LABORATORY GLASSBLOWING

L.M. PARR & G.A. HENDLEY

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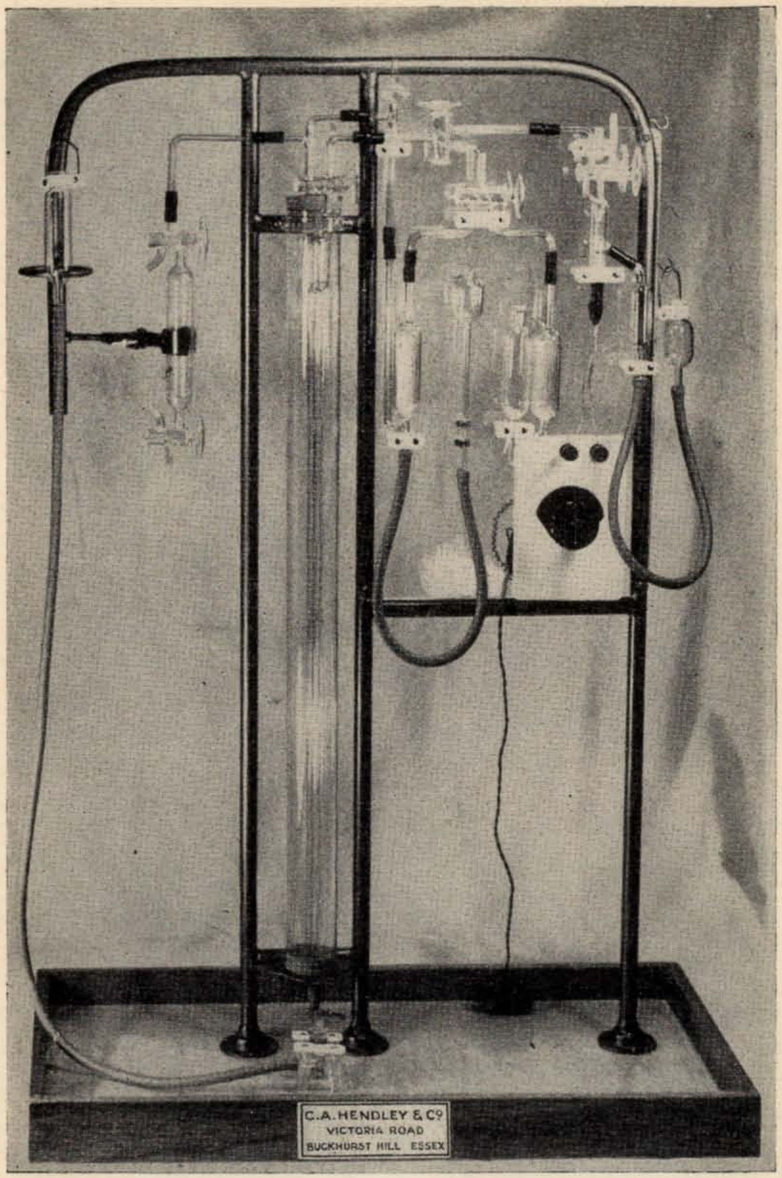

THE HALDANE GAS ANALYSIS APPARATUS

All the glass components in an apparatus such as this can be made by employing the fundamental glassblowing operations described in this book.

(*C. A. Hendley and Co.*)

LABORATORY GLASSBLOWING

Dealing with the fundamental operations of Glassblowing and Glass Working techniques for laboratory workers

BY

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in collaboration with

C. A. HENDLEY

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PREFACE

WHEN confronted with a piece of glassware which has been broken during a critical experiment, or when anxiously awaiting the delivery of some special glass apparatus, how many laboratory workers have ruefully regretted their inability to deal with the job themselves?

Through this book, the Authors hope to remedy this state of affairs. Herein are given instructions which they hope will enable any reasonably dexterous person to acquire sufficient skill, not only to execute repairs to broken glassware, but also to make quite complicated glass apparatus.

The first two chapters describe the necessary equipment for laboratory glassblowing, including the different types of blowpipes and how they are used.

Then follows a chapter on glass, in which are included the specific properties of the various kinds of glass which are available for laboratory purposes. Included also in this chapter are details relating to the important subject of annealing.

Then, after instructions have been given regarding the preparation of the glass and equipment, Chapters 4–11 deal with the actual glassblowing techniques, from the elementary operations, such as cutting, joining, sealing, etc., of glass tubes of varying types and sizes, to the more advanced processes employed in the blowing of laboratory glassware for special purposes.

Some of the methods described would perhaps be considered a little unorthodox by the professional glassblower; but, as these methods have been found to give good results, they will serve to encourage the unskilled laboratory worker, until, with more practice, he can master the correct technique.

The descriptions have deliberately been confined to the fundamental operations of glassblowing. Typical examples have, however, been given to show how the fundamental processes are combined to produce the finished article.

The Authors would particularly stress the importance of *careful preparation*, *deliberate manipulation*, and *constant practice*. The bad habit of rushing to the blowpipe with the first piece of glass which comes handy, without thought of the proper procedure, will give only disappointing results.

If each chapter is studied carefully, and in its correct sequence, the pitfalls will be avoided, and with practice the laboratory worker or student will acquire the necessary skill in a very short time.

The Authors wish to express their thanks to all those who have helped them by placing information and data at their disposal. In particular to Mr. W. J. H. Grainger for his help and encouragement, by supplying copies of papers not otherwise obtainable; to the Osram–G.E.C. Glass Works, for permission to reproduce data, including the Table of Weights of Tube in Appendix A; to Messrs. Griffin & George Ltd., for permission to reproduce illustrations; to Mr. A. G. Scott, who exercised great patience in producing the photographs; and finally to Mrs. E. Gray for typing the manuscript.

C. A. H.
L. M. P.

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CHAPTER I

EQUIPMENT

THE craft of glassblowing is one which may be practised with very little equipment. The barest necessities are a bench to work on, a blowpipe and bellows or compressor, a few simple tools which any handyman can make from scrap material and, of course, a supply of gas.

Until comparatively recent years, a large proportion of the German production of blown-glass articles was made by craftsmen working in their own homes, using an oil lamp and foot bellows—hence the expression "lampblown glassware"; and even now, many glassblowers refer to the blowpipe as the "lamp". It is not proposed to limit ourselves to such primitive equipment, but even so, there is no need to spend a lot of money on elaborate apparatus and tools. By far the best way of collecting the necessary equipment is first to buy the essentials, and then to purchase or make additional tools, and so on as the need arises.

The Bench

Obviously the first requirement is a bench upon which to work, and a suitable situation in which to place it. The bench or table should be rigidly constructed of wood or metal, and should be at least 4 ft. 6 in. long, 2 ft. 6 in. wide, and 30 in. high. The underside of the bench should be clear, in the centre portion at least; but a small nest of drawers can be installed under the right-hand end; in these drawers can be kept small tools, corks, and all the innumerable small articles which one inevitably accumulates in course of time.

The top of the bench must be covered with a sheet of asbestos or Sindanyo, which is completely fireproof, and is also soft enough not to damage glass articles, hot or cold, which may be laid on it.

The gas and air supplies, and also the switch for the motor blower, if one is used, should be located in convenient positions on the front rail of the bench; a scalloped rail, fitted to the back of the bench-top, will be found most convenient as a safe rest for glass tubing and articles while work is in progress.

If possible, the bench should be located in a position which avoids front light; the ideal arrangement is to have the source of light from either the sides or back of the bench. Sufficient room should be left around the bench to allow long articles to be manipulated with safety; for the same reason it is well to keep the bench away from the wall unless it is at least 3 ft. wide.

Air and Oxygen Supplies

The gas supply must be permanently piped to the bench. A $\frac{1}{4}$-in. main may be used, but a $\frac{1}{2}$-in. supply pipe is advisable; it should terminate in a substantial tap fitted with a riffled connection for rubber tube, located on the front rail of the bench. The local office of the Gas Board should be consulted before installing the gas line, as, particularly if it is proposed to use an oxygen–coal-gas

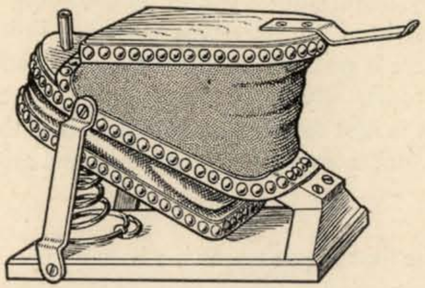


FIG. 1-1.—FOOT BELLOWS
(Griffin & George Ltd.)

blowpipe, they will probably insist on the installation of a non-return valve to protect the mains in case of a blowback.

The means of obtaining an air supply will depend upon the amount of glassblowing envisaged. For occasional use, foot bellows such as that illustrated in Fig. 1-1 will be adequate. This should be connected by means of a stout rubber tube to a tap fitted near the gas tap on the bench. If a compressed-air supply is laid on in the laboratory, this should be piped to the bench, if necessary through a reducing valve, to give a working pressure of some 5–12 lb./sq. in.

If much glassblowing is contemplated and no compressed air is available, an electric blower, such as that shown in Fig. 1-2, will be found to be a good investment. As this is rather noisy in

operation, it is as well to fix it in a remote position, where the noise will not be a nuisance, and connect the air line to the bench by a $\frac{1}{2}$-in. metal pipe; the electric controls should also be fixed to the bench—not forgetting to fit suitable fuses in the circuit.

If borosilicate and similar hard glasses are to be worked, a supply of oxygen will be required. This can be obtained compressed in metal cylinders. The most convenient size of cylinder contains about 200 cu. ft. of gas, which is sufficient for several

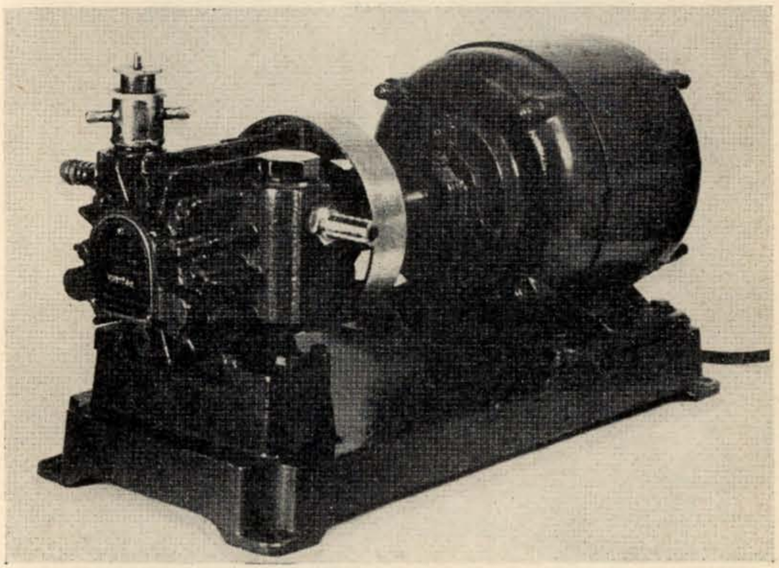


FIG. 1-2.—AN ELECTRIC BLOWER

hours' work, but is not unduly large to handle. It is not necessary, in fact it is undesirable, to purchase the steel cylinder, as the company from whom the oxygen is obtained will hire out the cylinders for a very nominal charge.

As the pressure in a new cylinder of gas is 2000 lb./sq. in., a reducing valve and gauge will be required (Fig. 1-3). This must be purchased, together with a length of special pressure tubing; to protect the cylinder from danger of explosion in case of a blow-back this tube should have an anti-flash fitting incorporated. This will be fitted by the makers of the valve and tube if specified on the order.

