the same as that of the potassium perchlorate charge. The value of the burning rate of this composition pasted on cotton seeds was 3 mm/sec, at 1 atm. This value is three times as large as that of the potassium perchlorate composition. The calculated values of the force of explosion, the heat of explosion, the specific volume and explosion temperature are 0.74×10^6 dm, 640 kcal/kg, 5701/kg and 3100°C respectively. This composition has been widely used because of its large explosive force and the simplicity of the manufacturing process. It must not be mixed with black powder, but as both compositions have the same black color care must be taken to take the right one.

Potassium-Nitrate Bursting Charge

The formula is no different from the normal formula for black powder (i.e. the weight ratio of potassium nitrate, charcoal and sulphur is 75:15 :10). As an adhesive 2% of glutinous rice starch is added to the total percentage. It is thought to be the safest composition with regard to friction and shock. The 2 kg drop hammer test showed the non-explosion point of 85 cm. The burning rate of grains made of cotton seeds, pasted with this composition, is about 2 mm/sec at 1 atm. This value is twice as large as that of the potassium perchlorate composition. In practice, in place of charcoal we use hemp coal which contains 10% moisture and 10% ash, and the pure coal remains as 80%. The counted value of the force of explosion is 0.3×10^6 dm, which is smaller than ordinary rifle powder. This is because a smaller volume of explosive gas is created. The values of the heat of explosion, the specific volume of the explosion gas and the explosion temperature are counted as 400 kcal/kg, 3701/kg and 1800°C respectively. This composition is extremely ignitable and has a large value for the burning rate, but its disadvantage is that the force of explosion is too small. It is used for relatively large shells.

To make the fire spread rapidly when the shell is ignited, the composition is pasted on to a nucleus. Cotton seeds, chaff or immature ears of rice are most frequently used as nuclei. With cotton seeds the ratio of the composition is 1:1.3—1.6 and in the case of chaff its ratio to the composition increases. In general the charge made of cotton seeds is used for relatively large shells which need only a small loading density, and that made of chaff is used for small shells which need a relatively high loading density. Sometimes these are mixed together. For example:

The Grains of Bursting Charge	Weight (%)
For Small Shells	
(less than 85mm. in diameter)	
Composition	80
Rice Chaff	20
For Intermediate Shells	
(from 125-175mm.)	
Composition	
(Potassium Perchlorate Bursting Charge)	52
Cotton Seeds	48
For Large Shells	
(from 200-300mm. in diameter)	
Composition	
(Potassium Perchlorate or Nitrate Bursting Charge)	52
Cotton Seeds	48

The composition is poured, with the nuclei and a suitable amount of water, into a vessel and stirred until the nuclei are covered with the composition. The grains produced in this manner are dried in the sun. The thickness of the pasted composition on the nuclei is irregular in the case of chaff but is 0.47-0.49 mm on average in the case of cotton seeds. More than this is not recommended because of its performance character as the bursting charge. Bursting charges which follow the above formulae show an apparent specific gravity of 0.48-0.50. The loading density of the bursting charge is counted, rejecting the nuclei which have values of 0.38-0.40 and 0.25-0.26, in the case of cotton seeds and chaff respectively. For example the amounts of the bursting charge used in shells, without nuclei according to the above specification are follows:

The Amounts of Bursting Charge for Chrysanthemum Shells

Diameter of the Shell (mm)	Amount of the Bursting Charge (grams)
89	44
125	70
150	140
178	290
215	400
240	940
315	1250

When cotton seeds and chaff are used as the nuclei they should be well dried beforehand.

Colored Flame Compositions

In general a colored flame composition consists of oxidizer, fuel and color-creating material. Some metal salts play the role of both oxidizer and color-creating material (e.g. barium nitrate, barium chlorate and strontium nitrate).

Oxidizers

When ammonium perchlorate is used as an oxidizer, it produces a relatively small amount of smoke in air with a low moisture content, because it creates very little solid material during burning. In moist air the burning gas produces small water particles and it creates a dense smoke cloud. Ammonium perchlorate gives the most clear and beautiful colored flame, when it is used with all the color-creating materials. For frame fireworks, ammonium perchlorate composition is recommended most if the cost will allow this. However, the contact of ammonium perchlorate composition with black powder or potassium nitrate creates ammonium nitrate, which is very hygroscopic and damages the fireworks. Ammonium perchlorate composition is very ignitable and generally requires no igniting composition.

Potassium perchlorate composition creates more smoke and less depth of color than ammonium perchlorate composition, but is more practicable. The fuel which is used to the best advantages in ammonium perchlorate compositions will not always give the same effect in potassium perchlorate compositions. When potassium chlorate is used as an oxidizer, the effect is not so different as that of potassium perchlorate, but the amount of smoke seems to be larger than the former and around the base of the flame, potassium chlorate creates a tubular ash, which disturbs the flame projection. For example in a lance, the flame does not come out of the end of the lance but branches out as it is diverted by the ash. The tubular ash also diminishes the light intensity of the flame.

The color of the flame depends upon the kind of oxidizer, even when we use the same fuel and color-creating material. For example an ammonium perchlorate composition with strontium carbonate as the color-creating material can give a very clear and deep flame, but with potassium perchlorate in place of ammonium perchlorate the flame looks reddish pink.

As for the fuel, it is advisable to use a material which gives no color to the flame, but such material cannot be obtained in practice, and we must be content with a material which gives as weak a color to the flame as possible.

Using ammonium perchlorate as the oxidizer, fuels were tested to discover which were least likely to disturb the flame color. The order of preference was as follows: shellac, wood meal, pine root pitch, amber powder, colophony, charcoal. Samples, 115 mm in length and 7 mm in diameter, each of which consists of a brown paper tube and 6 gm of a composition pressed in it to an apparent specific gravity of about 1.35, are ignited one by one at the end and their burning state is observed. The composition consists of 17% of a fuel and 83% of ammonium perchlorate, and contains no color-creating material so that the color disturbing effect of the fuels can be observed.

The result is summarized as follows:

Kind of Fuel	Flame Condition	Burning Rate (mm/sec)	Flame Length (mm)
Shellac	Weak reddish orange	1.51	90
Wood Meal	Weak reddish orange lines	1.27	60
Pine Root Pitch	Bright white	2.09	110
Amber Powder	Brilliant white at base	1.44	70
Colophony	Brilliant showing lines	1.46	100
Hemp Coal	Yellow and brilliant	2.80	90

For potassium perchlorate the most suitable fuel is pine root pitch, and then it should be arranged in order of merit as follows: Colophony, amber powder, hemp coal, wood meal. Shellac and potassium perchlorate burn with some difficulty. In the same manner as described above, with composition of 17% of a fuel and 73% of potassium perchlorate, we obtained results as follows:

Kind of Fuel	Flame Condition	Burning Rate (mm/sec)	Flame Length (mm)
Pine Root Pitch	Weak violet at the top and brilliant at the base	1.83	80
Colophony	Weak violet at the top and the rest white	1.24	50
Amber Powder	Accompanied by much white smoke	1.51	60
Hemp Coal	Yellow at the center and the rest reddish	4.80	—
Wood Meal	Violet white, burning with difficulty	0.69	20
Shellac	White, burning with difficulty	0.84	30

These compositions create much smoke. When we use wood meal or shellac with potassium perchlorate, we must also add other more combustible fuels.

When potassium chlorate is the oxidizer, pine root pitch is the most suitable fuel and shellac follows next. Colophony burns with difficulty. Amber powder gives a white flame and much smoke. The mixture of charcoal and potassium chlorate burns very rapidly and dangerously, and charcoal alone is seldom used as the fuel. Charcoal is generally used to adjust the burning rate of composition, to deepen the color of the flame, to increase its brilliancy or to be a supplementary fuel for some other purpose. The result of a test for compositions, in which 83% of potassium chlorate and 17% of a fuel are used as described above, is as follows:

Kind of Fuel	Flame Condition	Burning Rate (mm/sec)	Flame Length (mm)
Pine Root Pitch	Much smoke and violet flame	2.13	—
Shellac	Light violet, ash remains	1.20	80
Amber Powder	Much smoke, white flame	1.60	—
Colophony	No burning	2.26	—
Wood Meal	Violet flame, vibrational burning	2.26	30
	—	17.4	—

Hemp Coal (Charcoal)

Coal tar pitch disturbs the color of the flame remarkably and cannot be used as a fuel for colored flame compositions.

Color

Color creating materials have the following characteristics:

Red color creating materials: Strontium carbonate is one of the red color creating materials, and it gives the most beautiful red flame, but a high percentage in a composition causes the generation of very much smoke and creates burning difficulties. The effect of strontium oxalate is the same as strontium carbonate. Strontium nitrate gives a very beautiful red flame but it is a weakness of strontium nitrate that it is rather hygroscopic.

Yellow color creating materials'. Sodium oxalate gives a clear yellow color to the flame even in small amounts, but the color is somewhat reddish and not pure yellow. Borax gives almost pure yellow. Ultramarine leaves a residue on burning, and is not so commendable.

Green color creating materials'. Barium chlorate gives the deepest green, but creates much smoke when the amount is increased. This material resolves easily, and is not recommended. Barium nitrate cannot give the depth of color, but when we have a good formula and a high temperature it can give a green flame of practical use.

Blue color creating materials: Copper sulphate gives a good blue color to the flame in an ammonium perchlorate composition, and its effect is not inferior to that of Emerald Green (Paris Green). Copper sulphate powder is neither as fine nor as good as that of Paris Green. As a safety precaution it is forbidden to mix copper sulphate with potassium chlorate or other chlorates. Paris Green will give a good flame color with any kind of oxidizer. The only defect is that Paris Green is easily scattered in the air, and it is poisonous when workers inhale it. Copper arsenite shows almost the same character as Paris Green in handling and in coloring the flame.

As a cheap ingredient, calcium carbonate is sometimes used in place of other red color creating materials. In this case the flame is reddish orange and not so beautiful.

The colored flames for fireworks are founded on the useful band or line spectra, which are inherent in metal or metal compounds. But the color which appears to the eyes, depends upon not only the strength of the spectra caused by the color creating material, but also the following conditions: Every flame has background spectra, which depend upon the kinds of metal salts and fuels used in the composition. The flame temperature also has an influence upon the flame color. The paper tube, which contains the composition sometimes disturbs the coloring of the flames. The physiological condition of eyes, moisture, dust or mist in the air change the color of the flame. Note that an electric light which is white close-up looks reddish yellow at a distance of 1-2 kilometers. A green star, which looks light yellowish green at a short distance and appears to be useless, gives a deep and clear, beautiful green when we observe it at a distance of 50 meters. It is one of the general rules when designing the formula of a star composition that we must observe the burning star at a long distance.

The principle of designing colored flame compositions is as follows: First the oxidizer is selected according to the use (e.g. for stars, frame fireworks, flares) and then the color creating material and fuel which are suitable for the oxidizer. The flame color should be carefully chosen so that it is best for the purpose. The fuel should be carefully arranged to give the most adequate burning rate. To get a light of high intensity the flame temperature must be as high as possible, and the composition should be rich in oxygen content or should contain a metal fuel like magnesium powder. Chlorine gas in the flame deepens the color of the flame, especially when barium and copper salts (in the case of green or blue flame) are used as the color creating material. Potassium nitrate is not used generally as the oxidizer in colored flame composition, because it gives a low burning temperature which is insufficient to excite the coloring molecules or atoms in the flame. Ammonium perchlorate is not used in practice for shell stars because of its hygroscopic nature and difficulties in ignition at high velocity in the air. In the case of shell stars the composition may be allowed to create smoke to some extent and the flame is somewhat inferior in color, but should be well dried and not be hygroscopic. The compositions for frame fireworks should not create so much smoke and their tendency to absorb some water should not disturb their ignitability because they are not exposed to strong winds as shells are. Moreover they are loaded as powder, which is very ignitable.

When we solidify and form the composition into a certain shape for use, we must add some adequate solidifying material, a so-called "binder" to the composition. When water is used as a solvent, soluble glutinous rice starch is recommended, and shellac is used when alcohol is the solvent. If water is forbidden it may be possible to use linseed oil or other drying oil, and in this case care must be taken to disperse the heat of oxidation of the oil. Celluloid dissolved in amyl acetate can also be used as a binder. The amount of these binders should be as small as possible.

Colored flame compositions of practical use are shown as follows:

Colored Flame Compositions for Frame Fireworks (lances)	(%)
Red Flame:	
Ammonium Perchlorate	70
Strontium Carbonate	10
Wood Meal	20
Yellow Flame:	
Ammonium Perchlorate	75
Sodium Oxalate	5
Wood Meal	15
Colophony	5
Green Flame:	
Ammonium Perchlorate	50
Barium Nitrate	34
Wood Meal	8
Shellac	8
Blue Flame:	
Ammonium Perchlorate	70
Copper Sulphate	10
Wood Meal	10
Shellac	10
White Flame:	
Ammonium Perchlorate	40
Potassium Perchlorate	30
Antimony Trisulphide	14
Starch	11
Wood Meal	5

Each of these compositions is loaded in a thin brown paper tube of 9 mm in diameter with a density of 1.3-1.4 and so designed that the rate of burning should be 1.0-1.1 mm/sec. Generally when a powdered composition is pressed by hand into a paper tube and ignited at one end, the relation between the burning rate and the diameter of the tube differs with the type of composition, and the greater the diameter, the greater the burning rate below a diameter of 20 mm. For larger sizes than this limit, the burning surface becomes unsteady and causes flake dropping. When we take the burning rate at the diameter of 10 mm as the unit 1, the burning rate at a diameter of 20 mm reaches 1.7-3.0.

Color Flame Compositions for Stars	A Weight (%)	B Weight (%)
Red Flame:		
Potassium Perchlorate	67	54
Pine Root Pitch	13.5	—
Accaroid Resin	—	4
Magnesium/Aluminum Alloy (50/50)	—	14
Strontium Carbonate	13.5	10
Parlon	—	13
Soluble Glutinous Rice Starch	6	5
Green Flame:		
Potassium Perchlorate	46	10
Barium Nitrate	32	50
Pine Root Pitch	16	—
Accaroid Resin	—	7
Magnesium/Aluminum Alloy (50/50)	—	13
Parlon	—	15
Soluble Glutinous Rice Starch	6	5
Yellow Flame:		
Potassium Perchlorate	72	
Sodium Oxalate	7	
Pine Root Pitch	12	
Colophony	3	
Soluble Glutinous Rice Starch	6	
Blue Flame:		
Potassium Perchlorate	64	
Pine Root Pitch	13	
Paris Green	17	
Soluble Glutinous Rice Starch	6	

Red Flame A and Green Flame B produce a rather high temperature and a brilliant flame. These compositions can be consolidated using water, but dry the stars without heat to avoid cracks due to the reaction of the magnesium/aluminum alloy and water. In other compositions, when the pine root pitch is not available, accaroid resin can be used in place of it, the stars burn in this case rather slowly.

For stars used in chrysanthemum shells the design conditions depend especially upon the burning rate of the stars. Pine root pitch is used here to make the burning as fast as possible, and if there is another fuel which gives the same character, it is used in place of pine root pitch because the pitch is difficult to get. In order to obtain a good chrysanthemum, fuels must be chosen so that the compositions burn quickly without disturbing the flame color. The color of the green flame is not so good at a short distance, but is practicable from a long distance because of the physiological nature of the eye. If the relation of the

Table 23.1 Comparison Between the Burning Rates of Solidified and Pressed Compositions

	Solidified Star (mm/sec)		Pressed Star (mm/sec)	
	S.G.	B.R.	L.D.	B.R.
A Blue Star	1.6	1.79	1.47	1.70
A Green Star	1.64	1.18	1.60	1.52

(Here S. G. = Specific gravity; B. R. = burning rate; L. D. = Loading density)

burning rates between the solidified composition, which is made by the wet method, and that of pressed powder composition of the same formula were previously studied, it would be better to design the stars from the data of the pressed composition, which is easier to make. Insufficient study has been made hitherto, but a few examples are shown in Table 23.1.

Each of the solidified stars is a sphere of 12 mm in diameter, and the pressed stars are cylindrical using a paper tube 9 mm in diameter, into which the powder is pressed. The table shows that the relation between the burning rates of the solid and powdered state depends upon the kind of composition, and in practice the influence of the solidifying material (binder) must be considered. Studies of the burning rates of stars of different diameter but of the same composition have not yet been sufficiently made, but we know that the larger the diameter the larger the burning rate. A few examples are shown in Table 23.2.

In the case of the composition for shell stars (e.g. for color changing stars) there are many successive ignitions from one composition to

Table 23.2 The Relation Between the Diameter and Burning Rate of Spherical and Cylindrical Stars

	Spherical Stars (solidified)	
Diameter	18 mm	32 mm
A Blue Star	1.79 mm/sec	1.92 mm/sec
	Cylindrical Stars (pressed)	
Diameter	9 mm	21 mm
White Star	1.95 mm/sec	2.10 mm/sec
Yellow Star	1.15 mm/sec	3.00 mm/sec
Red Star	0.98 mm/sec	1.80 mm/sec
Blue Star	1.00 mm/sec	1.28 mm/sec
Green Star	1.04 mm/sec	1.60 mm/sec

another. For ignition without failure the amount of heat of burning, and the burning rate of the former layer and the specific heat of the latter layer, must be adequate. The star compositions for shells described above do not have very good ignition because of the potassium perchlorate, and the construction of stars requires some device to make them ignite easily.

Generally each of the colored flame compositions has a sufficient quantity of oxygen to oxidize the fuel it contains, and it burns progressively in the solidified or pressed state when it is ignited, but causes detonation when it is initiated with a percussion cap. We must pay close attention to this characteristic of color composition.

Fire dust spark composition

Colored flame is appreciated at both short and long distance, but the sparks described here, which are like fire dust, are admired at a long distance. The fire dust sparks are the phenomena caused by charcoal, metal and some ash which are projected at high temperature from a burning composition as unreacted matter, or newly formed matter, and make a second burning with oxygen in the air. This can be verified by burning the fire dust over a vessel of water when it will be possible to detect the unreacted or yet readable charcoal, metal or dust sparks must not contain enough oxygen to oxidize the fuel it contains. (Viz. the composition for fire dust sparks consists of a smaller amount of oxidizer and a larger amount of fuel than colored flame composition.)

The colored flame is admired for its spectra which is peculiar to the metal or the metal compound in the vapor phase. But in the case of fire dust sparks it is concerned with the temperature of solid or liquid particles. The color of the light emitted by a radiator changes according to its temperature, and in ordinary cases it follows thus:

500°C	dark red
700°C	red
850°C	orange
1000°C	yellow
1100°C	white

To obtain beautiful fire dust sparks it is necessary to adjust the combustion temperature of the composition.

Other problems arise, though, with fire dust stars. Are both the ignition characteristics and the separation of the fire, good or not? And generally, as regards appearances, the particle size of the dust, the density of the fire particles and the lifetime of the particles are the most important factors. When planning fire dust spark compositions we must have a clear knowledge of these conditions, but this has not yet been studied fully and systematically, and here we can describe only a few fragments, which have been made clear. In compositions of this kind we often see rather complicated formulas, but is seems that they depend upon the conditions described above and especially upon the regulation of the burning temperature of the compositions. Now we shall study the influence of the components upon the temperature of some simple compositions.

The character of the fire dust sparks caused by charcoal depends upon the formula, the character of the charcoal, and its particle size. It is impossible to adjust the color of the fire dust very much, for the color at best only lies between reddish orange and orange red. The composition of potassium nitrate, sulphur and charcoal, can produce the most beautiful fire dust sparks, but composition which does not contain potassium nitrate cannot succeed in producing such sparks. Charcoal, for example, with ammonium perchlorate, burns totally in the flame without discharging sparks. In the case of potassium chlorate it is the same as above, except that the burning reaction is more violent than the former. With potassium perchlorate it creates a few sparks, but most of the reaction finishes in the flame. Only in the case of potassium nitrate, where the flame is relatively small, can a large amount of fire dust sparks be produced from the flame. It seems that the potassium sulphide produced in the flame surrounds the particles of charcoal and disturbs the strong reaction in the flame. The smaller the particle size of the charcoal, the shorter will be the life of the fire dust sparks, and the phenomenon also depends upon the amount of sulphur and the kind of charcoal contained in the composition. Some examples of the formula are as follows. (These compositions are called "Tail" or "Chrysanthemum".)