Note that, in no circumstances, must oil or grease be applied

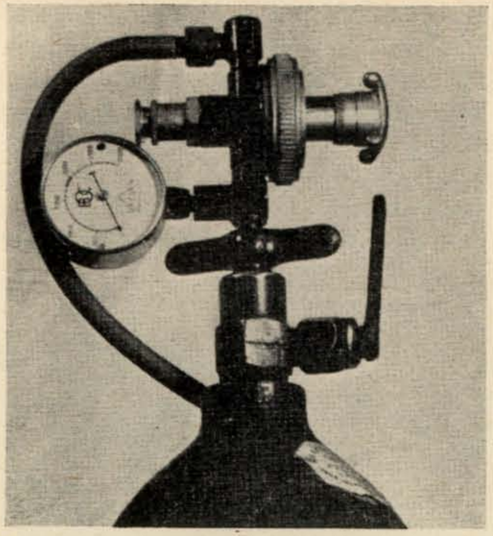


FIG. 1-3.—OXYGEN-CYLINDER REDUCING VALVE AND GAUGE

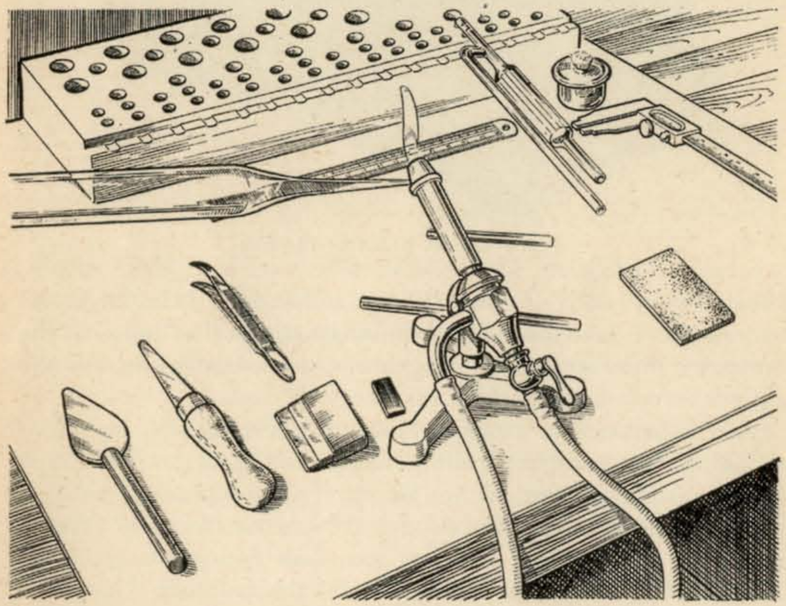


FIG. 1-4.—THE GLASSBLOWER'S BENCH
Note the tools and the wood block with holes to support glass while cooling.

to the valve or any other part used with oxygen, as a severe fire or even explosion may occur if such material is present.

The blowpipe, which will be considered in the next chapter, is

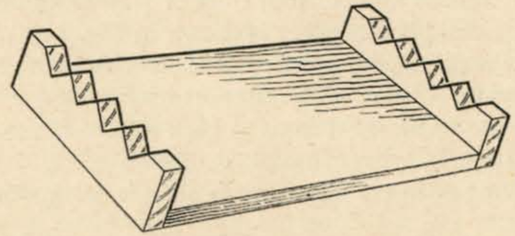


FIG. 1-5.—A USEFUL GLASS SUPPORT

located at the centre front of the bench-top; it should not be screwed down, as very often it is necessary to alter its position rapidly during blowing operations. It is connected to the gas and air taps by means of stout rubber tubes about 18 in. long.

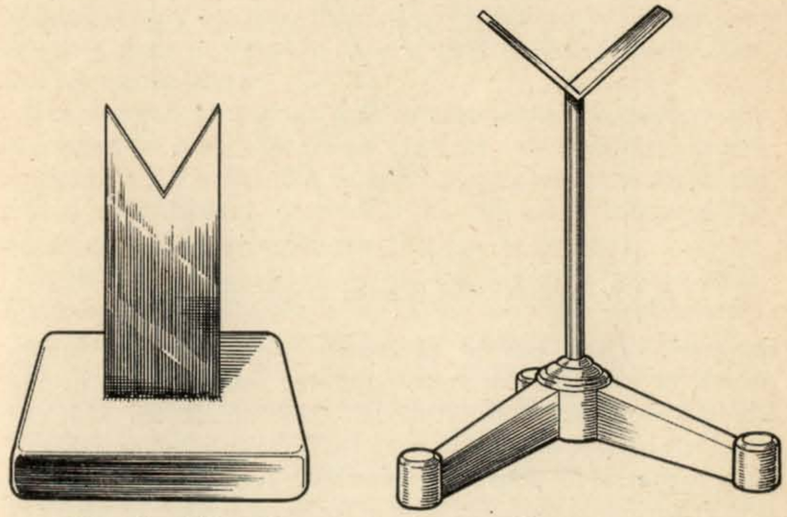


FIG. 1-6.—V-TYPE SUPPORTS FOR LONG OR HEAVY GLASSWORK
(Griffin & George Ltd.)

Fig. 1-4 shows a glassblower's bench such as that described, and on it are displayed a few fittings and tools which will be found necessary or convenient for efficient working. The glorified test-tube racks at the rear of the bench are for holding glass articles and tools while work is in progress. They can be made from scrap pieces of wood about 6 in. wide, 12–18 in. long, and ½ in. or more thick. Two such pieces are fixed about 4 in. apart by end pieces; the top has three or four rows of ¾-in. holes drilled in it.

Another useful glass support is shown in Fig. 1-5. It consists of a wood base fitted with notched ends, in which hot glass may be supported while cooling. The support may be of any convenient length, but the width from front to back should not exceed 6 in.

The V-supports, types of which are shown in Fig. 1-6, are used to support long or heavy glasswork while it is being worked in the

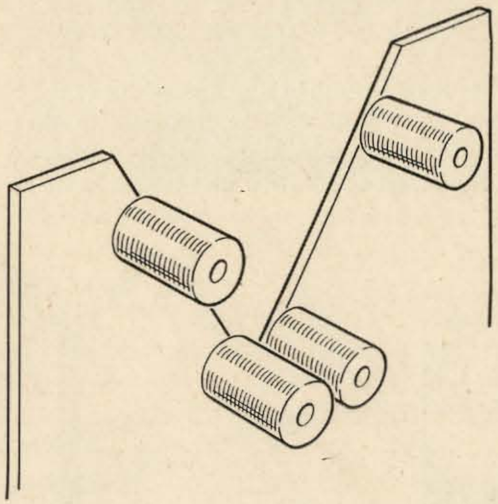


FIG. 1-7.—V-TYPE GLASS SUPPORT FITTED WITH ROLLERS

blowpipe. These can be purchased from laboratory supply houses, or can be made from oddments usually found in any laboratory or workshop. Although these are shown with the metal left bare, it is better to wrap the Vs with asbestos string or paper to prevent the glass being scratched. A further improvement is to fit horizontal fibre rollers on to the vertical edges of the Vs as shown in Fig. 1-7. A set of roller Vs such as this, fitted to a stand allowing adjustment for height, is well worth the trouble of making.

Tools

A triangular file can be used to cut glass, as described in Chapter 4, but a tungsten carbide knife, though expensive in the first

instance, is a very much better tool, which will last a very long time. When the knife ceases to cut nicely, it can be sharpened by drawing it smartly along a carborundum stone of the type found in any kitchen.

Several other pieces of equipment may be seen on the bench; these will be described at a later stage as the need for them arises, and a complete list will be found in Appendix B; we should like to draw special attention to the flat carbon plate, which is used for squaring the ends of hot tube, smoothing worked glass or flattening the ends of tubes. Carbon possesses the property of not adhering to glass, hence it does not drag or distort the hot material. At least one such plate should be purchased from the usual laboratory suppliers at the beginning of your glassblowing career.

Storing Glass Tube

Glass tube of all kinds is supplied in 5-ft. lengths, and storage always presents some problems. Whatever method is adopted, care should be taken to segregate the different kinds of glass. Nothing is more annoying than to find soda, borosilicate, and perhaps lead glass all mixed up, and to have to identify each before blowing can be started.

The method of storage will be determined largely by the amount to be stored, but in all cases the tube should be stored horizontally. Vertical tube racks are a snare and a delusion; the tube is easily broken, short ends are difficult to find, and the danger of serious cuts when selecting tube is very real.

By far the best method of storage is in horizontal pigeon-holes. These can be constructed either in the form of a professionally made rack or more cheaply by making light plywood boxes, about 6 in. square and 5 ft. 6 in. long, open at one end. These can be made and stacked on top of each other, or side by side, and the storage rack grows as the stock increases.

It is important not to forget that glass tube always gets jagged ends sooner or later, so that the store must be placed in a position where there is very little traffic, in order to lessen the risk of passers-by receiving serious damage.

Many glassblowers find it desirable to wear coloured goggles when working borosilicate glass, owing to the intense glare emitted by the material when very hot. Even more intense is the glow of molten silica; in fact, it is impossible to work it without dark goggles. The usual laboratory suppliers stock suitable types, such as " Bocal ", made by the British Oxygen Co. Ltd., and we would recommend the complete outfit, which includes both light and dark glasses. Whatever you get, do not purchase ordinary sun-glasses for this purpose. However good they may be, they will not remove the very actinic light, which can cause severe damage to the eyes.

CHAPTER 2

BLOWPIPES

THE blowpipe is the principal, indeed the essential, tool of the glassblower, so that skill and facility in using it is a necessity in all good glassblowing. The modern blowpipe is made in a variety of shapes and styles, all of which are designed to provide maximum flexibility of adjustment of the intensity, size, and direction of the flame.

Before describing these types of blowpipe, let us briefly consider the nature of flames. Fig. 2-1(A) is a diagram of the ordinary

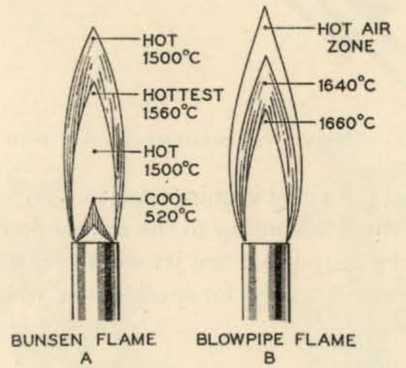


FIG. 2-1.—TEMPERATURE DISTRIBUTION IN FLAMES
A. Bunsen flame. B. Blowpipe flame.

bunsen flame, showing the temperature distribution; note that the hottest point is not the tip of the flame, but just at the tip of the inner cone; and that there is an inner cool zone at the base of the flame. While the hottest part of the flame is sufficient to melt soda glass, it is hardly sufficient for borosilicate.

If a blast of air is injected into this flame at the base, not only is the flame elongated, but a somewhat higher flame temperature is also attained. This is shown in Fig. 2-1(B); the cool zone at the base of the flame is considerably reduced, and the hot zone is more uniform.

B

The usual method of introducing the air into the flame is illustrated diagrammatically in Fig. 2-2 from which it will be seen that the air blast is introduced centrally, just inside the orifice of the

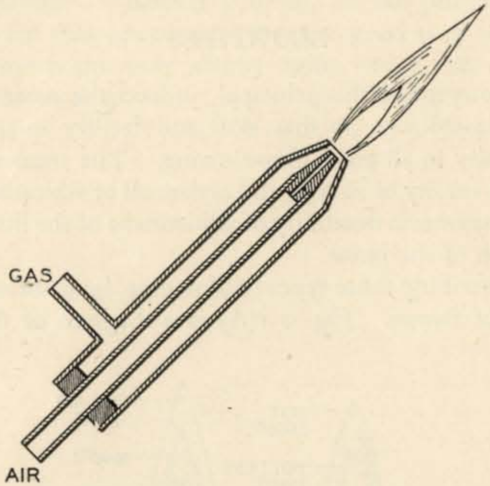


FIG. 2-2.—METHOD OF INTRODUCING AIR INTO FLAME

gas tube, and that the air jet is quite small and removable. Various sizes of jets are fitted according to the size of flame required, but it will generally be found that one jet will cover most of the glassblower's requirements, except for special jobs, when an extra large flame is required.

Types of Blowpipe

Fig. 2-3 illustrates a selection of modern blowpipes. The general construction is the same in all cases: a heavy foot; trunnions or universal joint supporting the blowpipe tube itself; and the necessary control stopcocks. Supported on the base of blowpipe *C* is the battery of various-sized jets; the blowpipes *A* and *D* are fitted with only a single jet. The air supply in blowpipe *A* is controlled by the rod projecting from the barrel, while in the other types it is controlled by the axial stopcock.

The blowpipe *B* is known as the turret type; three different barrels and a flat flame burner are mounted on a plate rotating on a central pivot, by which means the selected burner can be brought into instant use. This kind of burner is perhaps the

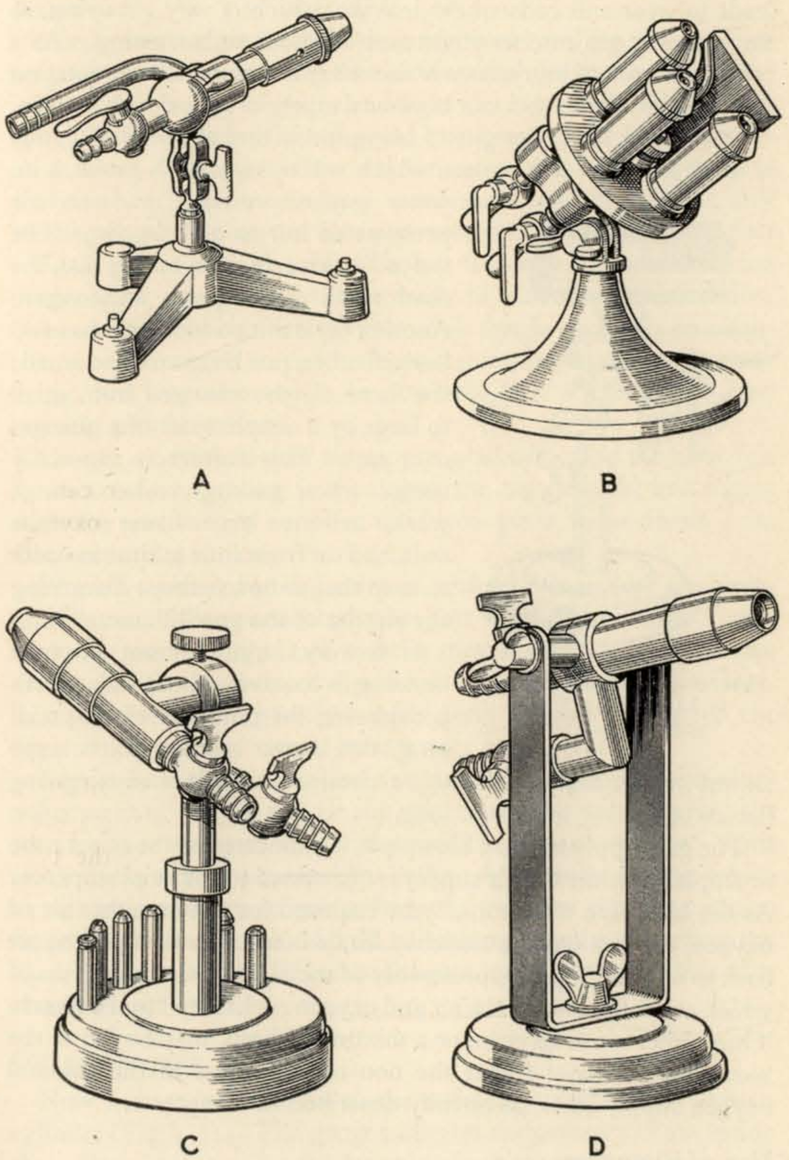


FIG. 2-3.—A SELECTION OF MODERN BLOWPIPES
(*Griffin & George Ltd.*)

least popular with the professional glassblower, as continued use leads to wear and consequent leakage, which is very annoying, as the escaping gas catches alight and becomes embarrassing. As a certain amount of lubrication is necessary to ensure smooth rotation of the turret, the burner can become dangerous if used with oxygen.

One of the latest designs of blowpipe is that shown at *D*: this is the "Bornkessel" burner, which will operate with gas at 2 in. water gauge pressure, and an air pressure as low as 2 lb./sq. in. The "250" series of this burner can be used with either air or oxygen. Another style of this blowpipe has two burner tubes, one large and one small; the flame can be changed from small to large by a simple twist of a change-over tap. This feature is especially useful when making seals in large work, as the large flame can be switched on from time to time in order to keep the job hot, without disturbing the setting of the small flame.

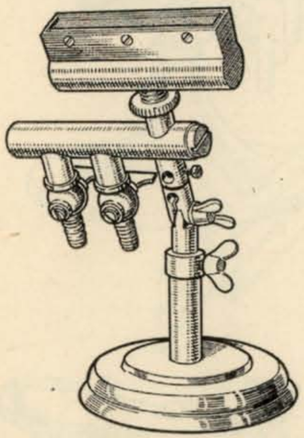


FIG. 2-4.—BURNER GIVING A LONG FLAT FLAME
(Griffin & George Ltd.)

If a very large amount of tube bending is contemplated, it is worth considering the purchase of a special long, flat, flame burner of the type shown in Fig. 2-4. This can be obtained in various sizes, giving flames of from 5 to 30 cm. long.

The gas supply to these blowpipes is connected to the offset tube or stopcock, while the air supply is connected to the axial stopcock. As the blowpipe will probably be required for use on either air or oxygen, or even oxygen-enriched air, it is usual to connect the air cock to a T- or Y-piece, preferably of metal, the other two arms of which are connected to the air and oxygen cocks fitted to the bench. Thus either air or oxygen, or a mixture of both, may be fed to the blowpipe. Do not forget the non-return valves in the gas and oxygen supply lines, as already described in Chapter 1.

Use of Blowpipe

When you have obtained and installed the blowpipe you have chosen it is worth spending some little time in exploring its capabilities and learning how to manipulate it with dexterity.

Check that the gas, bellows or compressor, and oxygen supplies are properly connected, and that all the supply stopcocks are shut.

Open the gas tap slightly, and light the blowpipe; if you turn the gas fully on before lighting you may scorch your face, as, with no air blast, the flame will be very large, and will burn in a vertical direction. If you are using a compressor, switch this on, still keeping the air tap on the blowpipe closed. If you are using foot bellows, pump until the reservoir bag is nearly full; when using the air blast, pump slowly and steadily to maintain this condition. Slow, even pumping with the foot is all that is necessary to maintain a sufficient air supply; frantic pumping is not only very tiring, but can also result in straining the reservoir bag and wearing out the valves.

Having established your air supply, gradually open the blowpipe air cock (not forgetting first to open the bench cock) and adjust both the gas and air supplies until you get a flame about ½ in. diameter and 4 in. long.

Procure a piece of stout iron wire, and with it explore the blowpipe flame. Note particularly the part of the flame which heats the wire most rapidly, and make a mental note so that you can always locate this part of the flame when using the blowpipe. Then explore the invisible hot-air zone beyond the tip of the flame, and get some idea of its intensity and extent.

Repeat your observations on various sizes of flame, obtained by adjustment of the gas and air supply; finally, by reducing first the air and then the gas, obtain the smallest flame you can. This small flame will be required for sealing operations, during which it will be necessary to use a large flame from time to time to keep the job hot. You should, therefore, practise adjusting the flame from large to small and back again until you can do this with certainty and speed.

Oxygen Supply

Now turn your attention to the reducing valve on the oxygen cylinder (Fig. 1-3). The gauge indicates the pressure of gas inside the cylinder when the cylinder valve is open, and enables one to determine how much gas is available. These cylinders are charged initially to about 2000 lb./sq. in.—a pressure far too high for use with the blowpipe. The purpose of the reducing valve is to adjust the outlet pressure to a much lower value. The thimble of the capstan handle shown on the right of the photograph is roughly graduated to indicate outlet pressure; adjust this to supply about 5 lb./sq. in.

Adjust the blowpipe to give a medium-size air–gas flame, and close the air cock on the bench, leaving that on the blowpipe untouched. Open the oxygen cylinder valve, using the special key provided for this purpose. As this valve is very tight when shut, you may find it necessary to tap it open with a piece of wood or anything handy—but do not use sufficient force to knock the valve wide open—a series of small taps will do all that is necessary.

Gradually open the bench oxygen cock to feed the oxygen to the flame. Remember that you will get a much fiercer and hotter flame than you did with air, so that if too much oxygen is used the flame may be blown out. Again explore the flame with the iron wire, and note the difference from an air–gas flame. Next reduce the oxygen supply, and open the air cock a little, adjusting the mixture until you are using half air and half oxygen, and examine the characteristics of the flame.

Do not forget to close the cylinder valve immediately you finish using oxygen, to prevent leakage and loss; the reducing valve cannot be relied on as a stopcock, and it is unwise to allow pressure to build up in the rubber connecting tubes.

" Premix " Burner

The blowpipes described so far are of the general type known as " blast " or " cannon " burners, in which the air and gas are mixed at the mouth of the jet. These blast burners have the advantages of flexibility; a wide range of flame size and intensity can be obtained with great facility by simple adjustments of the air and gas supplies. However, these burners make a great deal of noise, particularly when used with oxygen, and this is often a nuisance to those in the vicinity.

Less commonly used is the " premix " burner, in which the gas and air (or oxygen) is first mixed in a small chamber and then fed to the jet, where it burns reasonably quietly. These premix burners do not allow the wide range of flame size possible with the blast burner, and also suffer from the very great disadvantage that a fairly large volume of explosive mixture is always present

in the burner. This means that there is an ever-present real danger of an explosion; some safeguards certainly can be incorporated in the burner, but it must be realised that no liberties can be taken with them. The air or oxygen must always be turned off before the gas; if you use this type of blowpipe this procedure must become a fixed habit.

Unfortunately, premix burners are very expensive, so that unless a very great premium is placed on quietness of operation, or a large amount of work is contemplated, the economic factor limits their use.

The " Flamemaster " Torch

If you have to set up, repair, or alter large glass assemblies for gas analysis, vacuum work, or similar jobs in which glass parts

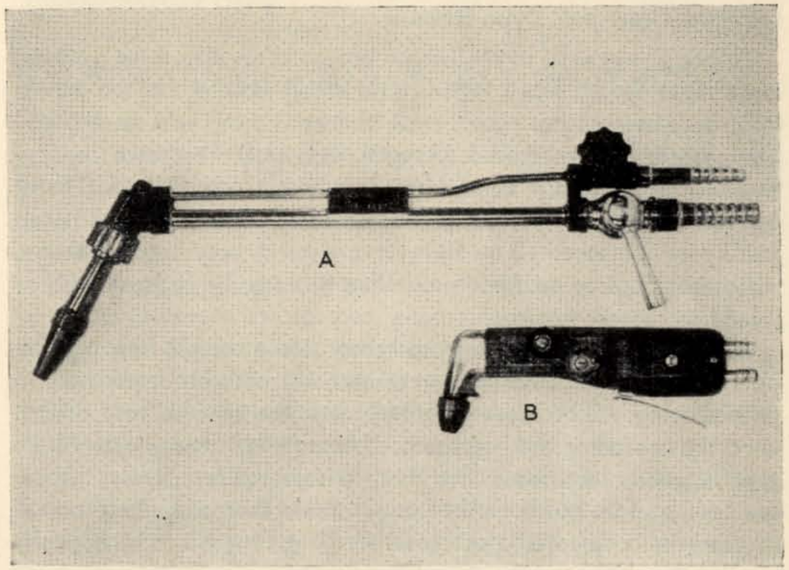


FIG. 2-5.—THE OXYGEN–COAL-GAS TYPE BURNER IS SHOWN AT " A " ABOVE, AND " B " SHOWS THE " FLAMEMASTER " TORCH

have to be joined up *in situ*, a small hand blowpipe is necessary. The most modern, and the most useful one, is the " Flamemaster " torch illustrated in Fig. 2-5(B). This is a delightful hand burner or torch to use, the gas and air supplies being instantly variable by means of the two fluted knobs mounted on the side, to give a large range of flame sizes, from a small pencil flame to a large, bushy one. The burners can be obtained to work either with air or oxygen. A fitting can also be obtained to make the gas–air type suitable for use with oxygen, and this can be attached or removed in a few minutes.

The trigger seen projecting from the handle of the burner is an economiser; when the torch is hung up or put down, the air is shut off and the gas supply reduced to a small pilot jet. For occasional use as a bench blowpipe, a simple bench clamp is obtainable which grips the handle part, and at the same time clamps the economiser in the open position. A very useful twin-bore rubber tube is also obtainable for this torch, and is well worth the extra expense, to avoid a tangle of loose tubes when in use.