	Weight (%)
Chrysanthemum 6.	
Potassium Nitrate	58
Sulphur	7
Pine Charcoal	35
Chrysanthemum 8.	
Potassium Nitrate	52
Sulphur	6
Pine Charcoal	42

The number six or eight means that the weight of pine charcoal is 6 or 8 relative to 10 parts of potassium nitrate. When a high velocity of burning or a large quantity of heat is required, Chrysanthemum 6 is used, and for the opposite requirement Chrysanthemum 8 is used. An intermediate composition or compositions outside this range are also used. To solidify the stars, soluble glutinous rice starch is added as a binder (The percentage is normally about 6%). To make a composition of very fine fire dust, which can produce sparks of high concentration, the above formula is prepared and charged into a wooden ball mill with porcelain balls and it is then driven for 24 hours. The life of the sparks is short in this case but they are very beautiful and elegant. When the composition has no sulphur, it is difficult to burn well, and the branching out of the fire dust is not good, for the stars keep the fire to themselves for a long time. This phenomenon produced by moving stars looks like the dawning of a weak fire dust band or tail in the sky, and it appears peculiarly elegant. Many fragments of the fire are seen to be falling down. This star is called "Chrysanthemum of Mystery":

	Weight (%)
Pine Charcoal	50
Potassium Nitrate	45
Soluble Glutionous Rice Starch	5

Sometimes 3-4% of Red lead oxide Pb_3O_4 is added to this composition. The purpose may be to use the special after reaction which is peculiar to minium, or to increase the weight of stars, but it seems that adding minium has little influence upon the fire dust sparks phenomenon. Other kinds of charcoal and other formulas are also used. A composition which contains black lampblack produces sparks with a reddish orange flame.

The defect of composition made of potassium nitrate, sulphur and charcoal is that it has less ability to ignite the next layer of the star than that of the colored flame compositions, because of the small calorific value and low burning temperature. This would be expected because of the lack of oxygen in the composition. Therefore when it is hard to ignite the second layer from the first layer, (which consists of a black powder type composition), it is necessary to put a new layer of a more easily ignitable and hot composition between the first and the second layers.

As a source of metal fire dust sparks, we usually use aluminum powder, and mix it with potassium chlorate, potassium perchlorate, potassium nitrate or barium nitrate, but from the stand point of ignition and safety, chlorate is not recommended. The sparks from these sources have a peculiar beauty. Sulphur, realgar, antimony trisulphide, charcoal are added to regulate the temperature of the sparks or to give good ignition to the stars.

Potassium nitrate and aluminum spark composition produce beautiful fire dust sparks which are reddish orange, gold or yellow white.

The so called "Fire Dust Branching" phenomenon occurs when a melted mass of high temperature branches out into fine fire dust by the action of air currents. To see this phenomenon it is important to test the burning star by projecting it in the sky. A star, which burns on the ground and generates very good sparks, does not give such a good effect in the sky, because the duration of the sparks looks too short. In the ground test it is seen that the melted ash after the burning reaction becomes a mass and has brightness without producing many sparks, though it creates good sparks in the air. On the other hand, it should be noted that the overmelted ash does not branch into much fire dust; in fact the duration the sparks becomes too long and the beauty diminishes. It is the same when potassium perchlorate is the oxidizer.

Falls	Weight (%)
Potassium Nitrate	41
Aluminum	49
Sulphur	4
Soluble Glutinous Rice Starch	6

A small amount of water is added to the composition and it is kneaded well; it is then pressed into a thin paper tube with a wooden or brass pounder. It is said generally that thorough kneading gives a long life to the sparks, but it does not always seem to be true. Coarse aluminum flake powder is good for making the sparks burn long enough, and sometimes we use aluminum foil flakes (flitter) in the falls composition. When the tube has been loaded with the composition it is dried in the sun. If it is noticed that the tubes are generating heat, they must be separated from each other in the shade to cool them. If a long time is taken to dry the tubes, the fire dust sparks will become somewhat reddish. The burning rate of a waterfall of 15 mm in diameter was 0.52 mm/sec. This falls composition can produce fire dust sparks of silver color which reach to the ground, hanging at a height of 3 meters. It is used for set fireworks "Falls."

Composition of this kind, which contains nitrate and aluminum and a small amount of water sometimes generates enough heat to catch fire, when it is left for a long time in the wet state. The heat comes from the reaction between nitrate and aluminum, which creates H_2, NH_3, NO or NO_2. To avoid accidents never leave the composition in the wet state. The addition of 1/2% boric acid usually prevents the composition from heating up.

Generally it is difficult to ignite stars, which consists of the two components, i.e. potassium nitrate and aluminum. When the amount of aluminum increases to 50%, it is impossible to ignite it by ordinary methods, but on the other hand the larger the amount of aluminum, the more beautiful are the sparks and we add other ingredients to the composition to get good ignition, even if it contains a large amount of aluminum. Sulphur is the most suitable ignition ingredient, but it seems to create trouble when stored for long periods. Next, in order of preference, antimony trisulphide or charcoal is recommended, but realgar is not so good for this purpose. The color of the fire dust sparks depends upon the burning temperature, and accordingly it is peculiar to the kind of fuel used. The following compositions are all of practical use, but note that they are difficult to ignite when they are made into stars, and it is necessary to cover the stars with an easily ignitable composition which is specially selected.

Golden Wave A	Weight (%)	
Potassium Nitrate	40	
Aluminum	50	
Antimony Trisulphide	10	
Soluble Glutinous Rice Starch	5	(Additional percent)
Golden Wave B		
Potassium Nitrate	40	
Aluminum	50	
Sulphur	10	
Soluble Glutinous Rice Starch	5	(Additional percent)
Golden Wave C		
Potassium Nitrate	40	
Aluminum	50	
Realgar	10	
Soluble Glutinous Rice Starch	5	(additional percent)

Compositions A and B produce very fine golden fire dust sparks. Composition C produces reddish golden sparks, which are of special elegance and different from the sparks of A and B. Potassium perchlorate and aluminum spark composition: The composition of potassium perchlorate and aluminum is more ignitable than the above potassium nitrate compositions, and it can be used without adding other fuel. We can increase the amount of aluminum to 75% without losing its ignitability, but when the amount of aluminum is over 65%, the fire dust branching is not so good. The practical compositions are as follows:

Silver Waves:	A Weight (%)	B Weight (%)	C Weight (%)	D Weight (%)
Potassium Perchlorate	50	45	40	35
Aluminum	50	55	60	65
Soluble Glutinous Rice Starch (Additional percent)	5	5	5	5

The amount of soluble glutinous rice starch in the formulas above is also suitable for pressed stars, and in round stars it should be 8-10% for ease of manufacture, but in this instance they are more difficult to ignite. The compositions which contain metal powder like golden waves or silver waves are less easily ignited than ordinary compositions for stars, and must be formed by means of a special process described later. (See page 384). Composition A appears with a short silver stream which has a short life in the air. As the composition changes its constitution from B to D the brilliancy of the stars gradually diminishes and the stream of the sparks becomes larger and longer.

Magnesium cannot produce such good fire dust sparks as aluminum, when it is used with potassium nitrate or potassium perchlorate, because magnesium is vaporized at the relatively low temperature of about 1100°C and burns completely without producing hot liquid or solid matter which can be projected out of the flame.

The phenomenon of the fire dust sparks is somewhat complicated, but by the application of the fundamentals described above it may be possible to plan various compositions for practical use.

Fire-Branching Sparks Composition

The so-called "Fire-Branching Sparks" is a phenomenon produced when liquid or solid matter of high temperature is projected into the air and explosively separates into many fire branches like a pine needle. It is therefore different from the fire dust spark described above, which does not branch explosively. This kind of spark is seen at short distances. There are two kinds of composition for the sparks: one contains charcoal and the other contains iron or magnesium powder. The former belongs to the toy fireworks "Senko Hanabi" and the latter to "Fountains" and "Sparklers", etc.

The spark composition using charcoal consists of potassium nitrate, sulphur and charcoal and belongs to the black powder type of composition, but the peculiar distinction from black powder is that the amount of charcoal is less than the amount of sulphur. The composition which produces good sparks contains 10-15% of charcoal. It seems that any kind of charcoal or soot, except crystalline carbon like graphite, can produce the pine needle-like sparks, but the finer the particles of carbon, the better the sparks. Accordingly pine soot is the best, followed by paulownia charcoal or hemp coal. Pine charcoal can also produce sparks, which are not so large as those of pine soot. A test showed that carbon black produces almost no sparks, though it does create, on rare occasions, very large ones. The examples of the formulas used in old times are shown as follows:

Senko Hanabi (Japanese Sparkler):

	A %	B %	C %	D %	E %
Potassium Nitrate	50	61	36	48	59
Sulphur	34	24	22	34	24
Pine Soot	—	15	7	12	14
Paulownia Charcoal	8	—	35	—	3
Pine Charcoal	8	—	—	6	—

In the author's laboratory the compositions were studied, by observing the sparks which are projected from the hot liquid drops produced by burning compositions, (of pine soot, potassium nitrate and sulphur) which are pressed in thin paper tubes. The results are shown with a triangular graph as in Fig. 23.1. The area with single shadow shows

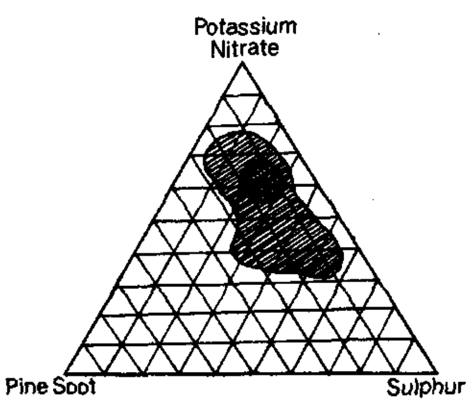


Fig. 23.1 Japanese sparkler compositions

the spark producing zone while the double shadow shows the zone with excellent sparks.

When we use other oxidizers in place of potassium nitrate, we do not get these pine needle-like sparks, which are peculiar to Senko Hanabi. Sulphur is replaceable by realgar, but other materials are unable to produce such sparks. Charcoal is not replaceable by other materials.

To manufacture Senko Hanabi (Japanese Sparkler) about 0.1 gm of the composition is twisted in a Japanese paper tape (20 cms. X 2.5 cms) or conglutinated on one end of a rush halm. When it is ignited, it burns violently with a flame at first; then the remaining ash keeping its red-hot state, contracts itself to a small red-hot ball, which is the so-called "Fire Ball". After a few seconds the temperature of the fireball gradually rises and fine particles begin to fly out of the ball. The particles become more brilliant at a short distance from the ball and explosively branch into pine needle-like sparks. The fire ball is red hot and is slightly transparent. The material in the ball moves around showing that it is reacting. As the reaction of the fire ball becomes gradually weaker, the sparks become like willow without branching and at last cease. The temperature of the fire ball measured by Dr. Nakaya and his colleague Sekiguchi is as follows:

Before projecting sparks	850°C
When the sparks are projected most actively	930°C
At the end of active spark projection	830°C

These data derive from the average of the values of ten measurements, respectively. The sparks projected from the fire ball consist of melted and reacting matter. The reaction of the fire ball is very active in oxygen, and ceases in nitrogen. When the fire ball is blown in a stream of air, the sparks become very active at once, and from these facts we know that a proper amount of oxygen is necessary to produce the sparks.

When we analyze the matter which makes a fire ball, we cannot find potassium nitrate in it. The main components are potassium sulphide, potassium sulphate and carbon. When we heat the potassium sulphide, which is separated from the fire ball matter (ash), to redness it melts, becomes a red hot ball and actively bubbles. In this case the red hot ball is covered with a thin smoke layer, which is thought to be sulphur dioxide from its smell. When the cooled and solidified fire ball matter is heated to red heat with the flame of an alcohol lamp, it becomes active again and produces sparks, but when it is inserted in the reducing part of the flame, the reaction, and accordingly the sparks, suddenly cease. It is thought that the chief components which cause the sparks may be potassium sulphide and carbon in the fire ball. If this is true, we can also artificially create the same phenomenon as Senko Hanabi, when we make a mixture of these two components, of an adequate ratio, and heat it. Accordingly, the following experiment was tried: 66% of potassium carbonate, 30% of sulphur and 4% of lamp soot (pine soot) was heated at a relatively low temperature in a porcelain crucible, being melted to make a mixture of potassium sulphide and carbon. A small amount of the product was fixed at an end of a nichrome wire and heated by the oxidizing flame of an alcohol lamp. As expected, the matter became a red hot fire ball in an active state and produced sparks which were the same as Senko Hanabi.

The mechanism of producing sparks from the fire ball is not yet known, and when we burn the Senko Hanabi, the fire ball is apt to fall down from the support, and the viscosity of the matter in the hot state needs also to be studied further.

Spark composition using metal: The fire branching of sparks is interesting where iron is concerned. Dr. Nakaya studied the iron sparks which are created by a grinder. In this case pure iron does not branch the sparks, but when the carbon content increases, the sparks branch twice or three times, but when the carbon content increases to more than 7%, the shape of the sparks does not change any more. Thus we can tell the amount of carbon in the iron by observing its sparks, when the carbon content is less than 7%. The iron sparks are very similar to those of Senko Hanabi.

When we use iron or magnesium powder as the ingredient for sparks, it must be coated with some resistant material to prevent it from rusting. For this purpose paraffin wax or a benzene solution of Japanese varnish etc. can be used. The examples of spark formulas are as follows:

Volcano	Weight (%)
Potassium Nitrate	55
Sulphur	9
Hemp Coal	13
Coated Iron Powder	23

This composition is pressed in a rather thick tube or cone with a fuse attached. It is ignited by the fuse, and produces sparks through the hole where the fuse is attached.

Fountain	Weight (%)
Ammonium Perchlorate	70
Coated Magnalium Powder	30

It is used in the same way as the Volcano. The coating of magnalium must be especially good; otherwise the life of the composition is very short.

Illuminant composition

A mixture of magnesium powder and barium nitrate is usually used as it produces the most intensive light, and for fireworks an aluminum and barium nitrate composition is also used. The color of the light is generally white, but in the case of the former it appears to be a whitish green. Magnalium is also sometimes used, but the composition sometimes burns so vibrationally, that it is not particularly recommended, though stars which burn vibrationally have been recently used to exhibit special beauty. When we use oxidizers other than barium nitrate or barium salts, the intensity of the light diminishes. Barium oxide in the flame has a strong molecular spectra and the condensed particles in the flame also emit a strong continuous spectrum. This is the reason why the light intensity of barium composition is high.

Magnesium Illuminant:	Weight (%)
Magnesium Powder Coated with 3% of Paraffin	50
Barium Nitrate	47
Linseed Oil	1.5
Caster Oil	1.5

This composition, which is pressed in a paper tube of about 10 cms in diameter by a hydraulic press to a density of 2.00 grams/cm^3, burns at a rate of 1.9 mm/sec, and the candle power of the light is 5000-7000 per square centimeter of the burning surface. To obtain a green light, the ingredients which produce chlorine or hydrogen chloride gas in the flame, (e.g. benzenehexachloride or vinyl chloride), are added to above formula. The amount of this ingredient should be 10-15%. This type of ingredient is also effective for the following blue and red colored flame compositions. To obtain other colored lights of high intensity, barium nitrate is replaced by potassium perchlorate, and a suitable color creating ingredient such as strontium carbonate for the red flame, sodium oxalate for the yellow flame or Paris Green for the blue flame is used. In the case of blue flame the amount of magnesium in the composition should be less than 20% to obtain good color. When we use ammonium perchlorate as the oxidizer the flame color tone is excellent, but the smallest amount of moisture will cause reaction between magnesium and ammonium perchlorate creating magnesium perchlorate which is very hygroscopic, and damages the composition. Accordingly, the composition which contains magnesium and ammonium perchlorate must be always kept in a perfectly dry state. Strontium nitrate behaves as an oxidizer as well as a color creating ingredient. It is not easy to store a composition which contains magnesium for long periods, and the pressed composition effloresces gradually on the surface which is in contact with air. To avoid this possibility the composition is pressed in a thin metal case or is packed with metal foil to protect the composition from moisture in the air. When we make stars with this kind of composition, water must not be used, only water-free organic solvents are permissible.

Aluminum Illuminant for Cores of Stars:	Weight (%)
Barium Nitrate	67
Aluminum	27
Soluble Glutinous Rice Starch	6

This composition is effectively used as cores of stars. When it is used as an ordinary illuminant pressed in a container, the starch is unnecessary. The stars of this composition must be covered with another composition of high ignitability. It is difficult to obtain a good colored flame with aluminum composition.

Sound Composition

There are two kinds of sound composition: report composition and whistle composition. The composition called "Thunder" belongs to the former. The explosive sound seems to be sharpened with the rate of explosion. The relation between the nature of the explosive sound and the rate of explosion is an interesting problem, which has not yet been made clear. The description of sound as "Round" or "Sharp" may have some relation to the rate of explosion which is peculiar to the composition. The report composition must not only have a rapid rate of explosion, but also be easily ignited with a fuse, so that the explosion can be produced easily. Generally this type of composition has a high sensitivity, and accidents occur frequently with sound composition. Lately, safer compositions which do not contain chlorate as the oxidizer, have become increasingly popular.

Potassium Perchlorate Report Composition

It is said that perchlorates are relatively safe to handle, but ammonium perchlorate is not suitable for report composition because of its hygro-

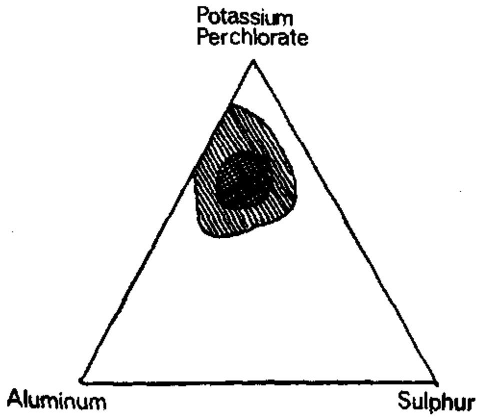


Fig. 23.2 Flash composition

scopic nature, and only the potassium salt is used. For the heat creating ingredient only aluminum is used. If we use ferrosilicon in place of aluminum the composition does not easily explode on ignition, and even if it explodes the sound is very small. It is necessary for the aluminum to be as pure as possible and in very fine powder. As the fuel sulphur or antimony trisulphide is used, there is almost no difference between them. Only when the material has to be kept for a long time would the latter be recommended. And if potassium chlorate is the oxidizer, it would be marginally safer to use antimony trisulphide rather than sulphur.

The intensity of the sound and the sound producing zone have been studied in a composition which consists of three components, potassium perchlorate, aluminum and sulphur, and the results are shown in the triangular diagram in Fig. 23.2. The shadowed part with single inclined parallel lines shows the zone in which the sound is produced, and the zone marked with crossed parallel lines shows the composition of the greatest sound. The sound zone is fairly wide. The amount of aluminum is generally increased as much as possible to obtain a strong flash. An example of the composition used is as follows:

Thunder No. 1:	Weight (%)
Potassium Perchlorate	50
Aluminum	23
Antimony Trisulphide	27

When we use sulphur in place of antimony trisulphide, the sound changes very little. In effect, it is necessary to select the most adaptable and economical composition in the sound creating zone for our purpose. This kind of composition does not explode but only burns when a small amount is ignited in a free state in the air. When the amount is large, the burning changes instantaneously to detonation. The limit of the amount is likely to be about 50-100 grams. Accordingly care must be taken not to accumulate large amounts of composition in the workroom, for the destructive power of the detonation caused by this composition is enormous. This kind of composition is not easily exploded by friction or shock.

When this composition is exploded by ignition with a fuse, the resistance provided by the container or the packing has a great influence. With increasing pressure the detonation limit of the amount of powder becomes smaller than would be the case in a free state (i.e. an unpacked state), and the time interval from the ignition to the detonation will be very much shortened. This is a very important characteristic of a powder, especially in the case of aluminum composition. A composition which contains ferro-silicon in place of aluminum is not as strong as aluminum composition. We must make the packing strong and ignition surface as wide as possible by attaching a small amount of black powder paste to the end of the fuse in order to obtain a good report.

The influence of the loading density on the sound is not so clear. From a test, changing the density from 0.5 to 1.2, it seemed that an increase in density gave an increase in sound. A loading density higher than this value will not always give a good result. Aluminum in fine powder gives a larger sound than when it is of large particle size, but in practice the influences of the particle size is very small compared with that of the strength of the container.

Potassium Chlorate Report Composition

The potassium perchlorate report composition which is described above is limited because a minimum quantity is required for detonation, and with less than this amount it cannot move to detonation from ignition. With a very small amount it is difficult to produce a report. Moreover its characteristically low sensitivity against shock and friction is sometimes a drawback for firework purposes. Potassium chlorate composition remedies the above defects, and although it is dangerous, we do still have occasion to use it.