Oxygen–Coal-gas Type Burner

Although a special oxyhydrogen burner is necessary for working large silica work, small repairs and small articles can be blown with oxygen–coal gas if a special burner is used. Such a blowpipe, made by the British Oxygen Co. Ltd., is shown in Fig. 2-5(A). It is a very large blowpipe, made originally for hand use for other purposes, but a suitable bench clamp to hold it can readily be devised. The blowpipe gives a very intense flame, sufficiently hot to enable small silica tubes to be bent, closed, or joined.

As a final comment, we would urge that a simple blowpipe be obtained and used until you have had considerable experience in glassblowing. The more elaborate varieties, though very useful, are often confusing to a beginner. Do not forget to keep the blowpipe in good condition. See that the taps operate freely, but do not leak, and do not use oil or grease more than absolutely necessary to ensure this, particularly when using oxygen. Occasionally inspect the rubber connecting tubes, and replace if weak spots are found, or if they show signs of deterioration; a defective tube may split with a loud bang which, though not dangerous, can be very disturbing.

CHAPTER 3

GLASS AND GLASS ANNEALING

GLASS is one of those materials that is so familiar in our everyday lives that few of us who are not specialists know very much about it. That it is transparent, heavy and dangerously brittle we all know, and that is all most people do know about this most interesting substance.

Strictly speaking, we should talk about " glasses ", for there are innumerable types of glass. However, in making laboratory lamp-blown glassware, we fortunately are concerned only with a limited range of types.

STRUCTURE AND GENERAL PROPERTIES

A glass may be approximately defined as a supercooled inorganic mixture of complex silicates; being supercooled, it is not crystalline. It is, in fact, in a condition analogous to a liquid which has become viscous to the point of solidity without crystallising.

On reheating, glass does not have a definite melting point, but gradually becomes less viscous, passing through a range of plastic flow. It is this property of plasticity when hot which enables us to manipulate glass in a blowpipe flame into complex shapes.

The kind of glass with which we are most familiar, in the form of window glass, bottles and the like, is what is known as " soda glass ", or more accurately soda–lime glass. It is made from soda, lime, and sand (which, of course, is silicon dioxide). Until some fifty years ago, nearly all laboratory glassware was made of this material, which is known as " soft " glass; it has a fairly low melting point and relatively high coefficient of expansion.

During the last thirty years or so, a " hard " glass, with a higher melting point and smaller coefficient of expansion, has come into general use. This type of glass, containing the oxides of boron and aluminium, is known generally as " borosilicate ".

Another type of glass, which has been known for a long time, contains a large proportion of lead oxide, and is therefore known as lead glass. It is much used in making lamp bulbs, as it flows readily and seals easily to platinum or "Dumet" (see page 101).

As is well known, ordinary glass articles have to be heated and cooled with care, otherwise they are very likely to crack or break. This is because the material is a very poor conductor of heat and, like all other materials, it expands when heated. Unless the rate of change of temperature is slow, heat is conducted away from the point of application too slowly, and unequal expansion takes place, causing excessive strains leading to breakage.

It is obvious that the smaller the coefficient of expansion of a glass, the less it is likely to break when subjected to rapid changes of temperature. A high silica content gives greater resistance to abrupt changes of temperature, or thermal shock as it is called; while the presence of increasing amounts of sodium or potassium oxides give increasing coefficient of expansion and less resistance to thermal shock.

When glass is heated to its softening point and then allowed to cool, the exterior parts cool more rapidly than the interior, and the thinner sections more rapidly than thick ones. Permanent strains are then introduced which will sooner or later cause breakages. It is therefore necessaiy to cool the glass at such a slow rate that the whole mass cools uniformly. This process is known as annealing, and will be discussed in greater detail later in this chapter.

Coefficient of Expansion

A knowledge of the coefficient of expansion of the various types of generally used glasses is of value to the glassblower for several reasons. First, it enables him to select the proper annealing temperatures; it is also of assistance in selecting the appropriate metal to use for glass-to-metal seals. Finally, such knowledge is necessary in order to determine if two dissimilar glasses can be joined successfully.

The coefficient of expansion of glass per unit length is very small, and in order to avoid the encumbrance of a decimal point followed by a number of noughts, it is usually multiplied by one million to give a whole number. The figure for soda glass will therefore be written as $9{\cdot}8 \times 10^{-6}$.

When glass is heated it expands uniformly up to a certain

temperature, beyond which the rate of expansion increases rapidly until the glass is hot enough to become soft and deform.

A typical Temperature–Expansion curve is shown in Fig. 3-1.

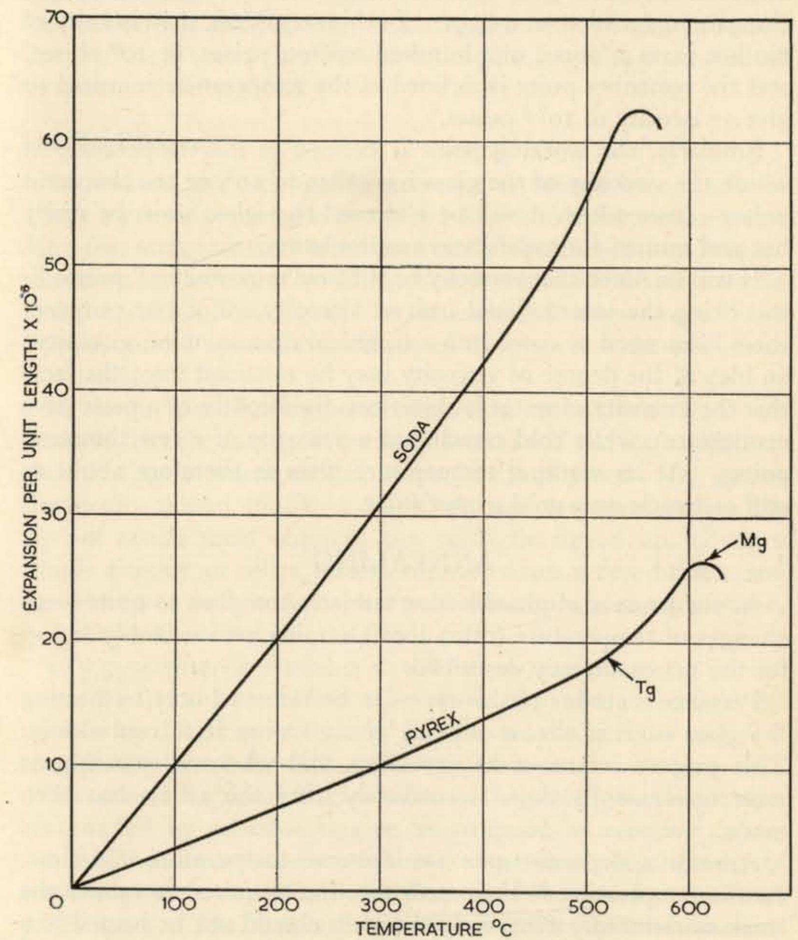


FIG. 3-1.—A TYPICAL TEMPERATURE–EXPANSION CURVE

The point at which the rate of expansion changes is known as the transformation point, and is seen as point *Tg* on the graph. The softening or deformation point is shown at *Mg*. To work glass, it must obviously be heated beyond this temperature, as at the temperature *Mg* the glass, though soft enough to deform, is far too stiff or viscous for manipulation. This is the highest point on the thermal-expansion curve. It is now a generally accepted convention that the softening or deformation point is the temperature at which the glass can be drawn into a thread, which thread will elongate under its own weight. In this condition, the viscosity of the hot glass is about one hundred million poises, or 10^8 poises, and the softening point is defined as the temperature required to give a viscosity of $10^{7 \cdot 8}$ poises.

Similarly, the working point is defined as the temperature at which the viscosity of the glass has fallen to 10^4, or ten thousand poises—from which it will be observed that glass must be really hot and molten for satisfactory manipulation.

It will be noted that viscosity or stiffness is quoted in " poises ", this being the international unit of viscosity. For our purpose, there is no need to enter into a technical discussion on viscosity; an idea of the degree of viscosity may be obtained from the facts that the viscosity of water is about two-hundredths of a poise (two centipoises), while cold treacle has a viscosity of a few thousand poises. At its working temperature glass is therefore about as stiff as treacle on a cold winter's day.

ANNEALING

As the process of glassblowing subjects the glass to quite large changes of temperature (often local), strains are inevitably set up for the reason already described.

Permanent strains of this type can be removed only by heating the glass until it almost softens, and allowing it to cool slowly. This process is known as annealing, and whenever possible, is most conveniently done immediately after the article has been made.

Annealing depends upon two factors—temperature and time. As the temperature is increased, the time required to relieve the strain is reduced. Obviously the glass should not be heated to a temperature high enough to cause softening to the point of deformation. Less obviously, however, there is a temperature below which strain is not relieved, however long the glass is maintained at that temperature. This lower temperature is the transition point *Tg* on the graph Fig. 3-1. The upper temperature is obviously the deformation point *Mg*. The range between these two temperatures is known as the annealing range.

When the glass is being annealed it must first be maintained at the higher temperature until it is uniformly hot; at the lower annealing temperature, *Tg*, the whole of the glass must still be at a uniform temperature. When this has been achieved, the subsequent rate of cooling may be as rapid as convenient, provided that the rate is not too great to allow the glass to maintain a uniform temperature throughout.

Muffle Furnace

In practice, the article to be annealed is heated in a muffle at a safe rate to a temperature just below the deformation point *Mg*; this temperature is stated in makers' literature as the " upper annealing temperature ". The article is then cooled in the muffle to the transition point *Tg*, or " lower annealing temperature ", at a rate dependent upon the thickness of the glass and the coefficient of expansion.

In large glassblowing establishments, special furnaces are installed, but the average laboratory worker will not have sufficient glassblowing to warrant such expensive equipment. A gas or electrically heated muffle of sufficient size to accommodate the type of article most required can easily be rigged up. Even a simple fireclay or silica muffle supported on a few bricks, and heated by two or three bunsen or meker burners, is capable of use, and is by no means to be despised.

If a pyrometer is available it will be an easy matter to set the upper temperature; failing this, some experiments should be made with the different type of glass, to set the burners to give a temperature just below the softening point.

To anneal a piece of glassware, it is placed in the muffle, surrounded by asbestos lagging or wrapped in asbestos paper; the muffle is heated to the required temperature, held steady for some five or ten minutes, depending upon the size and thickness of the glass. The heat is then reduced gradually until the temperature is well below the transition point, when the heat can be cut off and the muffle and contents allowed to cool naturally.

Flame Annealing

Where such a muffle is not available, flame annealing must be resorted to. This means heating the piece in a large, soft blowpipe flame, taking great care to turn the glass so that all parts are uniformly heated until near the softening point. The glass is very gradually cooled first by turning it about in the cooler parts of the flame; then the flame temperature is lowered by cutting off the air or oxygen slowly until the flame is yellow and sooty. Care must be taken to keep the glass moving in the flame until soot just begins to deposit on the glass. In spite of statements that the glass must be covered in soot at this stage, this is not necessary. The beginning of a sooty deposit indicates that the glass is cool enough to be placed aside (out of contact with anything cold) when it can be safely allowed to get cold in its own time.

The essential requirement of flame annealing is gradual and uniform cooling; this calls for good judgment on the part of the worker, as the glass must be heated uniformly without causing softening to just below the point where the glass can sag and distort; it must then be cooled equally carefully.

The Strain Viewer

The best, and in fact the only certain way of making sure that glass is entirely strain free is to view it through a " strain viewer ". This is an apparatus in which one views the glass by polarised light, which gives a multi-coloured image of the piece under examination; the variety and range of colours delineates the strain lines in the object very clearly.

However, unless a lot of glassblowing is done, the expense of such an apparatus is not justified. By the exercise of care in the annealing process, either in the flame or in the muffle, strain-free glasswork can be produced with a good degree of certainty. The use of borosilicate-type glass, because of its great resistance to thermal shock, is for this reason well worth the extra expense of the actual material and the oxygen consumed.

SPECIFIC PROPERTIES OF LABORATORY GLASS

As mentioned at the beginning of the chapter, there are several different kinds of glass used for laboratory apparatus; each type of glass has certain specific properties which render it particularly useful for certain purposes.

Soda–Lime Glasses

This type of glass was almost universally used for chemical glassware until comparatively recent years, and much simple

apparatus, such as thistle funnels, separating funnels, flasks, and beakers, are still made of soda glass.

The present tendency, however, is to restrict the use of this material to apparatus which is not subject to much heat, or in which metal seals have to be made. Experimental thermionic devices are generally made of soda glass or lead glass, both of which materials particularly lend themselves to the manufacture of this type of article.

Osram–G.E.C. Wembley X8 Soda Glass.—This is the most commonly used soda glass at the present time. It is a soda–lime–silica glass containing a little magnesia and boric oxide; it is obtainable in all normal sizes and wall thicknesses, as well as in the form of capillary tube and solid rod. Platinum, copper-clad (or Dumet) wire, as well as certain chrome–iron alloys, can readily be sealed to this glass.

The relevant data for the material are as follows:

Linear coefficient of thermal expansion between 20° and 350° C.	$9{\cdot}65 \times 10^{-6}$
Softening temperature (*Mg* point)	550° C.
Lower annealing temperature	400° C.
Higher annealing temperature	520° C.
Working temperature	900° C.

B.T.H. No. 94 Glass.—Another soda–lime glass supplied in the form of machine-drawn tubing, made for bench working.

Linear coefficient of thermal expansion between 50° and 400° C.	$9{\cdot}5 \times 10^{-6}$
Softening point	about 710° C.
Annealing temperature	515° C.

Glasses Containing Lead

Osram–G.E.C. Wembley L1 Lead Glass.—This material is a mixed-alkali glass containing a high proportion (30%) of lead oxide. It is used extensively for making lamps, valves and other electronic devices, having a high electrical resistance and making excellent direct seals to platinum, " copper clad " wire, and 50/50 nickel–iron alloy wire.

This material is rather softer than soda glass, and some care must be taken in working in the flame, as the free hydrogen and coal gas in an incompletely oxidised flame cause reduction of the lead oxide to metallic lead, giving black stains in the glass. To avoid this difficulty, lead glass should always be worked in the outer part of the flame, where the oxygen is in excess.

Linear coefficient of thermal expansion between 20° and 320° C.	$9{\cdot}05 \times 10^{-6}$
Softening temperature (*Mg* point)	470° C.
Lower annealing temperature	340° C.
Higher annealing temperature	430° C.

B.T.H. No. 12 Glass. This is a mixed alkali–lead–silica glass made as machine-drawn tubing for lamp manufacture.

Linear coefficient of thermal expansion between 50° and 400° C.	$9{\cdot}1 \times 10^{-6}$
Softening temperature ($10^{7{\cdot}6}$ poises)	630° C.
Working temperature	960° C.
Annealing temperature	435° C.

B.T.H. No. 54 Glass. A glass having a lower proportion of lead than either of the foregoing (about 20%).

Linear coefficient of thermal expansion between 50° and 400° C.	$9{\cdot}45 \times 10^{-6}$
Softening temperature	about 650° C.
Annealing temperature	470° C.

B.T.H. No. 73. Another 20% lead glass to match chrome–iron seals.

Linear coefficient of thermal expansion between 50° and 400° C.	$9{\cdot}85 \times 10^{-6}$
Softening temperature	about 650° C.
Annealing temperature	470° C.

Osram–G.E.C. Wembley M6 White Neutral Glass

All glasses are to a certain extent soluble in acids or alkalis, and for microchemical work and certain medical purposes (such as ampoules) it is very necessary to use a glass in which the solubility is kept as low as possible.

For this purpose, Wembley Neutral Glass has been developed. It contains a much smaller proportion of soda and potash than soda–lime glass, and a fairly large percentage of boric oxide and

alumina. The thermal expansion is intermediate between soda glass and borosilicate glass, and the manufacture is carefully controlled to maintain the requisite resistance to chemical attack.

Linear coefficient of linear expansion between 20° and 350° C.	$7{\cdot}3 \times 10^{-6}$
Softening temperature (*Mg* point)	600° C.
Lower annealing temperature	450° C.
Higher annealing temperature	580° C.

This material is also made as amber glass, where a non-actinic glass is required. The characteristics are slightly different from the white neutral glass.

Linear coefficient of thermal expansion between 20° and 350° C.	$7{\cdot}5 \times 10^{-6}$
Softening temperature (*Mg* point)	580° C.
Lower annealing temperature	400° C.
Higher annealing temperature	580° C.

Both of these materials are obtainable in the form of tubing in the usual sizes.

Borosilicate Glasses

The demand for a glass having a very much greater resistance to thermal shock led to the development of a hard glass which is essentially a compound of boric oxide and silica, containing very little alkali (soda or potash). This material has a very much lower coefficient of expansion than soda glass, and a greater acid resistance. Because of its higher softening and melting points, the type of glass is called " hard ", in contrast to soda–lime or lead glasses, which are known as " soft " glasses.

Because of the higher temperature required for working borosilicate glasses, oxygen–coal-gas or oxygen enriched air–coal-gas flames must be used. This slight inconvenience, however, is more than offset by the great resistance to thermal shock, which enables flame working to be done with much greater facility and less risk of strain and cracking than is the case with soft glasses. A beaker made of borosilicate glass, for instance, can be cooled rapidly through about 300° C. without breakage.

The principal varieties of this material are listed below with their characteristics. It should be noted that Pyrex, Phœnix, and Hysil can all be joined to each other without difficulty. In all cases, platinum cannot successfully be sealed to this material. Metal seals should be of tungsten, molybdenum, or certain nickel–iron alloys. Thin copper tubes may also be sealed to this material (for details of procedure see Chapter 8).

PYREX GLASS. This is one of the earliest of the borosilicate series, and is still extensively used.

Linear coefficient of thermal expansion between 20° and 400° C.	$3{\cdot}2 \times 10^{-6}$
Softening temperature ($10^{7\cdot6}$ poises)	820° C.
Annealing temperature ($10^{13\cdot4}$ poises)	560° C.
Working temperature (10^{4} poises)	1220° C.

Pyrex is obtainable in a very wide range of tube diameters and wall thicknesses, as well as in the form of capillary tube, rod, and flasks, beakers, etc.

PHŒNIX GLASS. This is another very popular borosilicate glass, available in all the usual forms and sizes.

Linear coefficient of thermal expansion between 0° and 300° C.	$3{\cdot}22 \times 10^{-6}$
Softening temperature	810° C.
Lower annealing temperature	520° C.
Higher annealing temperature	600° C.

CHANCE BROS. HYSIL GLASS. Most unfortunately the manufacture of glass articles and tubing in this material has now been discontinued; but as much of this glass is found in laboratories, and supplies are still available, relevant data are given here for reference.

Linear coefficient of thermal expansion between 20° and 400° C.	$3{\cdot}3 \times 10^{-6}$
Softening temperature	780° C.
Linear annealing temperature	575° C.
Higher annealing temperature	600° C.

MONCRIEFF MONAX. Linear coefficient of thermal expansion between 20° and 400° C.	$4{\cdot}4 \times 10^{-6}$
Softening point	720° C.
Higher annealing temperature	600° C.

WOOD BROS. FIRMASIL. This material is a newcomer to the borosilicate range, and is at the moment available only in the form of flasks and beakers. Data are available as follows:

Linear coefficient of thermal expansion between 0° and 400° C.	$3{\cdot}2 \times 10^{-6}$
Lower annealing temperature	475° C.
Higher annealing temperature	575° C.

B.T.H. BOROSILICATE GLASSES. The British Thomson-Houston Co. Ltd. make a series of glasses devised specifically for the manufacture of bulbs for lamps of various kinds. The harder types of this range are often used for micro-combustion tubes, owing to the high melting point of the glass.

B.T.H. NO. 9 GLASS. Used particularly where tungsten or copper–glass seals are required.

Linear coefficient of thermal expansion between 50° and 400° C.	$3{\cdot}65 \times 10^{-6}$
Softening temperature ($10^{7\cdot6}$ poises)	775° C.
Annealing temperature	525° C.

B.T.H. NO. 40 GLASS. This material will seal to nickel–iron alloys, and can also be joined to some types of porcelain.

Linear coefficient of thermal expansion between 50° and 400° C.	$4{\cdot}85 \times 10^{-6}$
Softening temperature ($10^{7\cdot6}$ poises)	710° C.
Annealing temperature	505° C.

Aluminosilicate Glass

B.T.H. NO. 46 GLASS. Glasses even harder than the normal borosilicate can be made by increasing the alumina content; such glasses are known as aluminosilicate. The No. 46 glass is extensively used for combustion tubes, particularly for microchemical work, owing to the high melting point.

Linear coefficient of thermal expansion between 50° and 400° C.	$4{\cdot}3 \times 10^{-6}$
Softening temperature ($10^{7\cdot6}$ poises)	about 900° C.
Annealing temperature	775° C.

OSRAM–G.E.C. LEMINGTON H.H. GLASS. This is a hard borosilicate glass, particularly suitable for making molybdenum seals.

Linear coefficient of thermal expansion between 20° and 450° C.	$4{\cdot}7 \times 10^{-6}$
Softening temperature (*Mg* point)	625° C.
Lower annealing temperature	500° C.
Higher annealing temperature	590° C.

OSRAM–G.E.C. LEMINGTON W1 GLASS. A hard borosilicate, specially developed to make strain-free seals with tungsten metal.

Linear coefficient of thermal expansion between 20° and 350° C.	$3{\cdot}75 \times 10^{-6}$
Softening temperature (*Mg* point)	600° C.
Lower annealing temperature	450° C.
Higher annealing temperature	570° C.

PRECISION BORE TUBE

Even with modern methods of manufacture, the bore of glass tubing cannot be held to very close tolerances. For certain purposes, such as precision manometers, flowmeters, viscometers, and the like, it is desirable that the bore of the tube be as uniform as possible.

To meet this demand, precision-bore tubing is made by special processes which entail shrinking the tube down on to a very accurate steel mandrel. By this means Messrs. Chance Bros. Ltd. and Messrs. James A. Jobling and Co. Ltd. produce tubing having bores uniform to $\pm 0{\cdot}01$ mm. over a length of some 30 cm. The outside diameters of these tubes are not, however, held to any great degree of accuracy.

Such tubes, made of either Hysil or Pyrex glass, can be obtained in a wide range of bores from 0·06 to 34·5 mm., and in lengths of from 6 to 20 in.; to special order, lengths of up to 48 in. can be made.

These precision tubes are, of course, very expensive, and apparatus should, therefore, be designed so as to exercise the greatest economy in this material.

Determining the Type of Tubing

If one has been careless and allowed the stock of tube to get mixed, or is faced with the task of repairing an unknown piece of glass, it is necessary to find out the particular type of glass with which we are dealing.

There are several ways of doing this. The most obvious way of distinguishing between soft and hard glasses is to try pieces in the flame; the ease with which the end of a piece of tube melts and closes up is, of course, a measure of the softening point of the material.

Lead glass may be distinguished by the fact that in a reducing flame (one with little air or oxygen) it will blacken after a few moments.

An extremely useful method of distinguishing between soda glass and borosilicate is by the use of trichlorethylene, an organic liquid used in degreasing under the name " Westrosol ". When immersed in this liquid most borosilicate glasses are invisible, while soda glass remains quite visible. A jar of trichlorethylene should be kept handy where much repair work is contemplated.

Having decided the type of the glass in question, if there still remains a doubt if the two materials will join in a satisfactory manner, it is best to make a butt joint between the two glasses; when the joint is cool it is easy to discover, by pulling or inspection, if a properly fused and strong union has been obtained.

Preliminary Trials

For general laboratory purposes, the greater portion of the glass tube stock should be of borosilicate. Much less soda glass will be required, and, unless a lot of thermionic devices are to be made, only a very small supply of lead glass will be required.

The sizes of tube kept in stock will, of course, depend upon the jobs anticipated, but for general purposes a range of tubing of from 4 to 40 mm. diameter, and capillary from about 0·25 to 3 mm. bore and about 8 mm. outside diameter will suffice. Tables of standard sizes and wall thickness will be found in Appendix A.

Before starting on the operations described in the following chapters, the beginner is advised to test the types of glass he expects to use by noting their behaviour in the blowpipe flame.