Red Explosive Composition:	Weight (%)
Potassium chlorate	63
Realgar	37

This is called "Red Explosive Composition" because of its red color, and the formula above is an example of this kind. It is very sensitive to shock and friction, and very dangerous to handle, in fact to handle it safely it is recommended that the wet process be used. The sound produced by this composition gives a finer sound wave than potassium perchlorate composition, and is sharper than the latter. On the other hand the strength of the sound produced by this composition seems to be weaker than that of the potassium perchlorate composition. A very small amount of the red explosive composition can produce detonation. Actually it detonates perfectly even when the strength of the container is small, and even when the amount of the composition is very small. This composition is used for toy "Cracker Balls", etc.

Toy Pistol Cap:	Weight (%)
Potassium Chlorate	60
Red Phosphorus	8
Sulphur (or Antimony Trisulphide)	32

One example of this is shown above. This composition is more dangerous than the Red Explosive composition, and so sensitive to shock and friction, that it must be produced by the wet process. Red phosphorus must be free from white phosphorus and phosphoric acid. In place of sulphur, antimony trisulphide is also used without much change in the character of the composition. The composition of the above formula is used for toy pistol caps, but the one in which sulphur is replaced by antimony trisulphide is used for igniters because of its large flame.

Thunder No. 2	Weight (%)
Potassium Chlorate	43
Antimony Trisulphide	26
Aluminum	31

This formula looks like the potassium perchlorate composition, but this composition is more sensitive to shock and friction than the perchlorate composition. But it is used in Japan because of its low price, its low limit of the minimum amount for detonation, and its ease of detonation even in a rather weak container. It is sometimes called "Flash Thunder", the name which comes from the dazzling flash of light in contrast to the realgar composition which produces only a weak light. It is the same with perchlorate composition, and to obtain a strong flash the amount of aluminum is increased at the expense of the oxidizer, provided that it does not disturb the production of the report. In the above formula it is also possible to use sulphur in place of antimony trisulphide.

Potassium Picrate Whistle Composition

In the above instances the sound of the explosion is used as a report. But the following composition is totally different for it gives a sharp musical sound under special burning conditions.

Whistle No. 1	Weight (%)
Potassium Picrate	63
Potassium Nitrate	37

The sound is like and is called "Whistle."

The manufacture of potassium picrate: A wooden tub (30 liters) is prepared, and 20 liters of hot water is poured into it. Steam is used to bring the water to boiling point, and the steam pipe should be made of aluminum. While injecting the steam 2 kilograms of picric acid is added and completely dissolved. 600 gms of potassium carbonate is then charged, a little at a time. It reacts with effervescence, and part of the potassium picrate begins to form because of its low solubility. The end point of the reaction is determined by the sudden cessation of the bubbling. At this time the charging of potassium carbonate is stopped, and then picric acid is charged into the tub. The over-charged potassium carbonate reacts with effervescence and when the bubbling ceases, the process is finished. The liquid is slightly acidic, and the purpose of ending in the acid state is to be able to filter the liquid easily afterwards and to avoid giving a hygroscopic character to the product. The contents of the tub are removed into another aluminum tub, which is cooled from outside with cold water, the contents being stirred with a wooden stick. When it is cooled too slowly, it produces crystals which are too large, and it is inconveniently dangerous to pulverize them. Thus it must be cooled as quickly as possible to obtain very fine crystals. When the cooling process is finished, the contents are removed into a porcelain funnel, which contains a filter paper. The product is spread on a paper sheet and dried in the sun. The yield is about 104 parts of potassium picrate per 100 parts of picric acid by weight. Potassium picrate consists of yellow needle shaped crystals, which are rather difficult to dissolve in water. Its solubility in water is about 6 gms per liter at normal temperature. Potassium picrate is rather sensitive to shock and friction, but not high as that of Red Explosive Composition. Even when it contains a small amount of moisture, it explodes. The burning rate in the air in the free state is very fast, and great care must be taken when handling it. The picrate should only be prepared in small quantities when it is necessary. The manufacturing process is very simple, but some skill is required. Care must be taken that the abandoned mother liquor of the reaction does not pollute the effluent system.

The standard formula is given as Whistle No. 1. Less potassium nitrate causes an explosion and more produces no whistle. Potassium picrate and potassium nitrate are mixed by a hair sieve in accordance with the mixing process for dangerous compositions described above. This composition seems safer than potassium picrate alone, according to the results of the drop hammer test.

Gallic acid whistle composition and other whistle composition

The standard formula of the composition which contains gallic acid is as follows:

Whistle No. 2	Weight (%)
Gallic Acid	25
Potassium Chlorate	75

This composition is very sensitive to shock and friction. The degree of danger in handling it is almost the same as in that of Red Explosive Composition. The mixing process is the same as that of Whistle No. 1. When more than 15% of water is added to the composition, it becomes less sensitive.

As a safer composition, a mixture of salicylate of sodium and potassium perchlorate is recommended. The whistle is somewhat smaller than that of the above composition, and this composition must be protected from moisture, because it is very hygroscopic.

Whistle composition is generally pressed into a paper tube leaving a half of its length unloaded. It is very important to press the composition firmly to avoid an explosion when it is burning. The paper tube should therefore be inserted in a mold and the composition pressed in it several times with a hand press. This process should take place behind a defense plate. The composition is carried in a safe container in small amounts from another room to the workroom to avoid a large unexpected explosion. An example of the product is shown in Fig. 23.3. The paper tube should be made of dense material. The ratio of the diameter of the tube to the length should be less than 1:3, but when

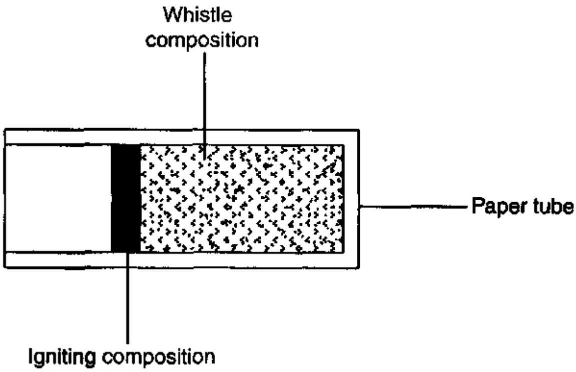


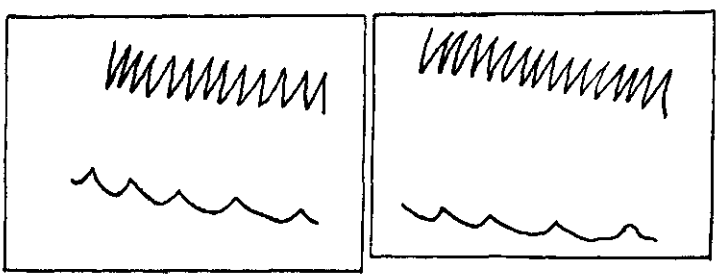
Fig. 23.3 Firework whistle

the tube is too long, it cannot produce a good effect, i.e. the larger the diameter, the louder the whistle and the tone decreases accordingly.

In the case of a very small tube of 3 mm in diameter the potassium picrate composition will not whistle, and only the gallic acid composition is usable. Fig. 23.4 shows the wave forms of whistle from Whistle No. 1 and Whistle No. 2. The frequency of both sounds is about 2600 per second.

Smoke Composition

Pyrotechnic smoke for practical use can easily be obtained from a simple smoke device without any special technique, and must be safe



a. Sound from Potassium Picrate composition (Whistle No. 1)

b. Sound from Gallic Acid composition (Whistle No. 2)

Fig. 23.4 Sounds

to handle. Here, only the smokes which are used for fireworks are discussed.

The processes are classified as follows:

1. The burning product grows to form a mist which absorbs the moisture from the atmosphere. For example the hexachloroethane smoke composition creates a vapor of zinc chloride or aluminum chloride, which becomes white smoke when it combines with moisture in the air. At present carbon tetrachloride smoke composition is seldom used.

2. The material is first vaporized by the heat of combustion and then condenses again to fine solid particles which create smoke. The white smoke caused by sulphur and yellow smoke caused by realgar belong to this type.

3. Smoke caused by incomplete combustion of a composition. This type of smoke is widely used as black smoke in fireworks. It utilizes the carbon particles created by the incomplete combustion of naphthalene or anthracene.

4. Colored smoke produced by vaporizing dye. A volatile dye is first vaporized and then it condenses the fine solid particles, which look like colored smoke. Generally this kind of smoke shows its own beautiful color by reflected light, but it looks dirty when the light is weak. In a cloudy sky it does not have a good color. Generally the color of the aqueous solution of dye from permeated light is the same as the color of cloudy solid particles in reflected light. Physically it is an interesting problem.

Hexachloroethane smoke composition.

This composition consists of three components, hexachloroethane, zinc and zinc oxide. The burning product of this composition is mainly the vapor of zinc chloride, and the temperature of the burning reaction may be about 900°C. The composition is generally contained in a completely moisture-proof can. The burning time of this composition is shown in Fig. 23.5 as an example, the dimensions of the smoke container were 80 mm in diameter and 114 mm in height.

The influence of the particle size of zinc oxide upon the burning rate of the composition is remarkable. Three kinds of the zinc oxide were used for a composition of 50% hexachloroethane, 28% zinc dust and 22% zinc oxide, and tested to give results, as follows:

Class of Zinc **Oxide**	**A**	**B**	**C**
Duration (sec)	227	267	347
Color	**greyish**	**greyish**	**pure white**

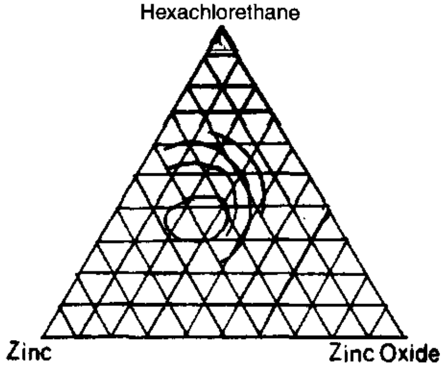


Fig. 23.5 Smoke composition

The quality of zinc oxide of class C is better than that of class A, and the quality of class B is better than that of class C. In short, the better the quality, the longer the duration. Zinc of good quality makes the color of the smoke pure white.

The quality of zinc dust and the particle size of hexachloroethane did not show such a marked influence upon the burning time. A particle size of hexachloroethane of less than 2 mm can be used successfully.

A mixture of zinc dust and hexachloroethane reacts violently, when water is added to it, drop by drop. It should be noted that this kind of smoke sometimes causes fire in the presence of moisture. This composition never explodes with shock or friction like other explosives. The so-called "Explosion of Smoke" seems to be the explosion of an aluminum composition, which is contained in the igniter for the smoke, or the explosive bursting of the tin by interior expansion, caused by the heat evolved when the water entered the tin.

Smoke composition is so completely sealed in a tin, that it must be specially designed to ignite without fail. Generally a brass cap, the thickness of which is less than 0.2 mm is soldered into the tin and a quantity of thermit is charged into it. An igniter star is inserted on the top as shown in Fig. 23.6. When the head of the igniter star is rubbed with a wooden striker, painted with a composition of red phosphorus and antimony trisulphide, ignition takes place. Next the thermit is ignited, generating a large amount of heat which melts the brass cap and the hot melted metal drips directly on the smoke composition, infallibly igniting it.

The manufacturing process for smoke composition is not dangerous, but care must be taken to reduce the moisture in the ingredients as far

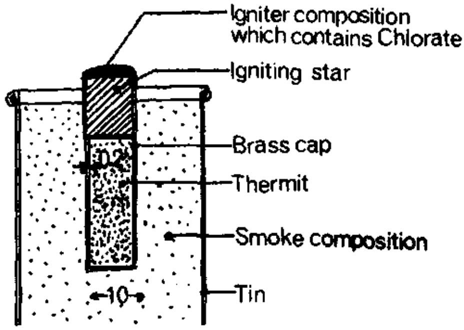


Fig. 23.6 Smoke cannister

as possible and frequently the temperature of the composition during mixing should be tested by hand or by some other method. During the mixing process the light zinc oxide is first charged into the mixer and the heavy zinc dust is charged last. When a rotary mixer is used, the number of revolutions per minute should be fewer than 20. It takes about 20 minutes to mix 100 kilograms of the composition. The volume of the mixer is designed so as to have $^2/3$ of the total volume empty with the volume of the charge occupying $^1/3$, the apparent specific gravity of the smoke composition being 1.1-1.5.

The composition is sealed in the tin with a canning machine, but it is rather different from the canning of food and more difficult especially with a large smoke. The mouth of a can must be an exact circle and must not be warped by the contents. The grove of the cap is filled with gum solution before the canning to keep it airtight.

There is another composition in which the zinc powder is replaced by aluminum powder. This composition creates greyish smoke and is not often used in Japan.

Sulphur Smoke Composition

The smoke is white and easy to generate, and this composition neither reacts with water nor is it hygroscopic. Therefore it is used widely in fireworks. The smoke consists of solid particles, and is not affected by the moisture in the air.

An amount of potassium nitrate and the same amount of sulphur are mixed well together, but a small amount of realgar is added so that it will ignite easily and to smoke smoothly.

Sulphur White Smoke	Weight (%)
Potassium Nitrate	48.5
Sulphur	48.5
Realgar	3.0

This composition is pressed firmly into a paper tube, both ends of which are sealed with gypsum, and a hole is bored into the composition on the side near to one end. A piece of quick match is inserted into the hole. When it is ignited white smoke issues through the hole. The hole must not be too large or else the smoke will burst into flame. This composition can also be used for white smoke stars, when it is mixed with soluble glutinous starch and shaped into cylindrical stars, each of which is covered with gypsum, and then a hole is bored into this gypsum for the smoke to come out. Care must be taken not to cause ignition during the drilling operation. A small amount of hemp coal is sometimes added to the composition for good ignition.

Realgar Smoke Composition

A composition which consists of potassium nitrate, sulphur and realgar can produce smoke of white, light yellow, deep yellow or purplish grey according to its formula. The yellow smoke is the most popular, and an example is as follows:

Realgar Yellow Smoke	Weight (%)
Potassium Nitrate	25
Sulphur	16
Realgar	59

In this formula the percentage of sulphur is rather small. The method of generating smoke is the same as that described in (2). The moisture in the composition seems to have a little influence upon the burning rate of this composition. In the case of smoke stars for shells, which are used for willow or chrysanthemum, the sulphur is increased much more to make the burning time shorter. For this purpose an amount of sand is sometimes added to the composition, or the stars are covered with gypsum so that they burn quickly under pressure as described in (2). An example of the formula for stars used in a willow shell is as follows:

Yellow Willow	Weight (%)
Potassium Nitrate	43
Sulphur	10
Realgar	37
Hemp Coal	4
Soluble Glutinous Rice Starch	6

The following composition is used for daylight shells. The smoke looks white, this may be only a smoke from a burning process, and it may differ from the smoke generators mentioned above.

White Chrysanthemum	Weight (%)
Potassium Nitrate	66
Realgar	13
Lamp black	5
Hemp Coal	5
Soluble Glutinous Rice Starch	11

The volume of the lamp black is so large that a little amount of starch is used as the binder. The distinguishing feature of this formula is that it has no sulphur.

Anthracene or naphthalene smoke composition

When a carbon rich compound like anthracene or naphthalene mixed with some oxidizer is burnt, it creates carbon particles due to incomplete burning. (If the amount of oxidizer is too large, a good smoke is not produced).

For example:

Anthracene Black Smoke I	Weight (%)
Potassium Perchlorate	56
Sulphur	11
Anthracene	33

This composition is filled, pressed into a tin and ignited through a small hole. When a flame blows out of it, a thick black smoke is generated from the flame. This composition is different from the other, because the flame appears first and then generates smoke from it. (In many other types the production of flame generally disturbs the smoke). The temperature of the flame may be about 800°C. This smoke is adaptable for a black "Dragon" with a parachute, but this composition is a little difficult to ignite and burning is only stabilized under pressure which is maintained by the smoke case. It is not easy to ignite this composition, even when it is in a powered state, and a special method must be applied, e.g. using thermit. The composition is safer to handle than the following composition, Naphthalene Black Smoke I, and care must be taken because of its explosive nature.

Naphthalene Black Smoke I:	Weight (%)
Potassium Chlorate	44
Antimony Trisulphide	24
Naphthalene	26
Soluble Glutinous Rice Starch	6

This composition is used to make stars which produce a beautiful black smoke, but it is also more explosive than Anthracene Black Smoke I. Naphthalene sublimes out of the star when it stands for a long time leaving behind potassium chlorate and antimony trisulphide which increases its explosive nature. In spite of this disadvantage it is still used widely in Japan, because it is the most beautiful of all black smokes, but it is better not to use this composition, if possible.

Naphthalene (Anthracene) Black Smoke II:	Weight (%)
Hexachloroethane	62
Magnesium	15
Naphthalene (or Anthracene)	23

This composition has no oxidizer. The hexachloroethane and magnesium react with each other producing a smoke of magnesium chloride, and the heat developed causes the isolation of carbon particles from the naphthalene, thus making the color of the smoke black. This composition is loaded into a tin and used as a signal.

Naphthalene (Anthracene) Black Smoke II.	Weight (%)
Potassium Perchlorate	57
Anthracene	40
Hemp Coal	3
Soluble Glutinous Rice Starch	7 (additional percent)

This composition is a modification of the composition Anthracene Black Smoke I for stars, but it is more ignitable.

Colored Smoke Composition with Dyestuffs

Dye smokes show their natural color by reflected light. The adjustment of color is achieved by the same principle as that of mixing dyestuffs for printing. A colored smoke composition consists of dyes, a small amount of oxidizer and some kind of carbohydrate, which adjusts the burning temperature. The composition is pressed into a case or is made into smoke stars, adding a binder (e.g. glutinous rice starch). Potassium chlorate is used as the oxidizer. To adjust the temperature and provide a fuel, starch or wheat flour is used. Sugar, or milk sugar, creates very beautiful colored smoke, but it is not widely used in Japan because of the rather high cost.

Dextrin is also a good ingredient for this purpose. The creation of flame disturbs the generation of smoke, and so the smoke must issue out of a small hole in the container after being rapidly cooled, or, in the case of stars, they must be projected rapidly through the air to extinguish the flame. The burning temperature of this type of smoke composition is about 400 to 600°C, and some part of the dye may be damaged at this temperature. If the temperature rises to a higher level than this during the burning process, the smoke becomes colorless. A few examples of formulas for colored smoke compositions are shown as follows:

	Weight (%)
Red Smoke:	
Potassium Chlorate	25
Rhodamine B	24
Para Red	36
Wheat Flour	15
Blue Smoke:	
Potassium Chlorate	28
Methylene Blue	17
Indigo Pure	40
Wheat Flour	15
Green Smoke:	
Potassium Chlorate	28
Auramine	10
Methylene Blue	17
Indigo Pure	30
Wheat Flour	15
Violet Smoke:	
Potassium Chlorate	26
Indigo Pure	22
Rhodamine B	16
Para Red	21
Wheat Flour	15

In the case of Red Smoke if the amount of Rhodamine B is increased, the smoke becomes reddish violet and, when decreased, it becomes orange red. In the case of Green Smoke, Auramine is somewhat hygroscopic, and it is better to protect the composition from moisture.

To increase the burning rate of smokes some people often add sulphur to the composition, but it is not recommended in view of the increased sensitivity. To increase the burning rate, it is better to widen the burning surface by granulating the composition with the smallest sized grains determining the burning time.

Potassium nitrate and potassium perchlorate are not such good oxidizers as potassium chlorate, because they cannot create colored smoke as smoothly as potassium chlorate and the percentage in the composition must be greater than that of potassium chlorate. Other heat producing materials such as celluloid and nitrocellulose are also used in place of oxidizer and fuel, but the ratio of the amount of this material to the amount of dye must be increased more than the ratio in the above formulas, and the volume of the smoke decreases accordingly. Guanidine nitrate is also used as a low temperature burning material and is combined with other heat producing materials, e.g. celluloid, nitrocellulose, to protect the dye from the heat and to keep the ash porous. For example a mixture of 40% guanidine nitrate, 35% celluloid powder and 25% dye makes as good colored smoke except in the case of a dye with a high sublimation point like indigo. This principle is also applied to insecticidal smoke. Nevertheless, the method of using heat producing materials in place of oxidizer and fuel is not so adaptable for fireworks because of the rather thin smoke, but it is recommended for some large signals of long duration.

Powder Pasted Paper

Powder pasted paper is made of Japanese paper with some kind of composition pasted on it, and is used widely as fuse and igniting material. The paper, on which colored flame composition is pasted, is used especially for the shell "Falling Leaves".