This is best effected by selecting a piece of small-diameter tube about 8 in. long, and, taking it in both hands, hold it in a soft flame. Slowly increase the air or oxygen supply until the glass just—only just—begins to soften; at this point, pull the glass gently (after removing from the flame) and notice how surprisingly resistant it is. Replace in the flame, increase the air supply and get the glass really hot and flabby; again remove from the flame and pull out to a long, thin tube or thread. Take particular note of these two conditions and the type of flame required to obtain them, so that you can at any time rapidly adjust the blowpipe to reproduce these conditions. Do this with all the types of glass you propose to use; in the case of lead glass, note particularly the amount of air which must be used to prevent the glass turning black.

Upon examining the tubes you have drawn out (particularly the soda-glass ones) you may note that where the diameter is reduced, the glass has become opaque. This state is known as devitrification, which occurs when glass is overheated for some time. It is a condition which must be avoided during glassblowing operations, as it makes the glass porous and renders it unfit for joining or blowing.

CHAPTER 4

PRELIMINARY GLASSBLOWING TECHNIQUES

We anticipate that by now you will have received and installed the blowlamp and blower of your choice, and having obtained a supply of glass tube, you are anxious to start glassblowing. We will therefore prepare to make a start.

Even the most complicated piece of lampblown glassware is made by a series of comparatively simple operations; it is our intention to describe these fundamental operations in detail, and finally to show how they may be combined in the manufacture of the finished article. While it is not given to all of us to become highly skilled glassblowers, practice and attention to detail will enable anybody who can use his hands with average dexterity to make good glass apparatus.

It cannot be stressed too strongly that while the individual operations of glassblowing are simple, each operation must be done thoroughly and completely before proceeding to the next. The instructions must be followed carefully, and the manipulation of the glass practised until perfection is attained. " Good enough " is definitely not good enough; rough and imperfect work is very difficult, if not impossible, to correct at a later stage in the process.

CUTTING

Glass tube is supplied in lengths of approximately 5 ft., and as it is only rarely that one requires apparatus as long as this, it is necessary to cut the tube to a reasonable length.

Let us start with the simplest cutting exercise by taking a piece of soda-glass tube about 6–8 mm. diameter. This can be cut quite readily by scratching with a sharp triangular file or one of the modern carbide knives described in Appendix B. As in all things, there is one right and several wrong ways of doing this.

First one should file or carve a number of different-sized grooves in the edge of the work-bench, on the left-hand front edge—these are shown in Fig. 4-1. Grasp the piece of tube to be cut in the palm of the left hand, the longer piece lying along the arm, while the thumb grips the tube as shown. The tube is rested in an appropriate-sized groove, the left wrist being turned outwards as far as is comfortable. Hold the cutting knife or file in the right hand, and place squarely across the glass tube (just beyond the groove in which it rests), pressing firmly on the glass, and keep it still. By slowly rotating the left wrist inwards a cut is made round the surface of the glass.

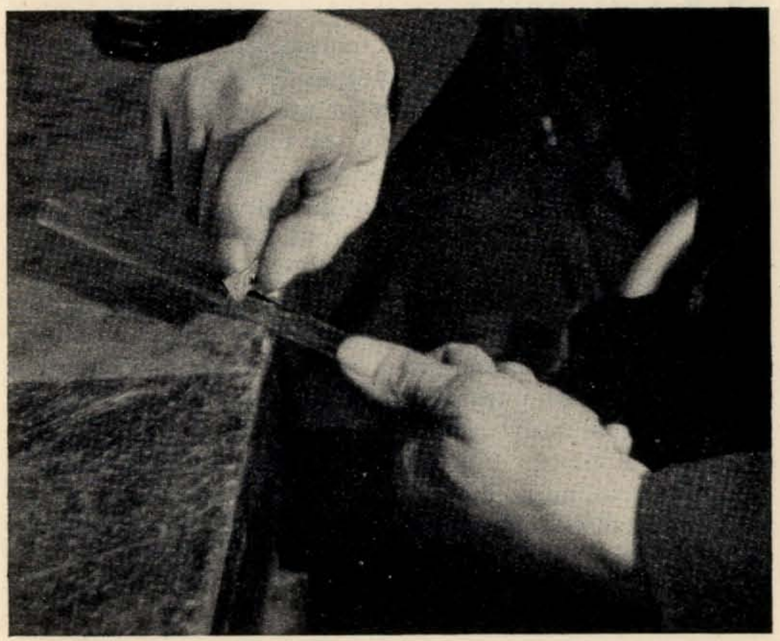


FIG. 4-1.—THE METHOD OF USING A GLASS-CUTTING KNIFE

A little practice will enable one to make a clean cut, squarely across the tube. If the cutting instrument is blunt there is a strong temptation to use a sawing motion, which only does harm, and may result in a jagged break—sharpening the knife is the proper remedy.

Having obtained a nice clean cut, the next step is the surprising one of wetting the cut with the finger; glassblowers always employ this trick, though few can give any reason, except that the glass certainly breaks easier and cleaner if the cut is moistened. The wetting reduces the tensile strength of the glass, though there is still much controversy as to why this should be so.

But to proceed; grasp the tube in both hands, as if breaking a stick, with the scratched surface outwards, and the thumbnails pressing on the tube opposite the cut. Exert pressure, using the

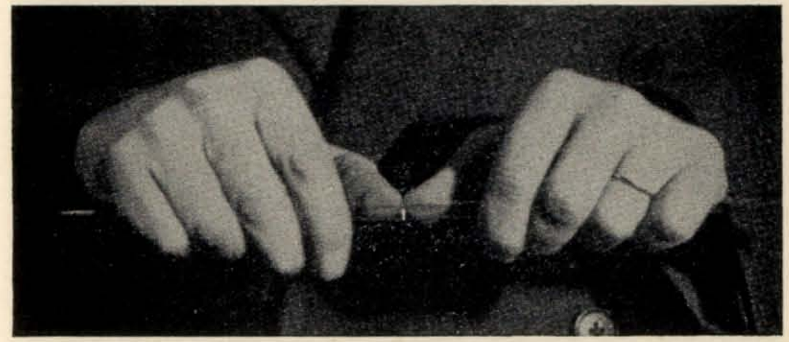


FIG. 4-2.—BREAKING A SMALL TUBE
Note the position of thumbnails.

thumbnails as a pivot, with a slight outward traction, and the tube will come apart easily. Fig. 4-2 illustrates the correct position of the hands.

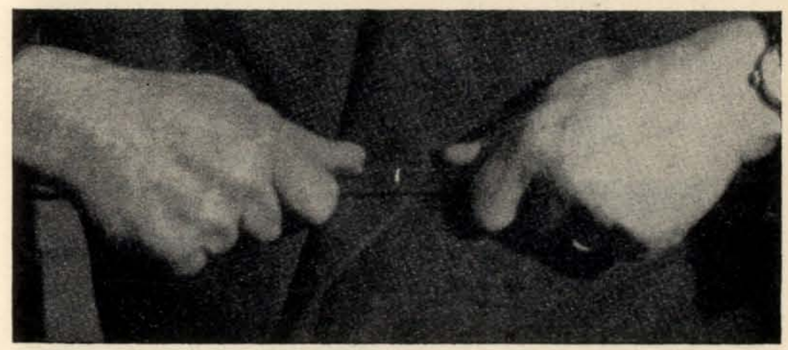


FIG. 4-3.—BREAKING LARGER TUBES
Note grip and position of hands.

When you have mastered cutting and breaking tube of this size, try next a piece of tube about 16 mm. diameter. The glass knife is used in the same manner, but the tube being much larger and stronger, a different hold must be employed in breaking it. This is illustrated in the next figure.

Grasp the tube with both hands across the chest, the wet scratch outwards, with the ends of the tube lying along the underside of the forearms, and pull the hands apart and slightly outwards, giving a radial motion which pulls the glass apart cleanly (see Fig. 4-3). After a little experience has been gained, tube up to 20 mm. can be cut or broken by this method.

Method for Large-diameter Tubes

Tube of larger diameter, however, requires different treatment, so let us next take a piece of 25–30-mm.-diameter tube. This

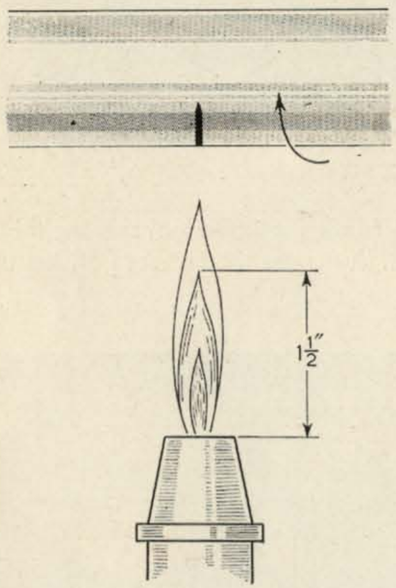


FIG. 4-4.—SOFT, POINTED FLAME FOR CUTTING LARGE-DIAMETER TUBES

This illustration is shown approximately half size to indicate the size of flame and position of glass tube.

should be marked with the knife as before, the cut being about an inch long. In this method the cut is not wetted. Light the blowlamp and adjust gas and air to give a small, " soft ", pointed flame twice the size shown in Fig. 4-4, that is about 1½ in. long to the tip of the just visible flame. Now hold the glass tube comfortably in the tips of the fingers of both hands, as in the photograph, Fig. 4-5, with the cut mark in line with the flame, and about 1 in. beyond the visible tip, rotating the tube slowly and continuously, with a steady motion. If, after a few moments, you do not hear a click, remove the tube from the hot zone by lifting the arms (still

rotating it) and blow sharply upon the scratched area. This should cause the glass to crack evenly all round; if the desired

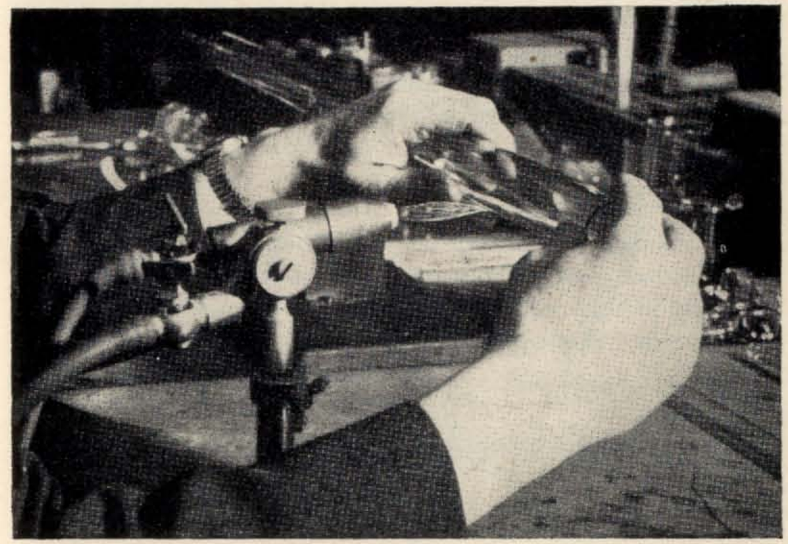


FIG. 4-5.—CRACKING-OFF A TUBE IN THE BLOWPIPE FLAME

result is not obtained, lower the tube into the original position and heat again, repeating until the tube cracks, when a slight pull will separate the two pieces cleanly.

Tubes of quite large diameter, and even bottles, can be cut by this method, but sizes of about 45–50 mm. diameter and above cut with much greater certainty if the knife-mark is first made right round the tube. This operation requires care to ensure that the cut is quite square, and that the end does actually meet and join the beginning of the cut. There is a very easy way of ensuring this. Obtain a piece of thick paper or thin card at least six times as long as the diameter of the tube to be cut, and having cut one edge quite straight, wrap round the tube so that the straight edge of the card lies in the position of the required cut—taking care

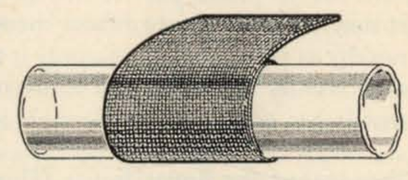


FIG. 4-6.—CARD BEING USED AS A GUIDE WHEN CUTTING A GLASS TUBE

that the straight edge remains in line and does not overlap. This is illustrated in Fig. 4-6.

Using the thumb of the left hand to keep the wrapped card in position, the straight edge of the card is used as a guide for the cutting knife; the cut can be made right round the tube, using short, definite strokes of the knife, avoiding above all duplicating the knife cut, or " sawing ". The tube can then be cracked in the flame as just described.

Using the Hot Iron Hook

Still another, and perhaps safer, method with large tube is to use a hot iron hook to crack the glass. The tube is first cut with the knife in the usual manner (without wetting) and a piece of iron wire or rod, shaped as in Fig. 4-7, is bent so that the half-round portion is a snug fit round the glass tube—snug, but not so tight that it clips the tube, which should lie and rotate comfortably in the loop. Suitable iron wires of $\frac{1}{8}$ in. diameter up to about $\frac{5}{16}$ in. diameter should be provided—the latter is large enough to hold sufficient heat to crack tubes of 60 mm. diameter and over. A small collection of such rod hooks should always be kept handy.

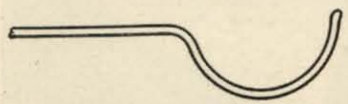


FIG. 4-7.—IRON WIRE HOOK FOR CRACKING LARGER TUBES

Having fitted our iron hook, it is heated in a large blowpipe flame to a dull red heat; hold the glass tube in the left hand, lay with the scratched part in the hot loop, and rotate continuously. It may be necessary to reheat the hook, which should be done as rapidly as possible, and re-apply it to the glass tube. Soon a loud click should be heard, and an examination of the glass will show that it has cracked right through, and can easily be pulled apart.

Treatment for Borosilicate Glasses

So far, we have been practising with soda-glass tube, which, because of its poor conductivity and large coefficient of expansion, cracks easily—sometimes too easily. Borosilicate glasses, such as Pyrex, Hysil, and Phœnix, and combustion glasses, having a much smaller coefficient of expansion and greater heat-shock resistance, are somewhat more difficult to crack, and require different treatment.

The smaller sizes, up to about 18 mm. diameter, can be cut as soda glass, but greater force is required to break. The neatest and easiest method of cracking larger borosilicate-glass tubes is to use a small hot glass tube to lead the crack round the glass to be cut.

The technique of the method is as follows. Choose a piece of Pyrex tube of about 24 mm. diameter, and make a knife cut about 1 in. long by the usual method. Obtain a piece of 6-mm. Pyrex tube about 6 in. long, and heat the end in the blowpipe flame (using a little oxygen) until it glows (do not bother if the end collapses inwards). Place the hot end of the tube on the glass to be cut, right in the centre of the knife cut; this will start a crack through the thickness of the tube. Reheat the small tube, and this time place it about $\frac{1}{4}$ in. from one end of the crack—on the crack, not beyond it, as in Fig. 4-8. This will cause the crack to extend at the heated end, generally perfectly straight. By now, the softened end of the small tube will have spread out into a button which should be removed by rapping smartly on the bench-top before reheating, during which time it is as well to examine the progress of the crack. Next time, place the hot tube $\frac{1}{4}$ in. from the straighter end of the crack, and repeat the process until the tube has cracked right round.

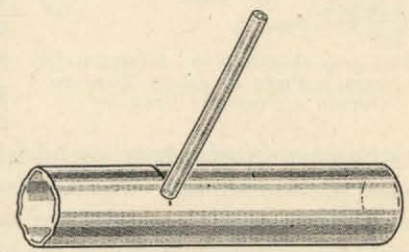


FIG. 4-8.—METHOD OF CRACKING A BOROSILICATE GLASS TUBE, USING A SMALL HEATED TUBE TO FACILITATE THE PROCESS

It often happens that the crack does not meet perfectly, so that when the two parts are separated a small jagged part is left. This can be removed quite easily by heating in the flame and " stroking " with a small (cold) glass tube, as shown in Fig. 4-9, rotating the larger tube all the time. It will be found that the glass, when hot enough, will adhere to the smaller tube and can be drawn off, leaving a reasonably straight and clean edge.

This method of cracking off can also be applied to soda glass, taking care, of course, to use a piece of soda-glass tube for the purpose. Rather more skill is required with these softer glasses than was necessary with borosilicate, however. The small tube must not be so hot that it will stick to the tube being operated upon, and it must not be allowed to dwell on the crack—a series of quick "jabs" (reheating when necessary) will be found the best technique. It will be as well to practise this cracking-off operation on a scrap piece of medium-diameter soda tube.

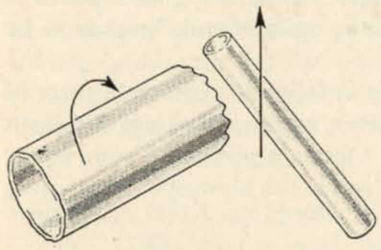


FIG. 4-9.—METHOD OF "STROKING" WITH A PIECE OF GLASS TUBE TO OBTAIN A STRAIGHT EDGE

Some glassblowers, when using the flame method of cracking glass described on page 34, prefer to wind wet pieces of tape about ½ in. on either side of the crack. This technique is particularly useful when cracking large, thick-wall glass tubes or bottles. The cut should be made all round the tube as already described, and the tape (or asbestos paper) must be quite wet. Winchester quart bottles can be cut very readily by this means.

CLEANING

When our pieces of glass tube are cut into the lengths we require, they must be thoroughly cleaned before we commence actual glassblowing operations. This preliminary cleaning is very necessary for two main reasons. First, particles of dust and grease become carbonised in the flame and burn into the surface of the glass, discolouring it, and even in extreme cases causing devitrification or roughening of the surface. Secondly, it is obviously easier to clean a straight piece of tube than it is to properly clean a complicated piece of blown glassware.

We would particularly warn you not to neglect cleaning, as dirty glass is responsible for many of the disappointments and failures encountered in glassblowing; for the same reason, the glassblower's hands should always be clean, as greasy finger-marks cause black marks on glass which has been heated in the blowpipe.

We will start by cleaning the outside of the tube first. This is done by first wiping off free dust with a clean rag, and soaking off any gummed paper which is sometimes attached to the tube. Next wash the tube thoroughly with clean warm water, using a little soap or detergent if necessary—not forgetting that wet, and particularly soapy, glass is very slippery!

Where the diameter of the tube will allow, the inside is best cleaned by means of a wad of clean rag or cheesecloth; first with a wet rag, and then with a dry one. The usual and most convenient way of doing this is to use a "pull through", similar to one used in cleaning rifles, as Fig. 4-10. A loop is made in a piece of cord about 6 ft. long, and the other end is weighted with a stick or small rubber bung. The rag can be threaded through the loop and pulled through the tube quite easily.

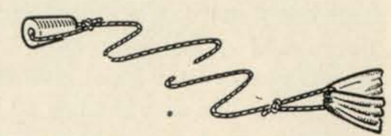


FIG. 4-10. — A "PULL-THROUGH" TYPE OF CLEANER FOR THE INSIDE OF TUBES

Here we must give a word of warning. Never, never use wire or any metallic substance on the inside of glass tubing. Small scratches are inevitably made which will cause the glass to break or "fly" when it is put in a flame. If a rod must be used to push a rag through a tube, make sure that a wooden one is employed.

If the glass you are cleaning is to be incorporated in a vacuum system, it is well finally to pull through with a piece of tissue paper, in order to remove any small particles of fluff which may be left by the rag.

Be careful where you put your cleaning cloth. Do not put it down on the bench, where it may pick up grease and dust. Keep it in a clean drawer or box.

Dichromate–Sulphuric Acid

Occasionally you will come across a piece of glass in which the dust or grease sticks with great obstinacy. In such a case more drastic measures will have to be employed. One end of the tube should be closed with a cork or rubber bung, and the tube filled with sodium dichromate–sulphuric acid mixture, which should be allowed to remain for several hours—overnight if possible.

This mixture is made by taking a saturated solution of sodium dichromate in water, and diluting with an equal volume of water. To this solution an equal volume of concentrated sulphuric acid is added, a little at a time—never add the water solution to the acid, as dangerous eruptive splashing will take place. If you are not a chemist it is best to get the solution made up by a chemical colleague. The solution must be used with great care to avoid splashing or spilling, as it not only stains the fingers, but is also both corrosive and poisonous. A bottle of dichromate–acid mixture should always be kept on hand; it can be used repeatedly until it turns green, when it should be thrown away a little at a time into a sink full of water.

After cleaning with this mixture, the glass must be washed out with a large quantity of water and thoroughly dried inside and out. If you are in a hurry the drying may be speeded up by rinsing with methylated spirit or acetone, and blowing warm air through until all traces of vapour are removed. If the blower is used to supply the air, put a cotton-wool filter in the line to remove any traces of dust or oil. Be sure to blow all traces of solvent vapour from the tube, otherwise an explosion may take place when the glass is placed in the flame.

Broken glassware which is to be repaired should always be cleaned with this dichromate mixture, and care should be taken that any broken edges which are to be heated in the flame are particularly clean.

MAKING "POINTS"

At last, after all these preparations, we are ready to start actual glassblowing by learning how to draw "points", which consists of pulling out a glass tube to a small diameter. This is necessary to facilitate manipulation of the larger size of tube; to economise in tube; and also to form shoulders for sealing or joining to other tubes.

It is desirable to master this apparently simple operation before attempting anything further, as not only does it give you familiarity in handling hot and plastic glass, but ability to draw good, well-shaped points will also be of great assistance in subsequent manipulation.

Method of Procedure

For your first attempt, a piece of soda-glass tube about 15 mm. diameter and 18 in. long will be most convenient. With a glass-marking or grease pencil make a short mark about 3 in. from one end of the tube and another mark 3 in. from the first. Adjust your blowpipe flame so that it is just a little bigger in diameter than the tube you are working on; this is a useful approximate rule when drawing points. Hold the tube at the right-hand end between the tips of the thumb and first three fingers, the tube resting on the three small fingers; with the left hand over the tube, grip by the thumb and first finger. This position of the hands and fingers is important, and is shown in the photograph Fig. 4-11, which should be studied carefully.

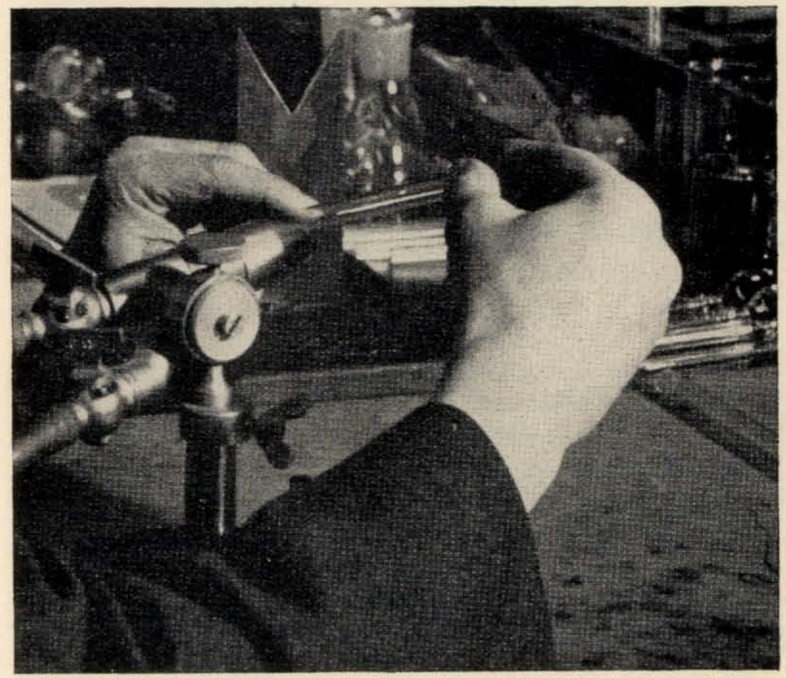


FIG. 4-11.—THE POSITION OF THE HANDS FOR DRAWING A "POINT"

The Rotating Movement

Having satisfied yourself that you are holding the tube correctly, sit in front of the blowpipe and, resting your left elbow on the bench, hold the tube just beyond the flame, with the left-hand end lower than the right. Settle yourself comfortably, and, rotating the tube, bring it *slowly* into the flame, just beyond the point of the blue cone. So far, this is easy; the difficult part comes when the glass gets soft, and tends to twist into a corkscrew. Here the marks we made with the pencil will come in useful. Most people find it practically impossible to synchronise the turning movements of the left and right hand, so, keeping your eye on the two pencil marks, do the driving as it were with the left hand, and keep pace with the right hand, turning the tube away from you, and going slower or quicker with the right hand according to the position of the marks. Do not attempt to turn too fast; a slow, uniform movement is what is required. You will not find this at all easy, and there is only one way of overcoming the difficulty—persistence and practice; keep trying, and get the glass really hot—most learners are afraid to make the glass hot enough.