The kind of the composition for powder pasted paper depends on its use, and it must be selected according to the purpose.

Black powder pasted paper: 4 parts of black powder is mixed with 3 parts of water in weight ratio. In winter potassium nitrate easily oozes out of the pasted black powder, and we must reduce this escape by heating it with some safe form of heat. Sometimes soluble glutinous rice starch is added to the paste to give it adhesive power, but when we use grains of gunpowder which are manufactured by milling, the adhesive power is so great, that there is no need to add starch to the paste. Newspapers are fixed on a work table as a protective cover and Japanese "Kozo" papers are spread out on them. Then the black powder paste is pasted on them uniformly with a brush of good quality. The pasted paper should be dried on a drying frame in the sun, and for manufacture a bright, clear and calm day must be chosen. Generally infra-red driers or other heat sources do not give such a good result as the sun because of the lack of uniformity in drying. When pasting, the powder paste must be stirred well, continuously, to prevent the components separating from each other. The quantity of the composition pasted on one side of the paper is 0.01-0.02 gm/cm^2 for fuse, 0.01 gm/cm^2 for ordinary use and 0.02 gm/cm^2 for special ignition material. The thickness of the powder pasted with the quantity 0.02 gm/cm^2 is rather large, and to obtain such a thickness it must be pasted on one side two or three times. For use as a fuse, paper pasted on both sides is generally used, but for other purposes paper pasted on one side is used. Test pieces (10 mm in width) taken from a thick paper, pasted on both sides with gunpowder, showed the burning rate of 1.7 cm/sec in the atmosphere.

Red Thermit Paper: A composition of red lead oxide, ($Pb_3 O_4$) and ferro-silicon, (e.g. in a ratio 4:1) called "Red Thermit", is mixed to a paste with 5% celluloid solution in amyl acetate. It is pasted on a Japanese "Kozo" paper like the black powder pasted paper. It is preferable to dry it in the sun for the use a drier is sometimes dangerous, because the vaporized gas of amyl acetate may come into contact with an overheated part of the drier and cause an explosion. Thermit paper is easily ignited by friction, and care must be taken in handling it. This paper can be effectively used for igniting smoke compositions which are difficult to ignite. In this case the thermit paper is used together with a black powder paper, one on top of the other, or sometimes by pasting red thermit on a black powder pasted paper. To adjust the burning rate of the paper the ratio of the amount of minium to ferrosilicon can be changed. When the value of the ratio is decreased the burning rate is delayed.

Colored fire paper This is manufactured the same way as black powder pasted paper using a colored flame composition which is used for stars. Sometimes, immediately after pasting the composition on the paper, the pasted composition is covered with another paper to hold the composition well between the two papers. When it is necessary, it is manufactured in several layers like a sandwich, and is used as a part of the shell "Falling Leaves".

Potassium Nitrate paper: A solution of potassium nitrate in water is spread on a Japanese paper and dried. This paper is used for igniting or for helping the ignition of some fireworks. If letters or pictures are drawn with the solution on paper, they disappear when it is dried, but when it is ignited at one point of the painted part, the fire runs only on the drawn line, and the original letters or pictures appear again, this is used as a toy. Hidden pictures can be made also with other oxidizers.

Powder pasted papers often produce fire when they are cut and are very dangerous, and the cutting of a number of multifold powder pasted papers at one time should be forbidden. Be sure to cut them in small quantities with a sharp knife and don't leave the cut pieces near the cutter during the operation, i.e. the pieces should be quickly removed from the cutter and the cutting place, and they must be kept in an incombustible container which must be covered with a lid. The process is successfully operated by two workers working together. There are examples of accidents caused by cutting black powder pasted paper, and the author has had an experience of fire when cutting red thermit papers.

Fuses: The purpose of the delay fuse for fireworks is to transfer fire and to ensure a time delay. It differs somewhat from industrial fuse.

Handmade fuse: Powder pasted paper, which is pasted with black powder on both sides, is cut to size (250 mm X 75 mm). A quantity of gunpowder powder is prepared, crushing the grains which are moistened first. The paper is then sprinkled with the powder uniformly. A long and slender bamboo stick (3 mm in diameter) is placed on one edge of the longer side of the paper and the paper is rolled on it by hand. This rolled powder pasted paper becomes the core of the fuse. A Japanese "Kozo" paper (360 mm X 270 mm) is attached with its one shorter side edge on the rolled core paper and rolled on it, so that the paper winds the core as a cover. It is rolled on a wooden work plate with both hands until it is firmly wound, and then the bamboo stick is pulled out and removed. The first securing operation is applied to this prewound paper as follows: after being put on a thick hard wooden workplate, it is pressed and rolled repeatedly with another wooden plate (450 mm X 90 mm X 32 mm), which is held in both hands. In this case care must be taken for heat is sometimes generated. At last the paper is firmly wound like a stick, or a pencil with a thick lead. With the hand pressure of an average man it is necessary to repeat the rolling about 100 times with the rolling plate. Another Japanese "Kozo" paper of the same size is wound again on the rolled stick as before, so as to reinforce the cover of the core. The starting end of the paper is fixed on the stick with paste. The same rolling process is done as a second securing operation. Then the third securing operation is applied the same way as the second. At last the end of the paper is fixed on the stick with paste and the product is dried in the sun. Fuse made by this process is 6.5 mm in diameter and its core of black powder is 3.5 mm in diameter. The burning rate of this fuse is about 1.08-1.25 mm/sec, and the deviation is rather wide. When the firework shell explodes in the neighborhood of the highest point of the trajectory, a deviation of such a degree may be allowed because the shell travels slowly when higher. When a hand rolled fuse is compared with an industrial fuse, the ignitability and ignition power of the former are better than that of the latter: the former can produce a longer flame than the latter, and on chopping or peeling, the former can hold its powder core intact, and this character enables us to enlarge the ignition power and ignitability, which we cannot do with industrial fuse. Nevertheless the former is handmade, expensive and has rather large time deviations. It is therefore preferable to use a machine-made fuse, but it must be specially made, e.g. the cover of the core powder must be free from tarry matter, because the core powder sometimes absorbs the tar from the tarred covering material and it makes the fuse unignitable.

Fuse made by the process described above is a normal one, and for 250 and 300 mm shells or even larger shells the diameter of the core and the thickness of the cover are further enlarged.

The process described above is for the main fuses of firework shells, but for other uses it may be simplified. As a powder core only the powder of gunpowder is used instead of powder pasted paper. The manufacturing process process in this case may be very simple.

Hand rolled fuse made in the way described above, has rather wide variations and care must be taken in the way fuse is selected for timed fireworks. For example, the shell"Five Reports" requires five accurate time intervals and so all five pieces of fuse must be cut from the same length, and care must be taken to separate different batches of fuse.

"Dark Fuse" which creates no visible sparks in the distance during burning is also made by the same process except that other core compositions are used, e.g.:

Dark Fuse	A Weight (%)	B Weight (%)
Potassium Nitrate	36	56
Realgar	45	34
Paulownia Charcoal	10	10
Sulphur	9	—

Fuse which contains realgar must not make direct contact with chlorate composition.

Fuse for toy fireworks: The fuse must be easy to ignite with a match; it must be easily ignited by a flame and not have a thick cover. In Japan a twist of paper which contains black powder is widely used because of its cheapness. Potassium nitrate paper is effectively used in this case.

Stars

Stars may be divided into two broad classes: one group consists of light stars and the other of smoke stars. Stars for night use belong to the former and stars for daylight use belong to the latter. But there are exceptions: a special intensive-light star sometimes used in daylight, and a smoke star which is sometimes used at night, being illuminated by other light stars to give a special mysterious effect.

Furthermore, stars are divided into other classes by form (i.e. cubic stars, round stars and cylindrical stars), the manufacturing processes being different from each other.

Binder for star compositions: In general stars are formed out of some colored fire or smoke composition, in which a quantity of binder is mixed. In this case water or other suitable solvent is added to it. It is also possible to form the composition in a dry state by pressing, without the binder, but pressing influences the property of the stars, and in practice the pressing process is laborious and troublesome. The weakness of the star making process using a binder is that after the stars are formed they must be dried, warmed or given an aging time. However this method can be applied to various kinds of compositions, requires no special forming machine and is not so laborious. There are two kinds of binders, water soluble and those insoluble in water. In Japan the former is generally used and the latter is used only in special stars in which water is impossible. In order to dry stars in a short time a water insoluble binder with volatile solvent is sometimes used.

Soluble glutinous rice starch is mostly used as a water soluble binder in Japan, and it can be mixed in a composition as a powder. Composition which contains this starch becomes a paste when we add water only to the composition and knead it by hand. The process of the pasting is simple and the starch contains no acidic matter, so it can be safely used. The amount of the starch in a composition should be small, just enough to solidify the stars. When there is too much starch, it makes stars unignitable or lowers their burning temperature. Generally the starch unfavorably influences the burning characteristics of the stars. The amount of starch required for solidifying the stars is not fixed definitely, but varies according to the kind of composition. For a black powder type spark composition or colored flame composition the amount is 2-6%, and for aluminum composition it is necessary to increase the amount to 7-10%. Round stars containing aluminum are especially difficult to form when the amount of starch is too small.

Gum Arabic and dextrine are also soluble in water, but the viscosity of the solutions is so low, that it cannot be compared with that of glutinous rice starch. For example when 20% solutions (20 grams of the matter in 100 cc. of water) are compared, Gum Arabic or dextrine makes a solution of comparatively low viscosity, but glutinous rice starch is gelled without any fluidity. The nature of glutinous rice starch enables us to solidify star compositions with the smallest amount of extra matter, and in Japan the starch is mostly used for forming stars under the name "Mizinko", with little use being made of Gum Arabic or dextrine.

By an old process, in place of glutinous rice starch ordinary rice starch is used as follows: The rice is first boiled to a paste, and then mixed well with the composition. Then the pasted composition is dried and ground to powder in a mill. This powder can be made into stars by kneading it with a quantity of water. It is said that ordinary rice starch gives a smaller amount of ash than glutinous rice starch, but the author has not been able to find such a difference. The residual ash after a star is burnt, can be produced not only by the binder, but also by the other components.

As a water insoluble binder a solution of shellac in alcohol is recommended. Shellac as a binder is used for relatively large stars, e.g. of 20-30 mm or more in diameter, and it would take about four days to dry stars of about 40 mm in diameter. When the stars contain hygroscopic materials, absolute alcohol is used. The amount of shellac which is necessary as a binder is roughly 5% or more of the composition.

Other kinds of binders such as a solution of celluloid in amyl acetate or collodion can be used, and the drying time is very short in this case. Linseed oil may also be used, and in this case the composition may be solidified without drying, but care must be taken that the oil does not damage the ignitability of stars. This method is not used in Japan except in special cases. Plastic binders are not used widely in Japan because of the manufacturing problems. The poisonous vapor, the heat of polymerization which sometimes causes fire, and the adhesion of the material to the container prevent its application in our firework processes.

Light stars: The manufacturing process, using soluble glutinous rice starch as the binder, takes place in the following way:

Cubic stars: An amount of composition with the binder "Mizinko" is placed in a bowl and a measured amount of water is poured into it. When the quantity of water is too great, it is difficult to cut the kneaded mass because the compositions sticks to the tools, and when the amount is too small, the composition cannot be solidified because there is insufficient adhesion. It is better in fact to work out before manufacture the amount of water required for each composition or to use the following method: A small part of the composition is taken out, and an amount of water is added to the remainder of the composition which is then kneaded into a paste. The former part of the composition is then added in small quantities, kneading and adjusting the viscosity at the same time. When the kneading is insufficient, the composition is not uniform and creates a lot of cinder with a lid so that it does not dry out. The tools for cutting the kneaded composition are prepared as in Fig. 23.7.

First a thick wooden chopping-board (30 cm X 60 cm X 3 cm) is prepared and around its edges are four thin, long, wooden edge-plates, the thickness of which is the same as that of the cubic stars, the edge-plates are fixed with small nails or brass screws. The kneaded composition is then placed on the chopping-board between the edge-plates, pressing with the fingers, so that the surface of the pressed composition is little higher than the edge-plate. Using a wooden hammer the surface of the composition is patted until it becomes as high as the edge-plates, and then a thin, long knife is pushed on and along the edge-plates from one side of the chopping-board to the other, removing the excess composition. The four edge-plates are then removed, so that a sheet of composition of uniform thickness remains on the board. The sheet is

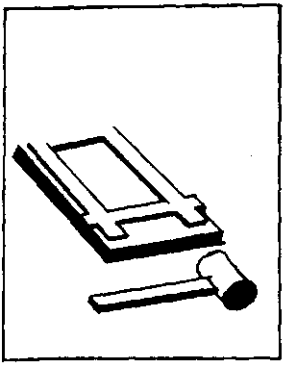


Fig. 23.7 Star making tools

cut checkerwise into squares as follows: First the sheet of the composition is sprinkled with powder of the same thickness as the sheet of composition, thus producing a row of several exactly square, sticks of the composition. Each stick is rolled 90°, so that the new surface produced by cutting is uppermost, and the old surface on which the composition powder was sprinkled is at the side, to prevent the sticks from adhering to each other. The cut pieces are removed to the other side, by sliding them along the board as they are cut, to produce a row of parallel strips. The strips are brought together and turned 90° so that they are in close formation. These pieces are cut with the knife at right angles to the strips, the same width as the thickness of each strip. Thus we have regular cubes of composition. The cubes are removed from the chopping-board into a sieve so that small particles of composition can be sifted out and the cubes which stick to each other can be separated. The size of the cube varies according to use. For example a cube with a 3 mm or 6 mm side is used for the core of round stars, while a 12 mm cube is used for smoke stars. The stars are dried in the sun, but the stars which are relatively large are best dried in the shade, because stars which are dried in the sun immediately after the cutting are likely to dry only on the surface, with the result, that the inner part of the cube is not easily dried, and finally it cracks on the surface. A worker should be able to make 30,000 3 mm or 15,000 6 mm stars in a working day. When the cubes are covered with an igniting composition in the way described later, they can be used as complete stars.

Round stars (color changing stars): Round stars are made by adding composition layer by layer, so that they are enlarged into balls of the proper size, and the cores are generally small cubic stars. The core has a 3 mm side for a completed ball less than 15 mm in diameter, 4.5 mm for a ball of 15-18 mm and *6* mm for a ball of more than 18 mm. In place of cubic stars some use rape-seed or cereal-seed, and sometimes shot for the cores. The rape-seeds are so light and so small, that very much time and labor is needed to enlarge them without them sticking to each other at the beginning of the manufacturing process, so they are not much used at present, but it is said that using such unignitable matter for the cores makes the end of the star-light quite clear, and the artistic view is excellent in chrysanthemum shells.

The manufacturing process of round stars from cubic cores is summarized as follows: The bowl for forming the stars has a spherical bottom and is made of aluminum or other light metal; in fact any bowl of 30 cm in diameter sold on the market for cooking is suitable for manufacturing stars by hand. For manufacturing a larger quantity of stars at one time it is better to use a larger bowl which has a base which is wider and flatter. In this case the bowl is hung from the ceiling with ropes and operated by hand. Compositions are prepared according to the color changing plan. A mushy paste of a composition, which is the same as the composition for sprinkling is prepared. One part of the composition is mixed with water in another small bowl and stirred to paste. Fireworkers in Japan call this mushy paste "Toro", and the viscosity of the paste is very important. When it is too high, the cores stick to each other in groups of two or three especially in the case of light cores, and when it is too low, the cores grow so slowly that the water in the Toro soaks into the cores. The viscosity of the Toro varies very much according to the type of composition, so the amount of water in the Toro must be adaptable for each composition, especially in the case of a composition which contains aluminum powder which has a very low viscosity. In this case it is necessary to add more glutinous rice starch than one would in ordinary compositions. In a word, the viscosity of the Toro should be as high as possible provided that the manufacturing process is possible. The development of the core into a star is shown in Fig. 23.8.

A correct quantity of the cores are put into the pasting bowl and a small amount of the Toro paste is poured over them; then the bowl is shaken round by hand or by other means until the paste completely and uniformly covers the core grains.

A small amount of powder, which consists of the same composition as the paste, is sprinkled on the pasted grains and the bowl is shaken round again. When the amount of the powder is correct, it is all fixed

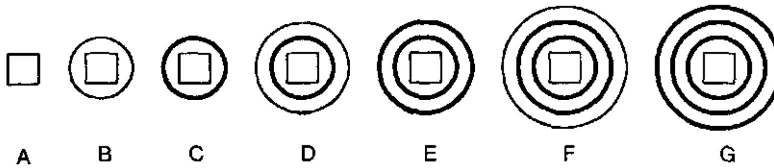


Fig. 23.8 Stages in the manufacture of round stars

on the grains and the bottom of the bowl is so clean that is glistens. When the quantity of paste is too large, the paste adheres to the inside of the bowl and prevents manufacture, and when it is too small the powder remains in the bowl without fixing to the grains. The process of covering the grains with the paste, sprinkling the powder on the grains and shaking, is repeated two or three times, and the grains gradually change shape from the cubic to round. Once they have been dried completely in the sun, and the operation is repeated, the grains become an almost perfectly round shape, namely A becomes B in Fig. 23.8. When the composition of the core is "Flash", it is difficult to ignite, and in this case the composition of the powder and the paste must be different from that of the cores for ease of ignition. This kind of composition is called "Cooperative Powder of Cores". Next a composition of very weak light intensity is layered on the grains. This layered composition is called "Changing Relay". This process is done once or twice, so that grains become like C. The purpose of the Changing Relay is to make the stars seem as if they change color simultaneously and clearly in spite of their irregularity though it only appears so, because the light intensity of the stars is weakened between the two layers. The grains are then coated with a layer of the next composition by repeating the same process. After coating two or three times the grains grow like D, and they are well dried in the sun. The grains are coated with the Changing Relay again like E and the next composition is layered on the grain like F. A three color changing star is shown in Fig. 23.8.

Changing Relay	Weight (%)
Potassium Nitrate	75
Potassium Perchlorate	7
Paulownia Coal	8
Antimony Trisulphide	3
Accaroid Resin	2
Soluble Glutinous Rich Starch	5

In the case of color changing stars, what kind of composition should be layered inside and what kind of composition should be layered outside a star construction? As a general rule, a dangerous composition is layered inside and safer composition is layered outside, or, an expensive composition is layered inside and a cheap one is layered outside. In the cores it is preferable to use a composition which produces light which ends clearly in a flash, so, taking into consideration the nature of the trajectory of the stars, a composition of high specific gravity is layered inside and one of low specific gravity is layered outside.

Lastly, black powder type compositions are layered on the grains as at G, and the stars are complete. Chrysanthemum 8 which has a burning rate which is relatively slow, is first used, and Chrysanthemum 6, which has a faster burning rate than that of Chrysanthemum 8, is used next. Thus the slower burning composition is layered first and the faster one next, while the fastest, (i.e. blackpowder) is sprinkled on the grains in the finishing process. The method outlined above is the usual process, but in the case of stars which are difficult to ignite such as those of aluminum, a specially prepared composition is first layered on the grain before the black powder type compositions mentioned above, in the finishing process. The problem of ignition is very important, not only with round stars, but also with everything else, and a new device for igniting may create new kinds of stars.

The speed of manufacture of stars is closely related to the drying time and the state of the grains to be dried. When the dried grains are again pasted and sprinkled with the next composition, the moisture soaks into the inner layer of the grains which have already dried. It soaks gradually deeper and deeper towards the core of the grain as time passes, and it is necessary to operate quickly, and at once put the grains to dry. The rate of soaking of the moisture varies according to the kind of composition, and it depends especially upon the amount of glutinous rice starch in the composition and the temperature of the stars. When the amount of the starch is too great, there is not very much effect in a short time, but if the grains are left without drying for a long time, the moisture soaks into the center of the grains. Thus the moistened grains make a hard dry layer on each surface during drying, and the center of each grain cannot be dried any more. The moisture is "Driven In". The composition which contains a relatively small amount of glutinous rice starch does not cause such a phenomenon, for in this case though the moisture soaks into the center of the grains easily during every pasting process, they can easily be dried out during every drying process (i.e. the moisture is driven out easily through the layers of compositions). The limit of the amount of starch (e.g. binder), which does not cause the "Drive In" phenomenon has not yet been systematically studied, but in the case of ordinary potassium perchlorate colored flame composition or spark composition containing aluminum it may certainly be about 6%. In the case of aluminum composition, the viscosity of the paste is too low to produce the grains. When the temperature of the grains is low, the rate at which the moisture soaks into the grains can be made slower, so it is better to leave the grains in a cool place after drying by heat and cool the grains sufficiently before the next coating operation.

The thickness of the layer that is added between the two drying steps depends upon the weather. In summer time on a clear hot day it should be rather thick, but in winter time on a cloudy day it should be rather thin, though in the case of a composition which contains a relatively large amount of glutinous rice starch and which has a high viscosity, success cannot be achieved by this procedure, and the relation between the thickness of the layer and the weather will be opposite to the above. In this instance, when the grains are dried in the strong sunshine and the new layer, coated on the grains, is too thick, only the surface of the layer is dried, and the inside cannot be dried easily. On the other hand even when they are dried on a cloudy day with a rather thick layer, the inner and outside part of the grains are dried successfully and uniformly, because the moisture soaks into the grains very slowly in this composition. Thus the thickness of each layer on the grains depends upon the weather and the nature of the composition, and is usually about 0.5-1.0 mm on average, though in black powder type composition the thickness is about a half of this. On a day with a clear blue sky in Japan the coating process is done three times a day in May, four or five times a day in March, and seven or eight times a day in June and July. The coating process must be finished by two or three o'clock in the afternoon in order to dry the grains during day time.

The above process depends very much upon the weather and it is rather difficult to work out a strict program. Accordingly it is useful to use a drier, (e.g. of infra red rays) to dry the grains as an auxiliary operation. A drier, where the heater is place under the drying frames, cannot be used to dry star grains because of the danger involved.

The complete round star grains, even when they are made very carefully, tend to have some small deviation in their dimensions. For example, a sample of the variations in the diameters of the grains is shown as follows. The values show the measured diameters of the grains. The letters S, K, A, B and C show the kinds of stars and the additional figures to the letters are the named diameters of stars.

S15 (mm)	K12 (mm)	A14 (mm)	A13 (mm)	B12 (mm)	C12 (mm)
16.50	13.10	13.40	12.60	12.28	12.70
16.00	12.92	13.20	12.90	12.68	12.39
15.40	12.70	14.80	13.35	12.69	12.37
15.75	12.70	13.75	12.60	12.35	11.73
15.80	12.80	13.70	13.00	12.18	11.92
15.40	12.80	14.30	13.00	12.15	12.00

As the star grains become larger and larger, the coating cannot be operated in one bowl, and they are divided into a few groups. At last they become a number of lots, each lot of stars being classified, packed and stored, and when the stars are loaded into a shell it is wise to fill the shell with stars taken from the same batch. When stars of a definite diameter are required, we must first select cores of the right size, and it is necessary to make frequent selections between the coating operations, though in practice the star grains are not selected in this way except in special circumstances.

Stars are manufactured mostly by hand in Japan. Some fireworkers use a coating machine, but there is a need in Japan to develop the demand for fireworks. For small quantities and large numbers of different types of stars the coating machine is not so adaptable. The machine must be so well cleaned when one composition changes to the next, that in the case of a star with layers of different colors or when manufacturing various kinds of stars, the machine operation is not as simple as the hand operation. The principle of manufacturing stars by machine is the same as that by hand, but the machine made stars are sometimes less easy to ignite because they tend to gain a higher specific gravity than those made by hand.

The manufacturing process with water insoluble binders is almost the same as the above process. In this case the use of large amounts of linseed oil make the stars unignitable. When a volatile solvent is used in place of water for the manufacture of stars, care must be taken to keep the material away from flames, fire, electric heaters, hot electric lamps, and electric switches. Moreover it must be remembered that the vapors of organic solvents are often toxic.

Fireworks Shells

Firework shells are classified into two fundamental types, the so-called "Warimono" and "Poka". Warimono is the type which draws a chrysanthemum-like flower in the sky by driving light stars or smoke stars in all directions, and is also named "Chrysanthemum". Chrysanthemum shells have a large amount of bursting charge and a strong outside shell which helps the action of the bursting charge. The name "Poka" came from the weak sound of the explosion of the shells and is difficult to translate into English. Poka is not a Chrysanthemum type, for its purpose is only to throw out and spread the contents in the sky; it has a small amount of bursting charge, enough to break the shell into two parts along its joining line. It has a weak shell, which is strong enough not to be broken when it is fired. But in practice there are shells which lie between the two types. Round shells of European type used to be the same as Poka in their effect.

Warimono (Chrysanthemum)

The most representative construction of Warimono is shown in Fig. 23.9. It can be seen that it consists of four main parts, i.e. shell A, star B, bursting charge C and fuse D. Shell (A) plays a role not only as the container for the stars and the bursting charge, but also to help and adjust the ejecting force of the bursting charge. The stars (B) are ignited by the explosion of the bursting charge, (C) and fly like the petals of a chrysanthemum flower, burning on the surface. The burning charge is ignited by the fuse (D) and breaks the shell into small pieces by the explosion which also ignites the stars and ejects them outwards in all

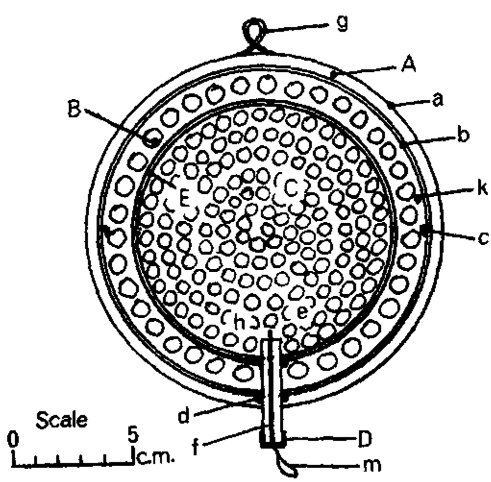


Fig. 23.9 Warimono shell

directions. The fuse (D) is ignited on its outside end by the flame of the lifting charge in the mortar on shooting, and it keeps a delay time until the shell reaches a desired height in the sky and ignites the bursting charge just after the delay time has passed. The principle points of these constructions are described as follows:

Shell (A) consists of the outer shell (a) and inner shell (b). Sometimes only the inner shell is called the "Shell", and in this case the outer shell is called the "Pasted Shell". The inner shell (b) is only the container, and its strength is not very important. As the raw material of shell (b), newspaper or cardboard paper is used and in Japan the newspaper shells are the most admired because of their uniform brittleness. The outer shell (a) is made of many layers of Japanese paper (Kozo) or of kraft paper, which is pasted on inner shell (b) to a thickness which is enough to give a suitable velocity to the stars on the explosion of the bursting charge (C). The structures of the stars, bursting charge and fuse have been described above already. The process of assembly of a standard type of shell as in Fig. 23.9 is shown in order in Fig. 23.10. This process is applied to the shells of middle size, e.g. 125 mm, 150 mm or 175 mm in diameter.

First the inner shell is prepared, a small hole being made in the center of the hemisphere of the shell, and a piece of fuse (f) is inserted through

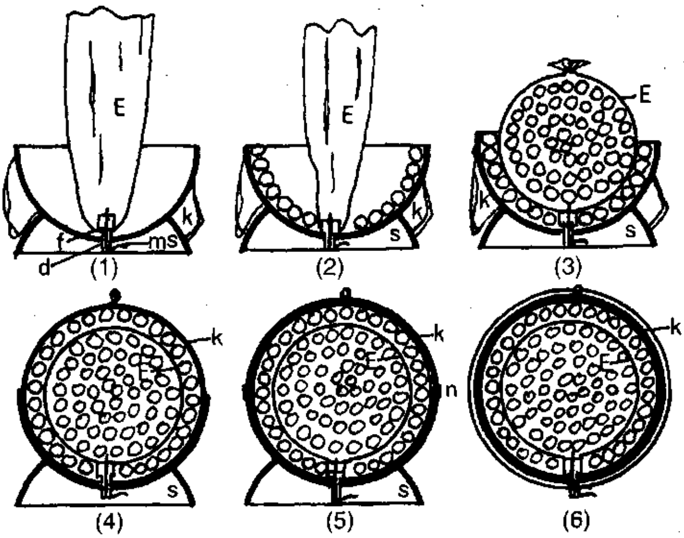


Fig. 23.10 Stages in shell manufacture

it, being fixed to the hemisphere with hemp (d). The hemp is well pasted and well fixed on the shell by winding it around the fuse. This is a very important process to prevent fire from entering the shell on shooting. The outside end of the fuse is protected by covering it with a paper cap. On the cap(m) generally the name of the shell or the kind of shell is registered. Before this fuse fixing operation a bag (E) made of Japanese paper, for the bursting charge, is attached to the inner end of the fuse, and the fuse is inserted into the hole of the hemisphere, from the inside. Then an outer bag (K) made of Japanese paper is pasted to the edge of the hemisphere, and it is turned over as in Fig. 23.10(1). The bag (K) is used for the arrangement of the stars of the upper hemisphere. Two bags, (E) and (K), are made generally of strong Japanese paper (Kozo) as described above, but recently we have found that they are often made of a rather weak copy paper. When we use a bursting charge of chlorate powder, the inner bag (E) must be made always of strong paper so that it cannot be broken during the arrangement of the stars. This avoids the bursting charge coming into contact with the stars and causing an accident, for the chlorate in the bursting charge together with the sulphur in the stars increases the sensitivity. The inner shell which is thus prepared is put on a rest (S) as in Fig. 23.10(1). Fig. 23.10(2) shows the arrangement of stars in the lower hemisphere. Then as shown in (3) an amount of the bursting charge is charges into the bag (E) and the hemisphere is tapped on the outside with a small wooden stick to avoid any looseness between the stars and the bursting charge. The bag is then sealed at the top being bound with a piece of hemp, the outer bag (k) is restored upwards and the stars of the upper hemisphere are arranged with the help of bag (k) as in (4). This arrangement is covered with another hemisphere on the top and it is pressed downwards by hand, being tapped with the wooden stick on the outside so that the two hemispheres meet each other at their edges. Sometimes the shell hemispheres have tally marks at the joining point of the two to make the operation easier. When the shell is correctly assembled the hemispherical shells meet each other with only a little pressure from the hand, thus avoiding any looseness between the stars and the bursting charge. If the hemispherical shells meet each other loosely, it shows that the amount of the bursting charge is too small, and it must be increased. The shell thus assembled has a ribbon tape pasted over the junction as in (5) shown by (n), or it is fixed with another hemispherical shell, which is attached on the side of the assembled shell to prevent separation while the shell is sent to the next process, pasting. (6) shows the complete product.

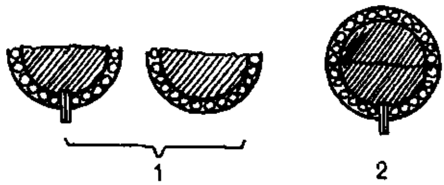


Fig. 23.11 Filling small shells

The process described above is most suitable for shells of middle size, but for smaller or larger shells the process must be managed conveniently according to the situation. The process shown in Fig. 23.11 is applied to a small shell of less than 4 inches in diameter. In this case the two hemispheres are prepared individually and then put together into one sphere.

Fig. 23.12 shows the process for larger shells of about 250 mm-310 mm diameter, and in this case (1) first the lower hemisphere is prepared and (2) then the upper hemisphere, in which a loading hole is made, is fixed to the lower hemisphere. Through this hole the bursting charge and the stars are loaded alternately, keeping the boundary between the bursting charge and the stars by the paper bag. (3) The hole is then sealed with the piece of shell which was previously removed from the upper hemisphere when the loading hole was made. During the process the sphere is tapped on the outside with a small wooden stick to assemble the contents tightly.

The processes described above are for the Chrysanthemum with single petalled flowers. The processes for double petalled flowers or special multipetalled flowers are described as follows: Fig. 23.13 shows the simplest form, and in this case the inner petal stars are mixed in the bursting charge. Fig. 23.14 shows the bursting charge composition

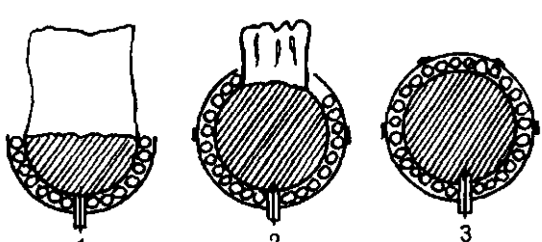


Fig. 23.12 Filling large shells

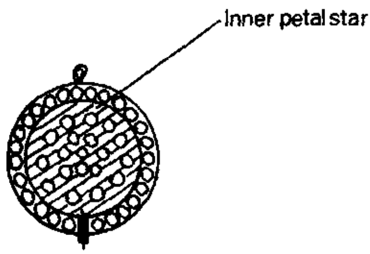


Fig. 23.13 Shells with inner petal stars

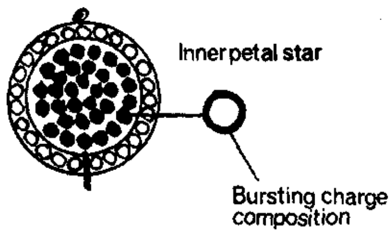


Fig. 23.14 Shells with inner petal stars

pasted on the inner petal stars. Fig. 23.15 shows a more elaborate shell where a part of the bursting charge is first shaped into a sphere by being wrapped with thin paper and wound on the outside with string.

The inner petal stars are then arranged outside the bursting charge sphere and wrapped again on the outside by the same process. This is the inner ball, which creates inner petals. Putting this ball at the center of the shell, we assemble and complete the shell in much the same way as described above.

Fig. 23.16 shows the process for a multipetalled Chrysanthemum and it is assembled in the way described above, the only difference

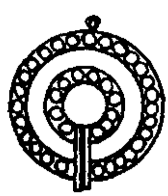


Fig. 23.15 More complex inner petal star shell

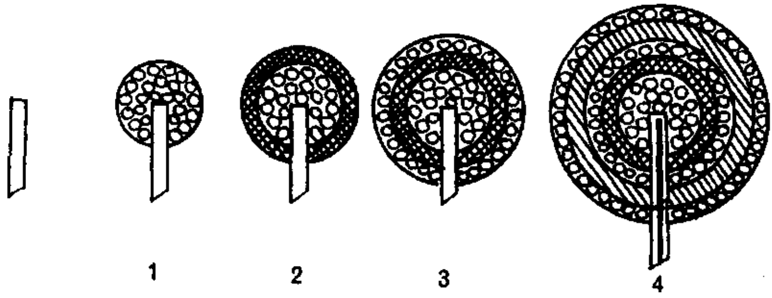


Fig. 23.16 Assembly of a multi-petalled shell

being to first make the inner double petalled ball. Fig. 23.17 shows the process for another elaborate inner multipetalled ball, i.e. a paper tube, which becomes the axis of the ball, and perforated at the center. The bursting charge and petal stars are arranged around the tube alternately, so that the hole is at the center of the ball. On assembly one end of the tube is connected to the fuse. This kind of ball with an axis is called "Nukishin".

The stars which are placed at the center, do not fly so far when the exploding charge bursts, and the duration of the inner stars must be made shorter than the outer stars. Moreover the grain size of the inner bursting charge must be smaller than that of the outside stars to strengthen the action of the bursting charge. If it is not planned in this way, we do not get a good flower.

The pasting process of making the outer shell is as follows:

As Fig. 23.18 shows, long pieces of paper are pasted on the inner shell like the stripes on a watermelon. In this case A-A' is taken as an axis, and the points A and A' become the poles. The procedure is as follows: First a paper tape is pasted around the assembled inner shell

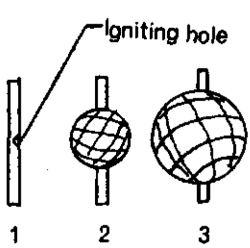


Fig. 23.17 Shell with an axis

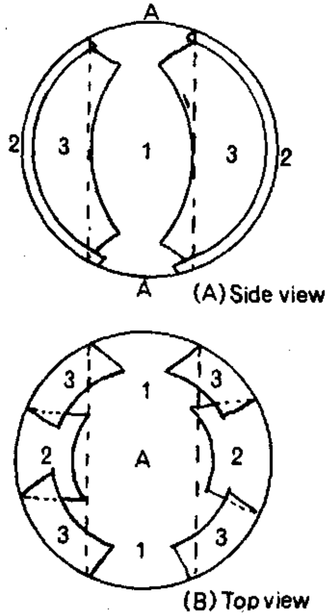


Fig. 23.18 Making outer shell covers

along the seam of the two hemispheres to prevent them from separating, first the axis is taken so that it becomes perpendicular to the seam. The paper pieces are made by cutting a sheet of paper so that the direction of the fibers is at right angles to the length of the paper pieces, in order to fit closely around the shell. Japanese paper, which is previously pasted in two or three folds is normally used. Kraft paper is so cheap and strong, that it is also used as the outer shell material. The paper pieces are prepared as follows: The paste, is made of one part of wheat flour and three parts of water, but some prefer to use a paste made of nonglutinous rice. The paste is spread on one side of the paper with a wooden spatula, and the pasted surface is folded in half, the pasted sides together. The purpose of this is to protect the paste from drying during the pasting operation of the outer shell. The pasted paper is cut into long pieces keeping them folded. The pasted shell with one layer is shown in Fig. 23.18. The width of the paper piece with another piece on the shell should be avoided if possible, as it is shown in (B), so that the shell may be uniform. In Fig. 23.18 the figure on each piece of paper pasted on the shell shows the order of the pasting. Then two other poles are taken so that the new axis is placed at right angles to the axis A-A' and the pasting process is repeated in the same way as before. When two or three layers of paper have been added, a process called "Gorokake" is applied; the pasted shell is placed on a thick wooden plate and another small wooden plate is placed on the shell, which is then pressed and rolled between the two plates. The edges of the pieces of paper on the shell are then perfectly fixed on the shell which becomes a perfectly round sphere. After this process is finished, the shell is dried in the sun. When it is well dried, the same process (i.e. pasting, Gorokake and drying) is repeated until the paper folds (i.e. the thickness of a layer of pasted paper) reaches the required degree. The necessary number of layer of the pasted paper is proportional to the diameter of the shell, according to the experience of fireworkers, and in ordinary cases, with Japanese Kozo paper 5 or 7 folds per 24 mm in diameter is recommended. For example, in the case of a 100 mm shell (in diameter), the number of all folds is 4 X 5 = 20, and in the case of a 150 mm shell (in diameter) it is 6 X 5 = 30, when we take the 5 folds per 24 mm.

These two shells have the same breaking strength against the bursting pressure according to the experience of fireworkers, and this is proved by the calculation based on the stress strain theory. Namely the folds of the pasted paper must be increased proportionally with the shell size to keep the same breaking strength. Fig. 23.19 shows a section of a shell which is pasted in this way. In the case of Kraft paper the strength

a. Kozo paper, 7 folds per 24mm

b. Kozo paper, 14 folds per 24mm

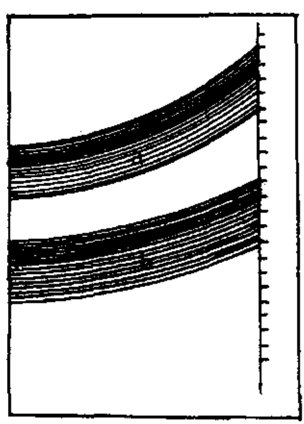


Photo 6 Sections of Shells (6 inch shell in dia.)

Fig. 23.19 Sections of shell

is twice that of Japanese "Kozo" paper, and the necessary layers become half of the above values.

Poka

The construction of Poka. The construction of the shell "Poka" is quite different from that of the shell "Warimono", i.e. Chrysanthemum. The shell has chambers in which various air floating objects are packed. The principle of the arrangement of the chambers in the shell is shown in Fig. 23.20. A is the simplest one, and consists of one fire chamber, but B has two chambers, a fire chamber and a fire prevention chamber. The fire chamber is so constructed that the flame of the bursting charge easily touches the contents. The fire chamber contains stars, reports, small flowers, falling leaves, comets, whistles etc. which must be ignited without fail. The fire prevention chamber is constructed in such a way that a wall is placed between the two chambers to protect the contents from the fire of the bursting charge when the shell explodes. This "wall" consists of cardboard or cotton seeds, the wall also acts as stuffing to prevent the contents from moving.

The method of fixing the fuse to the shell is the same as in the Warimono shells.

The amount of the bursting charge for Poka should be enough to break the shell into two pieces (i.e. the hemispheres), and it is fixed

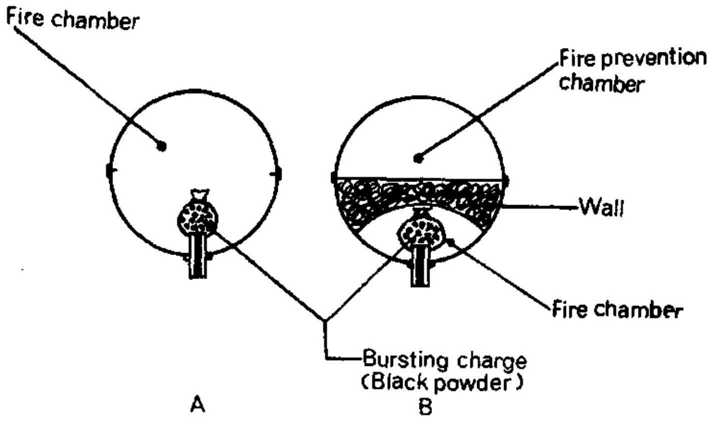


Fig. 23.20 Poka shell construction

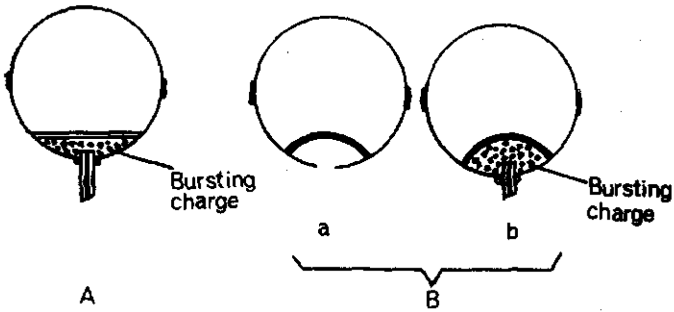


Fig. 23.21 Poka shell construction

in the shell as shown in Fig. 23.20 and Fig. 23.21. This method in Fig. 23.20 is to fix the charge on the inside end of the fuse, and is rather troublesome, but the bursting charge is well ignited by the fuse without failure.

Fig. 23.21 A shows a more simple method. In this case a few pieces of "powder-pasted" paper are inserted in the charge for perfect ignition. Fig. 23.21 B shows the shell with no bursting charge as in (a), which is afterwards charged and fixed with a fuse as in (b), when it is used. It can be handled as "paper" without the bursting charge during storage and transportation, and it is very convenient when it is used for paper Balloons called "Fukuromono" and Flags.

Fig. 23.22 shows the constructions of representative Poka shells. A is a report shell, "Thunder", which makes three or five reports with the same time intervals. B is a Flag or Balloon and C is a Flare, in which the fire prevention wall is made of cotton seeds to protect the

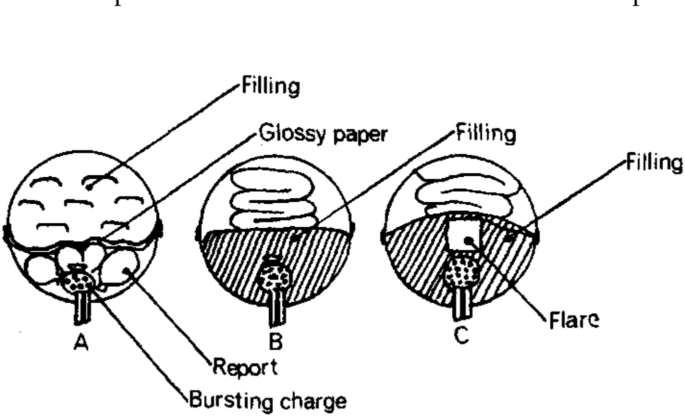


Fig. 23.22 Poka shells with flash reports or paper figures

parachute from the fire. The construction of chains are the same as that of Flares.

Planning of Poka Here the relation between the strength of the shell and the amount of the bursting charge must be considered. The shell must be strong enough not to be broken when it is fired, and if the weight of the contents is large, we must think also of the possibility of "Head Breaking", which means that the shell is broken by the shock of the firing and the contents are immediately projected out of the shell. It is necessary to maintain the strength of the shell during firing, but it is wise to have the minimum amount of the bursting charge, enough to break the shell into two hemispheres. The folds of the paper pasted on the shell are just adequate for these conditions. A few examples of the amount of the bursting charge are shown as follows:

The Bursting Charge of Poka (In the case of black powder)

Diameter of Shell (mm)	Amount of Charge (grams)	Diameter of Shell (mm)	Amount of Charge (grams)
75	2.0	175	6.0
100	3.0	200	7.0
125	4.0	250	8.0
150	5.0	300	10.0

The process for pasting paper on the assembled shells is the same as that of Chrysanthemum. The folds of the paper layer of the outer shell is 1.7-2.2 per 24 mm in diameter, on the seam of the two hemispheres which gives an average value of about 2.1 on the same part. The weakest position of the completed shell is the junction of the two hemispheres, and when the shell explodes, it is broken along this line. The inner shell is made of newspaper, and as described above its strength is unimportant in the case of the Chrysanthemum, but is important in the case of Poka, because the ratio of the strength of the inner shell to the whole is higher than that of the Chrysanthemum. 3 mm in thickness of a newspaper shell corresponds to the eight folds of Japanese Kozo paper in strength. Accordingly (e.g. in the case of 100 mm shell -in diameter-) the paper pieces are first pasted on and along the seam two or three times, and then they are pasted on the whole surface of the sphere just once. When the strength of the pasted paper along the junction is too great, the shell cannot be broken along the line, but is perforated in some other part by the explosion gas, which escapes out of the shell through this hole, but does not project the contents out of the shell.

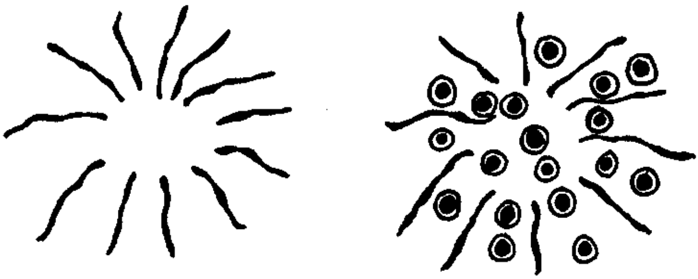


Fig. 23.23 Development of daylight chrysanthemum

Daylight Chrysanthemum

We will use the Daylight Chrysanthemum as an example of manufacturing technique. This most beautiful and elegant effect uses smoke and light in contrast to each other.

The effect of this shell is developed in two stages: in the first stage only thick smoke lines appear in red, yellow, green and blue. Dazzling red star light pistils then suddenly appear on the petals as the second stage. The smoke lines need to be short and thick, but the star lights must be very intensive.

Important points for the shell construction:

(A) The burning time for the smoke stars is about 4 seconds and must not exceed five seconds.

(B) The light stars must be an ammonium perchlorate and magnesium composition. The stars are covered with sulfurless blackpowder as a delay. The delay should be about 3 seconds. The light from the delays needs to be invisible in daylight.

(C) The number of paper layers on the outside of the shell are a half of an ordinary chrysanthemum, WARIMONO. The diameter of the flower must not be too large (i.e. about a half the normal size).

Manufacture:

Smoke stars: In order to obtain the broad and short smoke traces, the compositions need to be granulated. The granules are loaded into a paper tube which is ignited with sulfurless match.

The following are examples of smoke composition:

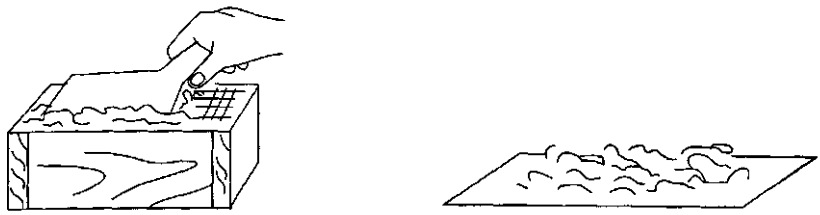


Fig. 23.24 Making smoke grains

	Red Weight (%)	Yellow Weight (%)	Green Weight (%)	Blue Weight (%)
Potassium chlorate	28	32	33	37
Milk sugar (Lactose)	20	28	27	27
Rhodamin B conc	30	—	—	—
Oil orange	22	—	—	—
Oil yellow	—	40	20	—
Phthalocyanine blue	—	—	20	40
Dextrine (additional %)	3	3	3	3
For 500 grams add				
Water	270ml	180ml	180ml	260ml
Ethanol	—	—	—	78ml
in order to knead the mixtures				

The materials are mixed by hand and then kneaded after the addition of the water. The blue does not mix well with water but the addition of the alcohol makes this easier. When the mass is well mixed, the dough is pressed on to a sieve of about 2 mm aperture with a wooden spatula so that the mass comes through the mesh like vermicelli. The sieved material is spread on paper and dried in the open air.

These smoke compositions are made with potassium chlorate and even though they are not too sensitive they should not be handled roughly. The sieve mesh tends to become loose with use and it is best self made. Making smoke composition is very dirty, but much trauma can be avoided with skill. This technique is an application of a smokeless powder, where the burning time of the powder is adjusted by the thickness of the granules.

Smoke Stars

The smoke granules are loaded into a kraft tube of about 30 mm inside diameter, 30 mm long and with a wall thickness of 2 mm. A small spherical shell case can also be used.

The star construction is illustrated as follows:

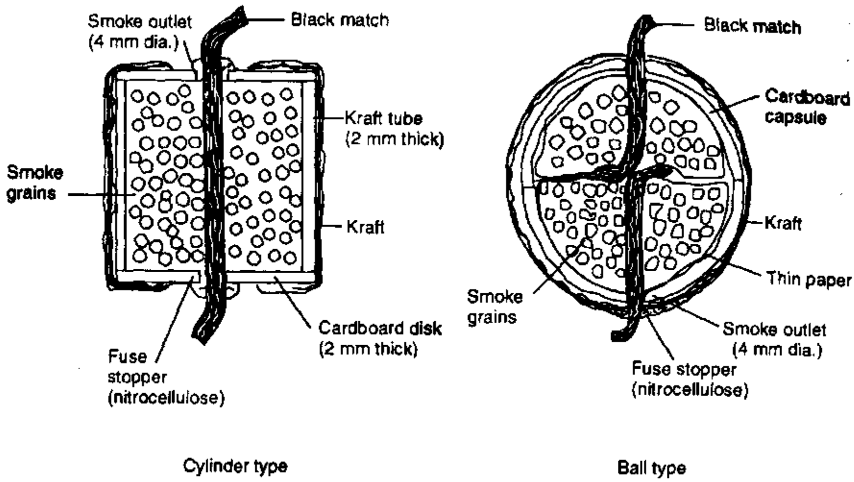


Fig. 23.25 Construction of a smoke star

The black match is only lightly fixed to the smoke outlet with a stopper which consists of a small amount of nitrocellulose solution in acetone. It is only there to stop the fuse from falling out.

The fuse composition is ideally made with sulfurless blackpowder to avoid the contact of potassium chlorate with sulfur. A suitable mixture would be: Potassium nitrate 80% and Pine charcoal 20%. This is wet with 3 parts of Gum Arabic in 40 parts by weight of hot water.

Light Stars for Pistils

The most beautiful effects in this type of shell are somewhat limited. The use of ammonium perchlorate composition is recommended although it is somewhat troublesome to manufacture. The magnesium needs to be coated with potassium dichromate to protect it from the ammonium perchlorate. This is done as follows:

50 gms of potassium dichromate are dissolved in 300 ml of hot water.
1000 gms of magnesium are pre-heated to a temperature of 100°C.

The hot dichromate solution is quickly poured into the magnesium in its aluminium bowl and mixed with a stick wearing rubber gloves. When it is uniformly brown it is dried after spreading on sheets of paper. When it is dry it is passed through a 30 mesh sieve.

Potassium dichromate is on the list of toxic materials and is known to badly affect the mucous membrane. People in industry come into contact with this substance for short periods and not every day, and it is unlikely to be a problem provided that gloves and dust masks are used. By comparison, smoking should be more harmful.

The waste fluid should be treated with iron (11) sulphate.

$$H_2Cr_2O_7 + 6FeSO_4 + 6H_2SO_4 \rightarrow Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + 7H_2O$$

In this way the most poisonous hexivalent chrome is reduced to the tetravalent form which is less poisonous. Further treatment is to treat the liquor with slaked lime:

$$Cr_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Cr(OH)_3 + 3CaSO_4$$

The value for the solubility of chrome hydroxide in 100 gm of water is 9.1×10^{-7} gm.

The Composition of the Light Star	Weight (%)
Ammonium perchlorate	43
Magnesium passing 80 mesh coated with potassium dichromate	35
Accroides resin	10
Strontium carbonate	10
Potassium chromate (Stabilizer)	2
Guanidine Nitrate (Stabilizer)	2 (additional)

The mixture is kneaded with a binder (10% nitrocellulose solution in acetone) and cut into stars of about 15 mm. cube. This is the size for 12" shells and will need some reduction for smaller shells. Stars for this purpose need to be larger than for night shells.

The stars are well-dried at room temperature and then coated with the following ignition mixture until the cubes become spherical.

	Weight (%)
First ignition coat:	
Potassium perchlorate	71
Accaroid resin	12
Pine charcoal	5
Potassium dichromate	3
Strontium carbonate	9
The last coating for the 3 second delay	
Potassium nitrate	65
Pine charcoal	35

A 10% solution of nitrocellulose in acetone is used for the coatings. These coatings are complete when the last one has a delay time of 3 seconds. The purpose of this delay is to make the flying stars invisible at the first stage of the flower display.

Bursting charge

The smoke stars and the light stars are very voluminous and so rather different from ordinary daylight shells. The bursting charge is therefore granulated so that the granules can fill up the space between the stars. The granules should be sieved to remove any dust.

Bursting charge for the daylight shell:	Weight (%)
Potassium perchlorate	68
Potassium nitrate	2
Hemp charcoal	30
Glutinous rice starch (additional)	3

The completed daylight chrysanthemum shell is illustrated in the following figure:

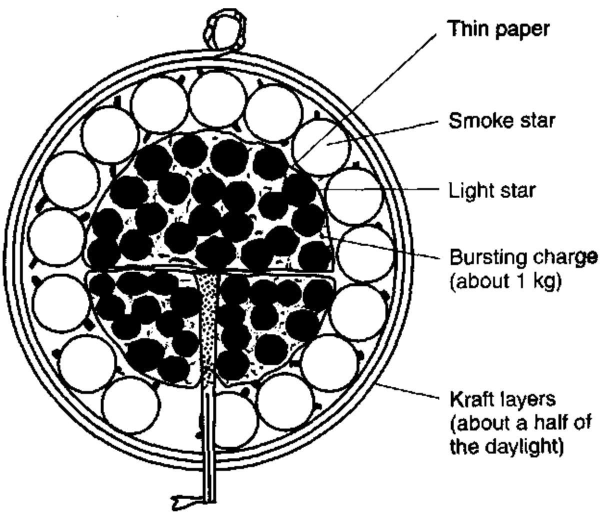


Fig. 23.26 Six inch, daylight chrysanthemum

GLOSSARY

Term	Description
1.1G (0333)	The UN classification of fireworks packaged for transport that pose a mass-explosion (detonation) hazard (See also: UN number)
1.2G (0334)	The UN classification of fireworks packaged for transport that pose a projectile hazard (See also: UN number)
1.3G (0335)	The UN classification of fireworks packaged for transport that pose a fiery projectile or thermal radiation hazard (See also: UN number)
1.4G (0336)	The UN classification of fireworks packaged for transport that pose a limited hazard (See also: UN number)
1.4S (0337)	The UN classification of fireworks packaged for transport that pose a very limited hazard, the effects of accidental ignition are confined within the package itself. (See also: UN number)
Aerial bomb	Preferred term: Aerial shell (See also: Aerial shell)
Aerial firework	In general a firework which functions above the immediate area of the ground - i.e. rockets, shells, roman candles and mines. (See also: Ground firework)
Aerial shell	A shell designed to function at high altitude. cf. water shell (See also: Water shell, Shell)

Alloy	A combination, usually of 2 metals, which takes on some of the characteristics of its components. Alloys cannot be separated into their constituent parts by normal physical methods. (See also: Magnalium, Ferro-Titanium)
Aqueous	Pertaining to water. In fireworks, aqueous usually refers to solutions used for damping stars in manufacture. Cf Organic (See also: Organic)
Atomic pattern	In a shell burst, usually taken to be three contiguous circles representing the orbits off electrons around a central nucleus (rather than the atomic "hazard" symbol) (See also: Pattern shell)
Bag mine	A mine without a rigid case that is fired from a mortar. The advantage of bag mines is their very low debris pattern. (See also: Mortar mine)
Banger	Usually a complete firework, designed to produce a loud bang rather than a component of a larger firework (e.g. a mine) - which are better referred to as crackers. (See also: Cracker)
Bare match	Black match without a sleeve, preferred term: Black match (See also: Black match, Raw match)
Barrage	A combination of several fireworks, most usually Roman candles and/or mines, designed to be fired with a single ignition (See also: Battery)
Battery	In fireworks a combination of, say roman candles, fused together for increased effect and/or duration. (See also: Barrage)
Battle in the Clouds	A shell producing a series of salutes after bursting
Bengal	A pyrotechnic coloured flare
Bickford Fuse	A slow burning fuse used either for preparation of internal shell delays, or for timing sequential firings (See also: Safety fuse, Delay)

Black match	Usually a cotton thread coated with blackpowder, in its raw state. Black match contained within a paper tube is usually referred to as piped match. (See also: Raw match, Piped match)
Black shell	Preferred term: Blind shell (See also: Blind shell)
Blackpowder	A composition, comprising Potassium Nitrate, Sulphur and Charcoal in the ratio 75:15:10 widely used in fireworks manufacture as a propellant and as the basis for compositions containing metal powders. It is considered by most people that blackpowder does not detonate on ignition, but merely burn extremely fast! (See also: Composition, Propellant)
Blasting powder	Blasting powder may be made with either Potassium Nitrate (type A) or Sodium Nitrate (type B) as the oxidant. (See also: Gunpowder, Smokeless powder)
Blind shell	A shell that fails to burst, having been successfully launched from its mortar. Potentially very dangerous
Blinker	An effect of periodic burning giving the effect of a flashing composition or strobe
Bomb	Inappropriate term for shell (See also: Aerial shell)
Bombardo racks	Usually a bottom fused multiple firing assembly (See also: Top fused, Finale barrage)
Bombette	In essence a mini shell, usually found as a component of a roman candle, and less often as a component of a mine or even as a sub component of a shell. (See also: Roman candle, Mine)
Bottom fused	The normal method of fusing of a shell, where the shell delay is ignited by the lifting charge of the shell. Also, for cakes where fusing is at the base of each tube (See also: Top fused)
Bottom shot	Typically a maroon as the last shot of a multibreak shell (See also: Multibreak shell)

Bounce	A charge of blackpowder at the base of a gerb - used to give an audible "crack" at the end of the burning of the gerb, and to enhance the effect (See also: Gerb)
Boxed finale	A rapid firing array, usually of shells, with a single point of ignition. Physically they comprise a number of pre-loaded mortars, very often with titanium salute shells (See also: Finale barrage)
BPA	British Pyrotechnics Association - a trade association concerned with all aspects of fireworks safety and use in the UK. Recently split into Retail and Display sections.
Break	A normal shell is referred to as "single break". In a multibreak shell there are many sequential bursts, each a separate entity (cf shell of shells for instance) (See also: Multibreak shell, Repeater shell)
British standard	Prepared in the late 1980s for consumer fireworks. The standard sets performance, labelling and constructional requirements for a variety of consumer fireworks available to the public in the UK and also prescribes test regimes and methods for compliance. (See also: DOT classification, European standard)
Brocade	Long burning star similar to but brighter and shorter burning than a kamuro star (See also: Kamuro)
Burning	Typically an exothermic oxidation/reduction reaction. For fireworks the oxidant is usually a solid oxygen-rich ionic salt such as Potassium Nitrate (See also: Detonation)
Bursting charge	The internal charge in a shell designed to break the shell at the predetermined time, spreading and igniting the contents of the shell. Bursting charges are typically made of blackpowder (for effects shells) or flash powder (for colour shells) (See also: Lifting charge)

Butterfly burst	A burst of a cylindrical tube from a central point, thus producing an effect akin to the wings of a butterfly. The term is also used for the more complicated burst pattern of a "butterfly" shell, although in many ways the theory of action is similar
Cake	Colloquial term for a multishot battery, arising from the outward appearance of many of the smaller items (e.g. 90 shot cakes) (See also: Multishot battery)
Calibre	In firework terms usually the inside diameter of the firing tube, although strictly the diameter of the projectile
Candle	Abbreviated term for Roman Candle (See also: Roman candle)
Cannonade	Usually an aerial shell containing several shots fused to explode at the same time after the shell bursts. Also a popular generic name for a multishot battery from China.
Capping	Usually a rolled kraft paper tube used to connect several fuses together in a spark-proof join. (See also: Kraft paper)
Case	Typically the tube containing the pyrotechnic composition of the firework.
Category 1 firework	Indoor firework as defined by British standard 7114; part 2 (See also: British standard, European standard)
Category 2 firework	Garden firework as defined by British standard 7114; part 2 (See also: British standard, Europeanstandard)
Category 3 firework	Display firework as defined by British standard 7114; part 2 (See also: British standard, European standard)
Category 4 firework	Fireworks defined in the British Standard as being not suitable for sale to the general public. Generally, but erroneously, taken to mean larger display fireworks. (See also: British standard, European standard)
Catherine wheel	The traditional name for the generic wheel. The name derives from St. Catherine (See also: Wheel)

Celebration cracker	Usually a roll of many hundreds or thousands of individual cracker units designed to be unrolled and hung from a solid object prior to lighting. These items, traditionally part of Chinese New Year celebrations are now widespread. However, recent legislation has banned their sale in the UK
Chain fused	A method of fusing several elements, particularly in a finale box or shell sequence
Changing Relay	A low light intensity composition used, particularly in Japanese shell manufacture, to accentuate and regularise the colour change in stars of a chrysanthemum or Peony shell
Charging	Usually the process of filling a tube with composition or units (e.g a Gerb or Roman candle)
Cherry bomb	A small powerful banger containing flash powder now banned in the US. The item was usually round and red - hence "cherry". (See also: M-80, Banger)
Chinese cracker	syn. Celebration cracker (See also: Celebration cracker)
Choke	The narrowing of a tube, most often associated with fountains and rockets. Chokes may be made by physically distorting the tube, by means of an end piece, or by clay or other material. (See also: Gerb, Fountain)
Chrysanthemum shell	A spherical burst, typically Japanese, in which the stars leave a visible trail. Cf Peony shell. (See also: Peony shell, Dahlia shell)
Chuffing	The sound produced by the unstable burning of some rocket motors - usually a sign of instability.
Class B firework	The US categorisation for Display fireworks (See also: DOT classification)
Class C firework	The US categorisation for Consumer fireworks (See also: DOT classification)
Closed circuit	A complete electric circuit, usually in the context of a circuit ready to fire. (See also: Open circuit, Short circuit)

Coconut shell	Usually a shell containing large comets (gold, silver or crackle) which produce a typical coconut palm type effect on bursting. Typically the shell will also be fitted with a complementary rising tail (See also: Palm burst)
Colour enhancing agent	Usually a chlorine donor such as PVC or Cerechlor added to a colour composition to enhance the intensity of the colour. The chlorine forms metal-Cl species in the flame which emit strongly in the visible part of the spectrum. It is thought that potassium chlorate/perchlorate may play a similar, though diminished, role (See also: PVC)
Comet	Usually a solid cylinder of composition, manufactured in a mould by hand or by machine. The effect is that of a large star rising (from say a Roman candle). The comet is completely self-consuming and thus particularly suitable for sites where debris is a problem (See also: Roman candle)
Comet pump	A larger version of a star pump typically used to make Roman candle stars and splitting comets (See also: Comet, Splitting comet)
Composition	The generic and widely used term for all pyrotechnic mixtures. More specifically composition is taken to mean the list of ingredients in a particular pyrotechnic mixture. All compositions contain at least an oxidant and a fuel, together with additional ingredients for colour/effect production etc. (See also: Oxidant, Fuel)
Cone	A specialised type of fountain in the shape of a cone. The advantages of a cone are predominantly ease of filling, and the fact that the burning area increases as the fireworks proceeds, thus compensating for the increase in diameter of the choke. (See also: Fountain)

Confinement	The process by which some explosives, e.g blackpowder, can change from extremely rapid burning to something approaching detonation. For instance, blackpowder confined in a tube will produce a loud report when lit, whilst blackpowder burning loose does not. (See also: Explosive)
Continuity	An electric circuit is said to be continuous when it is complete - thus a continuity check of a circuit is carried out to ensure that the circuit is not open (See also: Ohm meter, Closed circuit)
Convolute wound tube	A tube wound from a piece of paper the same width as the tube is long. Convolute tubes tend to be stronger than spiral wound tubes, although they are also more expensive to produce (See also: Spiral wound tube)
Covalent bond	A type of chemical bond in which electrons are shared by the participating atoms. This type of bond typically occurs between non-metallic elements. In fireworks the important occurrence is in high energy species in the flame producing colours (See also: Ionic bond)
Cracker	A better term, and less emotive, than banger. Also an assembly of many crackers often referred to as a "Chinese cracker". A novelty cracker, commonly used at Christmas in the UK is another use of the term
Crackle	A relatively recent effect comprising many small sharp bangs, thrown from a relatively low intensity comet. Chemically, most crackle compositions contain either lead or Bismuth oxides
Croaker	Syn. Screecher (See also: Screecher)
Cross match	Typically a piece of thin raw match used to facilitate ignition of a shell's internal time fuse. Generally made by either splitting or punching the time fuse
Crossette	The American term for a splitting comet. (See also: Splitting comet, Mosaic)

Crossing stars	Typically a pyrotechnic effect formed by fitting two stars together in a tube with a central bursting charge. Also known as French Splits (See also: Splitting comet, Butterfly burst)
Crown	As in "Crown Chrysanthemum" shell - syn. Kamuro (See also: Kamuro, Brocade)
Crown chrysanthemum	syn. Diadem chrysanthemum. Typically a chrysanthemum like shell bursts with longer burning stars that continue to fall to the ground after the normal maximum burst diameter. Very often the stars have a colour change at the end of their flight. (See also: Kamuro, Brocade)
Crown wheel	syn. Flying saucer (See also: Flying saucer, Tourbillion, Girandola)
Cut star	A star, usually cuboid in form, prepared from a rolled sheet of composition (See also: Round star, Pillbox star)
Cylinder shell	An aerial shell of typically European manufacture which is cylindrical in form. Very often a "stack" of cylinder shells is combined, with suitable modification, to produce a typical multibreak shell. Cylinder shells are usually "spiked" to produce a harder burst. (See also: Aerial shell, Spiking)
Dahlia shell	A spherical shell burst, similar to a peony, but usually with fewer, brighter, stars (See also: Chrysanthemum shell, Peony shell)
Dark fire	In Roman candle terminology the low light-emitting composition applied to the surface of Roman candle stars acting as a sort of prime. The term has also been applied to the composition applied between colours in colour changing stars (See also: Changing Relay, Prime)
Daylight shell	A shell designed to be fired in daylight and thus incorporating one or more of the following effects:- noise units (crackers, whistles etc.), smoke, magnesium stars (See also: Aerial shell)

Deflagration	A particular type of explosive propagation in which propagation is faster than mere burning, but is not detonation. (See also: Detonation, Burning)
Delay	Usually a pyrotechnic composition that burns at a predetermined rate and used for timing either within a firework assembly (e.g a Roman candle) of between firework elements (e.g in a shell sequence). (See also: Sequence)
Delay fuse	A pyrotechnic composition designed to give a delay before functioning the next device in the explosive train. The most common use for a delay fuse is to provide a number of seconds for the operator to retire from the device before it functions. Also the internal delay within a shell used to ignite the bursting charge (See also: Fuse, Shell delay)
Detonating cord	A high powered explosive material encased in a plastic or cloth sleeve that burns by propagation of a detonating shock wave (typically 5000-7000 metres/sec) (See also: Safety fuse)
Detonation	An exothermic chemical reaction in which the propagating front travels at supersonic speeds and thus an explosion always results (See also: Deflagration)
Detonator	Not to be confused with a firework igniter, or squib, a detonator is used to initiate high explosives. As such, detonators are security attractive items and their possession is controlled in many countries (See also: Igniter, Squib)
Display area	Usually the area in which the rigging of the display takes place (syn. firing area), but more generally the entire area encompassing spectator area, firing area, safety area and fallout area (See also: Fallout area, Firing area)
Display firework	Usually a large firework intended for use at

	large public/private displays. In the US it is erroneously synonymous with UN 0335 (1.3G) fireworks (See also: British standard, Transportation)
DOT	Abbreviation for the US Department of Transportation. In the UK the similar department is now called the Department of Environment and the Regions (Abbr. DETR)
DOT classification	The assigning of fireworks by the US DOT into one of three classes (See also: British standard, European standard)
Double base propellant	Homogeneous propellants which usually contain nitrocellulose in nitroglycerine and typically used in small arms ammunition and military rockets but rarely in fireworks
Draw-out shell	A two break shell in which the first burst is usually colour, the second colour and report
Driver	A specialized gerb, usually more powerful than a gerb used on a static set piece, whose primary purpose is in turning a wheel or similar item. In the past turning cases were invariably gold, usually made with neat blackpowder with the addition of charcoal, and produced very few sparks. Modern drivers often include titanium for additional visual effect. (See also: Gerb, Turning case)
DTI	In the UK the Department of Trade and Industry, responsible for aspects of the sale of fireworks to the general public
EIG	The Explosive Industry Group of the British Confederation of British Industry. The EIG is not a trade organization and as such does not actively promote the firework industry. Its primary purpose is liaison with Government on safety and legislative matters (See also: BPA)
Electric firing	The process of firing a display electrically. Many varied systems have been developed ranging from simple "nail boards" to automatic, computer controlled systems.

Electric igniter	The preferred term for the device used to ignite pyrotechnics electrically (See also: Squib)
Electric match	syn. Electric igniter
Electrostatic sensitivity	The tendency of a composition to ignite (usually accidentally) from the energy supplied by an electric spark. (See also: Sensitivity)
European standard	A proposed standard (CEN 212) for consumer fireworks in the EU. The standard is due to come into force in 1999. (See also: British standard)
Explosive	Technically - any material that is capable of undergoing a self-contained and self-sustained exothermic chemical reaction at a rate that is sufficient to produce substantial pressures on their surroundings thus causing physical damage. ALL fireworks are classified as explosives (See also: High explosive, Firework)
Explosive train	The progress of fire from one explosive element to another. For instance within a hand-lit shell the train is Delay Fuse-> shell leader-> lifting charge-> shell delay-> bursting charge-> star prime-> star
Fallout area	The area designated for debris to fall at a firework display. Obviously the position and size of the fallout area are critically dependent on the wind direction and strength at the time of the display. Careful planning at the design stage must allow for variations in the fallout area and position. (See also: Safety area, Firing area)
Ferro-Titanium	An alloy of Iron and Titanium which is finding increasing use in firework manufacture. Different ratios of Fe:Ti are available although generally all burn with a much more silver flame than Fe alone. (See also: Alloy)
Finale barrage	A rapid firing, pre-fused, sequence (usually of aerial fireworks) that is typically fired at the end of a display,
Firecracker	syn. Cracker (See also: Cracker)

Firework	Technically an explosive assigned one of five UN numbers (0333->0337). For our purposes a device which is designed for entertainment and that comprises pyrotechnic composition (See also: UN classification)
Firing area	The best term for the actual area of firing (rather than display area)
Firing current	The current that is applied to an electric igniter that causes it to function (See also: Safe current)
First fire	A composition used, particularly in gerbs, to initiate the explosive train. It is not synonymous with prime (See also: Prime)
Fix	Old English term for a gerb that is not a turning case. Very often these gerbs had a "bounce" (See also: Turning case, Bounce)
Flanked	Usually applied to racks or mortars or Roman candles on a frame in which 3 or more tubes are angled to produce a dispersed effect.
Flare	A pyrotechnic device used to produce coloured light when ignited. In the US this is typically a tube, similar to a large lance. In the UK the term is often applied to distress signals (See also: Torch, Fusee)
Flash paper	A form of nitrocellulose, easily ignited and used to produce a puff of flame
Flash powder	An extremely powerful pyrotechnic composition, typically made from Potassium perchlorate (or rarely pot. chlorate) and powdered aluminium (or magnesium). In fireworks flash powder is often used for powerful maroon shells, and for bursting colour shells
Flash rocket	A rocket that usually only contains flash powder as its payload and thus functions with a loud report and a flash. Flash rockets should never be fired in multiples from cones for risk of detonation. Flash rockets find much use for bird scaring (See also: Flight rocket)
Flight rocket	Usually a small calibre (approx. 14mm)

	rocket fired in a large number simultaneously from a rocket cone or rocket frame to produce a characteristic fan-like effect. (See also: Volley, Rocket cone)
Flitter	A spark effect (usually silver/gold) produced by the incorporation of relatively coarse metal powders (usually aluminium). The glitter effect is similar but distinct (See also: Glitter, Strobe)
Flower pot	A shell misfunction in which the shell bursts within the mortar propelling the shell contents upwards as if from a mine. Cf Muzzle break (See also: Mine, Muzzle break)
Flying saucer	An unusual firework device, usually constructed from a ring of plastic or wood, with turning cases and lifting cases. The functioning of the device usually involves rotation around a vertical axis, followed by ascent into the air. "Double acting" saucers fall and then reascend to the crowd's delight! Also called Girandola (See also: Crown wheel, Tourbillion)
Flying squib	A toy firework of erratic flight now banned in many countries. Not to be confused with the electrical squib
Fountain	A device comprising pyrotechnic composition charged into a tube which may or may not be choked. The composition may be hand charged, or more commonly nowadays, machine charged (See also: Cone, Gerb)
Friction Sensitivity	The tendency for a composition to ignite as the result of frictional energy (i.e. rubbing). (See also: Sensitivity)
Front	Usually an arrangement of fountains, mines, set pieces or Roman candles along a line parallel to the spectators and fired simultaneously (See also:Line)
Fuel	In a pyrotechnic composition that which the oxidant oxidises. Common fuels include charcoal, sulphur, aluminium and magnalium. All common pyrotechnic compositions con-

	tain at least an oxidant and a fuel (See also: Reducing agent)
Funnel and wire	One method of charging tubes with firework composition (See also: Charging)
Fuse	The generic term for the means of transferring fire to a firework, or from one part of a firework to another (See also: Delay fuse, Shell delay)
Fuse cover	The protective cover for the initial fuse of a firework. Often coloured to aid identification in the dark
Fusee	A long duration flare, usually red, which may be used as a warning flare on the highway or railway. Fusees may also be used to light fireworks Cf Portfire (See also: Flare, Portfire)
Garden firework	A firework, usually of limited power and composition weight, intended to be used in restricted areas outdoors (See also: European standard, British standard)
Gerb	Usually a relatively thick-walled tube filled with composition and having a choke. A gerb functions by throwing out a shower of sparks. From French-gerb-sheaf of corn (See also: Fountain)
Girandole	syn. Flying saucer (See also: Flying saucer)
Glitter	An effect that produces drossy droplets of molten composition which reach with the air to produce a sparkling or glittering effect that is not as distinct as a strobe effect. Similar but distinct from flitter (See also: Flitter, Strobe)
Glutinous rice starch	A binding agent much favoured by Japanese star makers (See also: Paste)
Greek fire	Used in combat, Greek fire was an early use of pyrotechny, although some descriptions of compositions do not contain an oxidiser. It comprised sticky long-burning composition usually fired from catapults
Green man	The symbol of the Pyrotechnics Guild Inter-

	national. The "Green men" were performers (c 1600) who carried flaming clubs and scattered fireworks (probably sparks) as they headed processions (See also: PGI)
Ground burst	A low level burst of a shell and potentially very dangerous
Ground firework	A firework designed to function at ground level
Ground maroon	A single powerful cracker designed to produce a loud report and a flash.
Ground salute	syn. Ground maroon (See also: Ground maroon)
GRP mortar	Glass Reinforced Plastic-a relatively recent addition to the design of mortars. GRP mortars, usually spirally wound are light, cheap and extremely strong. However there is some doubt as to their suitability for cylinder shells especially in larger calibres (See also: HDPE mortar, Steel mortar)
Gums	Usually applied to binding agents soluble in water (See also: Resins)
Gun	A poor term for mortar (See also: Mortar)
Gunpowder	Fireworkers prefer the term Blackpowder although chemically and physically the two are the same (See also: Blackpowder)
Hammer shell	A shell, typically multibreak, comprising colour breaks and reports timed to break in alternation
Hanabi	Japanese word for Fireworks, roughly translated as "flowers of fire"
Hang fire	A fuse or pyrotechnic composition that continues to burn very slowly, often almost invisibly, rather than at it's design speed. As such a hangfire presents a serious danger to firers (See also: Misfire)
HDPE mortar	High Density PolyEthylene--an extremely useful material for mortars. Belling rather than fragmentation of HDPE mortars tends to occur with failure of normal (not salute) shells
High explosive	An explosive that is capable of detonating

	when unconfined (See also: Low explosive, Propellant)
HSE	The British Health and Safety Executive-the legislative and enforcement body in the UK
Hummer	A device that produces a humming sound, usually made from a thick walled tube filled with composition, sealed at both ends, and pierced tangentially to the inner diameter. The sound is made as the device spins rapidly in flight
Hygroscopic	The property of a material that causes it to absorb and retain moisture from the air. As such, Hygroscopic compounds find only limited use in firework manufacture
Igniter	Shortened term for Electric igniter (See also: Electric igniter)
Igniter cord	Some types are more properly called Plastic Igniter Cord. Generally made for the blasting industries in several speeds. The slow cord finds use in fireworks manufacture, particularly for fitting of delay fuses
Ignition	The initiation of burning of a pyrotechnic material
Indoor firework	In terms of the British and European standards devices of very limited power suitable for use indoors. Types include sparklers, snakes and other novelty items. (See also: British standard, European standard)
Ionic bond	A type of chemical bond characterised by transfer of electrons from one atom to another. Thus common salt is written Na^+Cl^-. Most oxidants and colouring agents for firework compositions are ionic compounds. (See also: Covalent)
Japanese style shell	The ultimate spherical burst shell. The Japanese strive to produce perfect symmetry and patterns in their shells. Japanese shells are also noted for the contrasting coloured pistils that form part of the burst of many effects (See also: Peony shell, Pattern shell)
Kamuro	A long burning star, usually silver or gold,

that falls a substantial distance from the shell burst before, perhaps, changing colour at the end of its flight (See also: Brocade, Crown chrysanthemum)

Kraft paper	A strong paper used for pasting shells and for capping (See also: Capping, Paste)
Lance	Usually a small, thin walled, tube containing coloured composition used to make lancework (See also: Lancework)
Lancework	Usually a message, logo, or design made on a wooden lattice work frame comprising many lances fused together
Leader	The initial fuse of a shell that transfers fire from the delay fuse (if any) to the lifting charge of the shell. For small calibre shells the leader may be used to lower the shell to the bottom of the mortar tube, but this is not good practice with larger calibre shells
Lifting charge	The charge beneath an aerial shell (or Roman candle unit) which propels the unit into the air. The listing charge almost universally used in firework manufacture is granulated blackpowder (See also: Bursting charge)
Line	In electrical firing one "line" is a single circuit, perhaps comprising many individual ignitions, that are fired simultaneously (See also: Electric firing)
Line rocket	A rocket designed to travel along a wire or rope (See also: Pigeon)
Low explosive	An explosive that burns or deflagrates on ignition rather than detonating. Almost all pyrotechnic compositions are low explosives (See also: High explosive, Propellant)
M-80	A type of small, but powerful, device containing flash powder. M-80s are now banned from sale in the US (See also: Cracker, Thunderflash)
Machine	A construction, commonly used in the 19th and early 20th Centuries, to "enhance" the spectacle of a fireworks display. Great ef-

	forts were made to disguise the presence of fireworks within statues and ornaments, which would then be ignited to produce the intended, but concealed, firework effect
Magnalium	The most commonly used alloy in firework making. Magnalium is usually a 1:1 mixture of magnesium and aluminium and is described chemically as a eutectic mixture of A12Mg3 in Mg2A13. (See also: Alloy)
Manufacture	The process of making fireworks from the raw materials. The term is more generally applied to any manipulation of firework components (e.g fusing shells).
Maroon	An exploding device that produces a loud bang. Aerial maroons are the most common, the composition being with blackpowder or flashpowder. From French-marron-chestnut (from the noise they make in a fire) (See also: Salute, Flash powder)
Match	The generic term for quickmatch, black match etc (See also: Quickmatch, Piped match)
Meal powder	Finely divided blackpowder available in several grades. (See also: Blackpowder)
Mesh size	The designation of the number of wires of standard thickness per inch used to make a sieve. For instance a 60 mesh sieve has a screen size of 250 microns (See also: Sieve size)
Metal salt	The combination of an electropositive metal ion with an electronegative anion. For instance Potassium Nitrate (See also: Ionic bond)
MIDI	A method of computer control of firework displays in which cues are programmed like notes on a score. MIDI is an internationally recognised coding standard usually used for composing music (See also: Electric firing)
Mine	Typically a complete article with firing tube, but generally the firework itself (See also: Mortar mine, Bag mine)

Mine bag	syn. mortar mine. (See also: Mortar mine)
Mini mine	A Roman candle in which each shot produces a mine effect many stars, rather than the more typical single star per shot (See also: Roman candle)
Misfire	In general any failure of a firework to function as predicted. Modern usage restricts the term to the failure of a firework fuse (See also: Hang fire)
Mixture	Usually synonymous with "composition", but may mean the list of ingredients of a composition (See also: Composition)
Mortar	The tube used to fire an aerial shell, or mine. Mortars can be constructed from paper, plastic, GRP or metal (See also: Aerial shell)
Mortar mine	A mine fired from a mortar (See also: Mine)
Mosaic	The French term for splitting cornet (See also: Splitting comet, Crossette)
Multibreak shell	An aerial shell comprising more than one section producing a separate effect in sequence and ignited by the bursting of the preceding section. The public may incorrectly refer to a "shell of shells" as a multibreak effect (See also: Shell of shells, Repeater shell)
Multishot battery	The generic term for a collection of pyrotechnic pieces lit at a single ignition point, but often used exclusively for items referred to as "cakes" (See also: Cake)
Muzzle break	A malfunction of a shell where the bursting charge operates just as the shell leaves the mortar. This is a common point of shell failure as the pressure changes that act on the shell are great at this point (See also: Flower pot)
Niagara falls	Brocks often fitted Niagara falls with a loud whistle accompanying the visual effect (See also: Waterfall)

No-fire current	The upper limit for a current that will not fire an igniter, and thus the upper limit for a test current for electrical circuits (See also: Safe current)
Noise mine	A mine in which the principle effect is ejection of pyrotechnic noise units (e.g crackers or whistles) (See also: Star mine)
Nomatch	A specialised system for igniting fireworks using a shock tube. The advantage of Nomatch is the extremely high speed of propagation leading to almost simultaneous ignition of several pieces at great distances.
Ohm meter	A device for measuring the resistance of a circuit, and typically build into electrical firing panels. The current applied by the Ohm meter must be less that the no-fire current! (See also: No-fire current)
Open circuit	An electric circuit that is not complete--i.e will not fire when a current is applied (See also: Closed circuit)
Orange book	The United Nations book on the Classification and Testing of Dangerous Goods (See also: UN classification)
Organic	In our terms a solvent that is not based on water (e.g Acetone or Cyclohexanone) (See also: Aqueous)
Oxidant	The component of a firework composition that supplies the oxygen to the reaction (e.g Potassium Nitrate) (See also: Fuel)
Oxidising agent	In firework compositions syn. Oxidant
Palm burst	The central burst, similar to a coconut shell, of a colour shell. For instance a "Red peony with palm core"
Parallel circuit	An electrical circuit in which the current is divided to pass through several igniters. Parallel circuits are less easy to test for line breaks and short circuits than series circuits. (See also: Series circuit)
Paste	The most common usage is that referring to the pasting of aerial shells to enhance the burst of the shells (See also: Spiking)

Pattern shell	A shell, usually with many fewer stars than a chrysanthemum shell of the same calibre, whose burst pattern is such that a pattern rather than a sphere of stars is produced. Pattern shells come in many levels of complexity, but perhaps the most pleasing is the simple single circle (See also: Atomic pattern, Saturn pattern)
Pellet	An alternative term for a star, usually restricted to pumped, cylindrical form, stars (See also: Star)
Peony shell	A typical Japanese style of shell in which the stars do not leave a trail of sparks (See also: Chrysanthemum shell, Dahlia shell)
PGI	The American "Pyrotechnics Guild International"
PIC	Plastic Igniter Cord (See also: Igniter cord)
Pigeon	A specialized type of novelty firework in which a rocket motor is forced to run horizontally along a wire or rope, usually accompanied by a whistling effect. Often, the pigeon will make the journey several times, first in one direction, then the other (See also: Line rocket)
Pillbox star	A star made from pressing (usually by hand) composition into a small thin-walled cardboard tube. Pill box stars are rarely made nowadays, but their effect can be dramatically different to round or pumped stars. Pill box stars usually have a longer burning duration that pumped or round stars (See also: Star)
Piped match	Raw match enclosed in, usually, a paper tube used for transferring fire from one firework to another. Piped match also forms the leader of a shell (See also: Raw match, Black match)

Pistil	In typical Japanese shells a central core to the burst of a contrasting or complementary colour to the main burst (See also: Chrysanthemum shell, Peony shell)
Plug	Typically the closure of a mortar tube, but more generally the closure of any tube (e.g a Roman candle tube)
Poka shell	A weak busting shell of Japanese design commonly used for deploying parachutes or tissue-paper flags (See also: Warimono shell, Japanese style shell)
Polverone	syn. Pulverone
Portfire	Usually a thin-walled tube filled with slow burning composition used to ignite other fireworks. It is similar to a fusee, but its flame is usually less fierce and varies in colour. A test for a good portfire is that it should continue to burn after being dropped vertically onto its lit end at arm's length!
Post	A geographical position on a firing site used to identify the layout of the site. For instance, there may be 3 posts of Roman candles spread along the front of a site (See also: Line)
Press	A machine used to fill composition into tubes (e.g gerb press), or for making fireworks (e.g Roman candle press)
Prime	Often a slurry of blackpowder, a binder and water occasionally with added ingredients (e.g silicon) to increase the burning temperature used for ensuring ignition of reluctant compositions (See also: First fire)
Priming	A process carried out to ensure ignition of a pyrotechnic composition when the composition itself is difficult to ignite. For instance, round stars are often primed for use in shells where the ignition time is short, whereas the same stars may be used without priming in a mine where the ignition time is longer

Propellant	A composition used, typically, in a rocket motor to provide force. In more general terms any composition used to propel a firework into the air (See also: Explosive, Rocket motor)
Pulverone	Granulated rough powder (usually of the same composition as blackpowder) used as the bursting charge of a shell
Pumped star	A star produced by compressing composition in a mould. Pumped stars are usually cylindrical in form (See also: Round star)
Punk	A wick for lighting small fireworks (See also: Portfire)
PVC	Poly Vinyl Chloride-one of many chlorine donors used as colour enhancing agents in firework compositions (See also: Colour enhancing agent)
Pyrotechnic	The generic term for any item (or composition) which reacts in a self-sustaining chemical reaction and is generally produces an effect of light, smoke, noise or heat. Pyrotechnic articles are classified differently to fireworks and the term is usually restricted to theatrical effects and specialised items such as mole smokes or thermite charges (See also: Firework)
Quickmatch	syn. Raw match (See also: Raw match, Piped match)
Rack	An apparatus, usually for firing rockets. The term may also be applied to "racks" of mortars (See also: Rocket rack)
Rain	Usually Silver rain or Gold Rain, in modern fireworks the long lasting stars from a shell or rocket that fall all the way to the ground. Care must be taken in the use of rain shells. In older terminology a "Golden Rain" was a particularly attractive type of hand held fountain (See also: Glitter)
Ram	The rod which is used to compress powder within a tube. The ram is usually quite a tight fit to the tube (cf funnel and wire)

Ramming	The process of filling a firework case with composition. Ramming is usually applied to a mechanical process rather than to a manual process.
Raw match	Blackpowder coated thread used for linking fireworks (See also: Quickmatch)
Reducing agent	The chemical role of a fuel in a firework composition. As the oxidising agent oxidises the fuel, the fuel can be said to reduce the oxidant (See also: Oxidising agent, Fuel)
Repeater shell	Usually a cylinder shells with several timed colour bursts at regular intervals. Repeater shells are often fired in sequence--1 break, 2 break, 3 break, 4 break etc. Cf Multibreak shell (See also: Multibreak shell)
Resins	Usually applied to binding agents soluble in organic solvents e.g Accaroid resin (See also: Gums)
Resistance	The property of a material which acts to impede the flow of electrical current. In electrical firing of fireworks the resistance of a line is measure to prevent accidental "open" or "short" circuits. (See also: Ohm meter)
Ring shell	An aerial shell that produces a symmetric ring of stars on bursting. Ring shells often are stabilised in flight with a rope "tail" to control the orientation of burst (See also: Pattern shell)
Rising effect	Often synonymous with "tail effect", but may also be applied to shells in which, for instance, whistles or small shells (rising flowers) have been attached and which function on the shell's ascent (See also: Tail effect)
Rocket	An aerial device propelled into the air by a motor (cf shell), many of the public will describe any aerial firework as a "rocket".
Rocket cone	A device for firing flight rockets usually made from sheet steel curved into the characteristic cone shape (See also: Flight rocket)

Rocket motor	The power unit of a rocket, typically manufactured nowadays by pressing blackpowder into a choked tube without a spindle. Rocket motors occasionally find other uses in pyrotechnics-as wheel drivers, and as short duration fountains (See also: Rocket)
Rocket rack	A rack, usually made of wood or metal, for mounting many rockets prior to firing
Rocket spindle	The spike (usually metal) used to form the older type of rocket motor with a central cavity for increased burning pressure (See also: Rocket, Choke)
Roman candle	A tube, usually cardboard, in which several charges are loaded, each with their own delay fuse and lifting charge, which function in a sequential manner
Round shell	An aerial shell in the form of a sphere. Round shells usually contain coloured stars (See also: Cylinder shell)
Round star	A star prepared by rolling, thus applying layer upon layer of composition onto a central core
Roundel shell	An aerial shell comprising several maroons that burst in a ring pattern one after another (See also: Siatene shell)
Safe current	The current level that it is safe to test an electric igniter without ignition (See also: Firing current)
Safety area	The area around a display site, usually not including the fall out area which is considered separately (See also: Fallout area)
Safety cap	syn. Fuse cover
Safety fuse	A specialised fuse, designed for commercial blasting of construction similar to Bickford fuse but with a heavy waterproof coating (See also: Bickford fuse)
Salute	American term for maroon. (See also: Maroon)
Saturn pattern	Usually refers to a "Chrysanthemum in Circle" type shell rather than an "Atomic" pattern shell (See also: Pattern shell, Atomic pattern)

Scratch mix	A coarsely sieved mixture of Potassium Nitrate, Charcoal and Sulphur primarily used as a prime for stars (See also: Prime)
Screecher	Physically a whistle with a hole through it, producing a much more "rasping" sound. In a screecher the instability arising from the oscillations of burning interfere with each other almost to the point of causing the resulting firework to detonate
Senko hanabi	A delicate pyrotechnic sparking effect, commonly produced in Japan, produced from the burning of a sulphur-rich blackpowder composition. When burned, the droplets of molten composition that form react further with air to produce attractive branching sparks
Sensitivity	The ease of ignition of a firework composition. Highly sensitive compositions (e.g flash powder) require extremely careful handling. (See also: Electrostatic Sensitivity, Thermal stability)
Sequence	Usually refers to the pattern of firing of a section of a display. For instance a sequence could comprise 10 X 3" gold shells followed by 10 X 4" gold shells followed by 5 X 5" gold shells
Sequencer	An electrical firing system used to send regular electric pulses to fire a number of fireworks in a very accurately controlled manner
Series circuit	The preferred method of linking multiple electric igniters. Series circuits are arranged so that the current runs through each igniter in a sequential way. Series circuits are much easier to test for continuity and correct wiring than parallel circuits (See also: Parallel circuit)
Serpent	Usually a small tube filled with composition and possible a report charge, that is fired en masse from shells, mines, or rarely Roman candles. The serpents fly about in a random fashion prior to bursting with a report or stars
Set piece	A generic term for a ground firework but

usually distinguished from Lancework. The set piece may be static or revolving and is made up from gerbs and/or noise and colour units. (See also: Lancework)

Shell — The most spectacular of fireworks comprising a lifting charge (to propel the shell into the air) and a bursting charge to eject stars or subassemblies in the air after a predetermined delay. Shells are fired from mortars (See also: Bursting charge, Lifting charge)

Shell delay — A more precise term than delay fuse, this refers to the internal delay within a shell to permit it to ascent to its desired height before igniting the bursting charge. Shell delays are commonly made from composition pressed into a card tube (for cylinder shells, especially those with plastic moulded cases) and variations of Bickford fuse (See also: Delay fuse, Bursting charge)

Shell of shells — An aerial display shell that contains internal shells that are ignited when the main shell bursts, and subsequently produce secondary bursts

Short circuit — Usually the accidental completion of an electrical circuit which causes the current not to flow through the electric igniters and thus leads to line failure. Short circuits can usually be discovered readily in series circuits by electrical testing of the circuit with an ohmmeter

Shot — Usually refers to the single functioning of, say, a Roman Candle. Thus typically Roman candles are referred to as "8 shots"

Siatene shell — An aerial shells comprising several maroons that burst in a ring pattern at the same time (See also: Roundel shell)

Sieve size — The size of the hole in a sieve. (See also: Mesh size)

Smoke — An air suspension of particles usually from incomplete combustion of a composition

Smokeless powder — A pyrotechnic mixture containing nitrocellulose and nitroglycerine so called because, un-

	like blackpowder, it does not produce much smoke on burning. In this way it found favour as a propellant in small arms devices, although its use in fireworks is rare
Spark	The typical effect caused by incandescent particles ejected from the burning surface of a composition
Sparkler	Usually a wire coated with pyrotechnic composition that gives off small sparks when burnt. Sparklers, although considered safe, are the cause of the greatest number of hospitalised accidents in the UK each season
Spider shell	An aerial shell having a small number of relatively large stars producing a web effect. Spider shells having 24 large comets are sometimes called Octopus shells. (See also: Palm burst)
Spiking	syn, stringing. (See also: Cylinder shell, Stringing)
Spiking horse	The device used to facilitate the spiking, or stringing, of shells
Spiral wound tube	A paper tube wound from several narrow paper strips at an angle. Roman candles made with spiral tubes are prone to failure if fire can be transferred by loose composition trapped in the spiral winding (See also: Convolute wound tube)
Splitting comet	A comet in which there is an internal charge (usually of flash powder) which when ignited splits the comet into several pieces. The effect is of a comet that travels for some period and then fragments. Splitting comet stars are typically found in shells, mines, and especially Roman candles. syn. Crossette
Spolette	A shell or Roman candle delay fuse usually made from pressing blackpowder into a small bore tube (See also: Roman candle, Shell delay)
Squib	syn. Electric igniter
Star	Pellets of composition (usually cylinders,

	cubes or spheres) used in mines, shells, roman candles, rockets and occasionally gerbs (See also: Round star, Cut star)
Star mine	A mine in which the projection of coloured stars is the principle effect (See also: Mini mine, Noise mine)
Steel mortar	A mortar made from steel tube, usually with a welded steel base. Steel mortars are increasingly rarely used due to worries about their fragmentation should a powerful shell burst within the tube. However, for some shells (particularly cylinder shells) they are still the material of choice for most people (See also: HDPE mortar, GRP mortar)
Storage	The holding of fireworks prior to their use. In most countries storage of fireworks above a certain quantity requires a licence (See also: Transportation)
Stringing	syn. Spiking the process of winding a strong string around the outer surface of a shell to produce a more regular bursting pattern (See also: Spiking, Cylinder shell)
Strobe	The effect of a strobe is the regular pulsing "on-off-on-off" of light as a firework composition burns. There are several proposed explanations of this effect. Strobe effects are most often seen in ground fireworks (strobe pots) or as stars in an aerial shell or rocket (See also: Blinker)
Tail effect	Usually a term applied to a shell in which a star (comet) has been attached to the outside and which produces a rising column of sparks on the shell's ascent. "Tail" may also be applied to rockets, Roman candle stars or even whistle units where a persistent (usually silver) spark follows the flight of the device (See also: Weeping willow shell, Trunk)
Temple	syn. Machine
Thermal stability	The tendency for a composition to ignite from the energy applied by heat. Thermal sta-

	bility testing is routinely carried out as part of the authorisation procedure for fireworks in many countries (See also: Sensitivity)
Thermite	A mixture of aluminium and iron oxide (FE304) still used for in situ welding of railway tracks
Thunderflash	A generic term for a report with flash (See also: M-80, Cracker)
Tiger tail shell	Usually a solid sphere of composition fired in exactly the same manner as a shell. The effect produced is of an extremely thick rising comet. Optionally there is a small shell burst at the apex of its flight (See also: Tail effect)
Titanium	A silver metal much used for producing brilliant white sparks (e.g., in a maroon or gerb). Titanium does not corrode (cf aluminium), but is extremely hard and may increase the friction sensitivity of a firework composition (See also: Maroon)
TNT equivalent	A measure of explosive strength used as a comparison to TNT, usually for determining safe loading of buildings
Top fused	Usually an aerial shell in which the time fuse (shell delay) for the functioning of the bursting charge is physically at the tope of the shell and lit independently to the lifting charge (See also: Bottom fused)
Torbillion	Also Tourbillion. Either very similar to a serpent unit, or a larger aerial firework comprised of a saxon and wing, designed to rise into the air on ignition (See also: Crown wheel, Serpent)
Torch	syn. flare
Torpedo	A flying squib or throwdown usually containing silver fulminate. The term has also been applied to railway signals (See also: Flying squib)
Transportation	The process of consigning a load of fireworks, usually taken to apply once the consignment has left the factory gates. Transpor-

	tation of fireworks is subject to heavy legislative control
Trunk	The rising effect seen on willow shells, and increasingly on many other shells (See also: Weeping willow shell, Coconut shell)
Turning case	A specialised type of gerb used for driving wheels. Typically turning cases are made from composition containing a larger proportion of blackpowder than the equivalent gerb (See also: Gerb, Fix)
UN classification	The assignment of a packaged firework into one of the UN's 5 classes for fireworks (See also: European standard, UN mark)
UN compatibility group	The "G" of 1.3G. The compatibility group, largely irrelevant for most firework usage, prescribes which explosives may be transported with which others. For instance detonators should not be transported with primary explosives, explosives containing toxic agents should not be transported AT ALL!
UN hazard code	syn. UN number
UN mark	A complicated index assigned to the PACKAGING of dangerous goods. (Cf UN number) (See also: UN classification)
UN number	A four digit number assigned to any hazardous goods after classification in its TRANSPORT PACKAGING according the methods prescribed in the "Orange Book". For fireworks the relevant numbers are 0333 (1.1G), 0334 (1.2G), 0335 (1.3G), 0336 (1.4G) and 0337 (1.4S). The UN number should always be quoted as it uniquely identifies an item AND its hazard. (See also: UN classification, Orange Book)
Visco fuse	A fuse, commonly used on consumer fireworks as the delay fuse, which is usually made by wrapping a core of blackpowder with thread and lacquer
Volley	A term usually applied to a mass firing or rockets (See also: Flight rocket, Rocket cone)
Warimono shell	A Japanese term for the type of shell that

	produces a spherical burst of stars. Most shells are of this type. Cf Poka shell. (See also: Poka shell, Japanese style shell), Warimono means Chrysanthemum.
Water firework	The generic term for any firework fired on the surface of water to maximise the visual effect of its reflections (See also: Water shell, Water gerb)
Water gerb	Usually a gerb or fountain weighted at one end and attached to a piece of cork designed to function on the surface of water. A water gerb may be lit by hand and thrown onto the water's surface, or fired like a shell from a mortar (in each case with a suitable delay fuse).
Water shell	A shell designed to function on the surface of water (e.g a lake) producing a hemisphere of stars. Water shells may be fired from mortars angled at a low angle, or may be set up on the water's surface prior to the start of the display (See also: Shell)
Waterfall	Usually an extended curtain of silver sparks from vertical or horizontally burning tubes filled with a composition containing aluminium. Waterfall shells produce the same effect and are best fired en masse to produce a spectacle
Weeping willow shell	Syn. Willow shell
Wheel	A rotating set piece, usually powered by gerbs or turning cases, and most often rotating in a vertical plane (See also: Set piece, Turning case)
Whistle	Usually a tube containing a composition made using potassium benzoate, potassium salicylate, or rarely nowadays, potassium picrate. On burning the composition burns in a rapidly oscillating manner, and the resulting pressure waves are amplified by the tube in a manner similar to an organ pipe (See also: Screecher)
Whizzer	American alternative name for hummer

Willow shell — An extremely attractive shell comprising stars made with a high percentage of charcoal. The effect is of long-burning golden stars which often (but undesirably) fall all the way to the ground. The shell may optionally be fitted with a "trunk" (syn. Weeping Willow Shell)

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