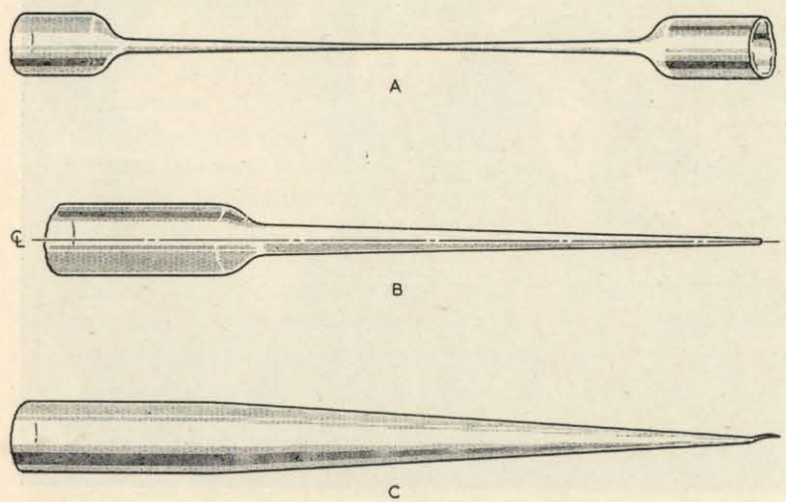


FIG. 4-12.—STAGES IN THE MAKING OF A " POINT " IN A GLASS TUBE

A. The hot rotating tube drawn apart to form two " points ".
B. A correctly formed " point ".
C. A badly formed " point ".

When the tube feels really " sloppy ", raise it from the flame and, *still rotating the tube*, draw the tube apart, when the tube will look like Fig. 4-12(A).

Hold the centre in the flame, which will melt the glass, and draw out the tube so that you have two " points ", which upon examination you will most certainly find to be very sorry specimens—the points not in line with the tube and the drawn-out portion having very thin walls. But do not be discouraged; mark the other end of the tube in a similar manner as you did before, and try again.

This time, make sure that you do not pull the tube while it is in

the flame—this should never be done, as the wall of the tube becomes paper thin in an extremely short time by this treatment. To avoid pulling, the hands should be slightly pushed together; holding the left hand lower than the right will assist in this. Also, when you remove the tube from the flame—you will find it most convenient to do so by raising the hands—keep the tube rotating. Pull fairly quickly but do not snatch, and you will feel the resistance grow greater as the glass cools. A double point about 12 in. long is about the right size, and a good point should look like Fig. 4-12(B).

The point should be straight and accurately on the axis of the main tube; note that there should be a well-formed shoulder in which the glass wall is of the original thickness of the tube—a point shaped as Fig. 4-12(C) is not of much use.

You get this kind of long-drawn-out effect if you do not keep the flame steady on the tube in one place; if the glass is not hot enough; or if the tube is pulled in the flame.

After a few attempts you should be able to perform this operation without much trouble; when you have reached this stage try your hand on a larger piece of tube—about 20 or 25 mm. diameter, using a larger flame, of course. The use of a V-rest shown in Fig. 4-13 may be found of assistance with this larger tube.

Handling Large Tubes

Before we finish with soda glass, it is advisable to try your hand with larger tubes of say 30 or 40 mm. diameter. There are two ways of handling the larger material. The first is to hold the end of the larger tube in the edge of the flame, rotating continuously until the end melts and closes down, as shown in Fig. 4-14(A).

Then take a piece of similar tube about 10 mm. diameter in the right hand, heat in the flame, until it also is hot enough, and " stick " on to the end of the larger tube with a firm pressure, to unite the two molten surfaces. No attempt should be made to obtain a respectable joint. The smaller tube can then be used as a convenient handle while drawing the point; note that the temporary joint should be kept warm in the flame until the actual drawing-off takes place.

The second method, of use when dealing with really large tube,

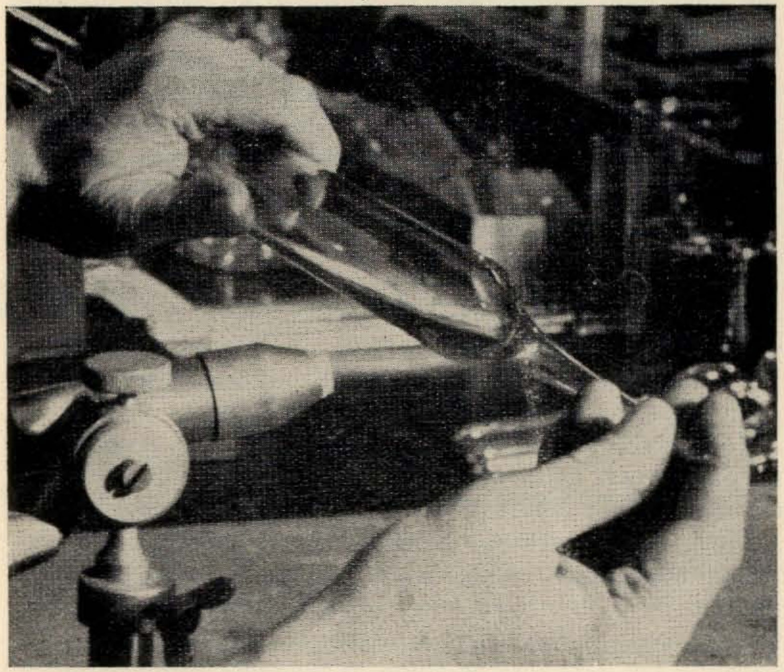


Fig. 4-13.—The Proper Method of Holding the Glass and the Use of the V-Rest

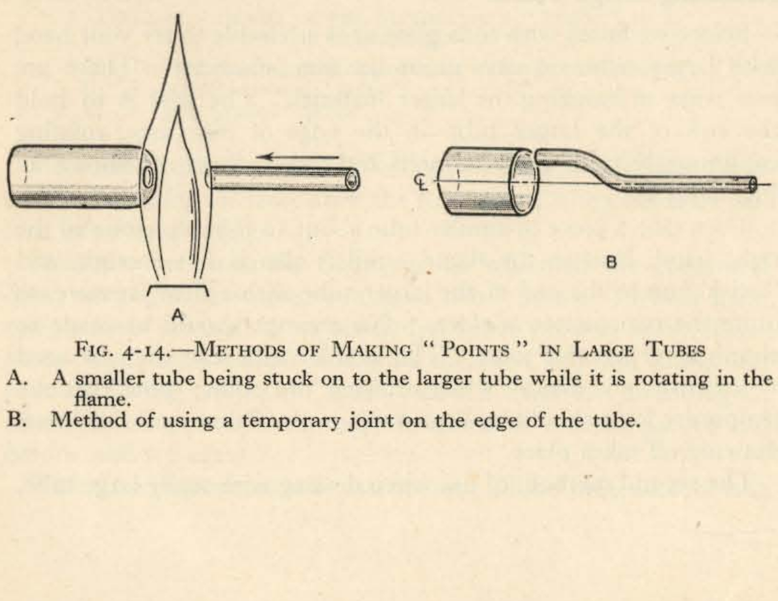


Fig. 4-14.—Methods of Making "Points" in Large Tubes

A. A smaller tube being stuck on to the larger tube while it is rotating in the flame.
B. Method of using a temporary joint on the edge of the tube.

is to warm the larger tube in the flame as before, and make a temporary joint on one edge of the tube as shown in Fig. 4-14(B). The small tube must then be bent so that the handle part lies on the axis of the larger tube, and the point is drawn in the usual way. Do not forget, however, that the larger tube should be brought slowly into the flame, and should be cooled in the flame to avoid cracking. The whole of the operation of drawing points above described should now be repeated using borosilicate glass in an oxygen-enriched flame, making sure that the glass is hot enough to work properly.

CLOSED-END TUBES AND FLANGING

The next operation to practise is to make a closed-end tube. Once again we will use 15-mm. soda glass. Draw a point at each end of a piece of this tube, leaving about 1 ft. of the original diameter tube between the points, and cut the tube in the centre, giving you two pieces.

Adjust the flame to a "hard", pointed flame about $1\frac{1}{2}$ in. long and, taking one of the pieces by the larger end in the left hand in the usual manner, hold the "point" in the fingers of the right hand as shown in Fig. 4-15, the tube resting on the first and second fingers, with the thumb and the other two fingers in front of the tube. This will give you complete control of the tube.

Hold the tube in an inclined position, see Fig. 4-16(A), so that the tip of the flame is directed upon the shoulder of the "point", and rotate until the glass is really soft; do not let the flame spread too much—the heat must be confined over a very small width of the glass. When the glass is hot enough the tube should appear as in (B) if the flame has been properly adjusted.

A slight "jab" with the right hand will collect surplus glass on to the small tube, which should be pulled away smartly *in the flame*, leaving the larger tube with a closed end which, at the first attempt, will probably have a blob of glass in the centre, see (C).

Discard the small tube and, reducing the flame still more, direct the point of the flame on the end of the tube. When soft, remove the tube from the flame and blow gently into the open end to produce a small bubble (D); do not blow hard, or a very large, thin bubble will be produced. The idea of this operation is to spread the glass evenly over the end of the tube. By reheating the bubble and end of the tube, see (E), the end will collapse, giving a flat end (F), which can be blown out by a gentle puff to a hemispherical end (G). Examine the tube, and if the end is not of uniform thickness, blow another bubble and

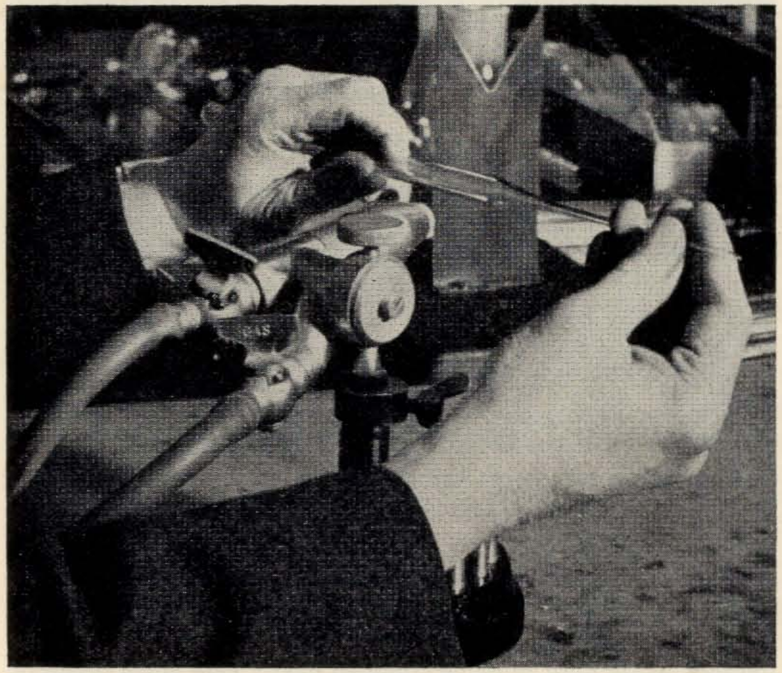


FIG. 4-15.—STUDY PARTICULARLY THE POSITION OF THE FINGERS

repeat the above operation until the desired uniform end is produced.

You will find that a surprisingly small amount of practice will enable you to make perfect closed ends—once this is achieved you should try larger tubes, and again repeat the whole process with borosilicate glass, using an oxygen-enriched flame, by which time you will have accumulated a number of round-bottom tubes which it will be as well to finish off by properly flanging the open ends.

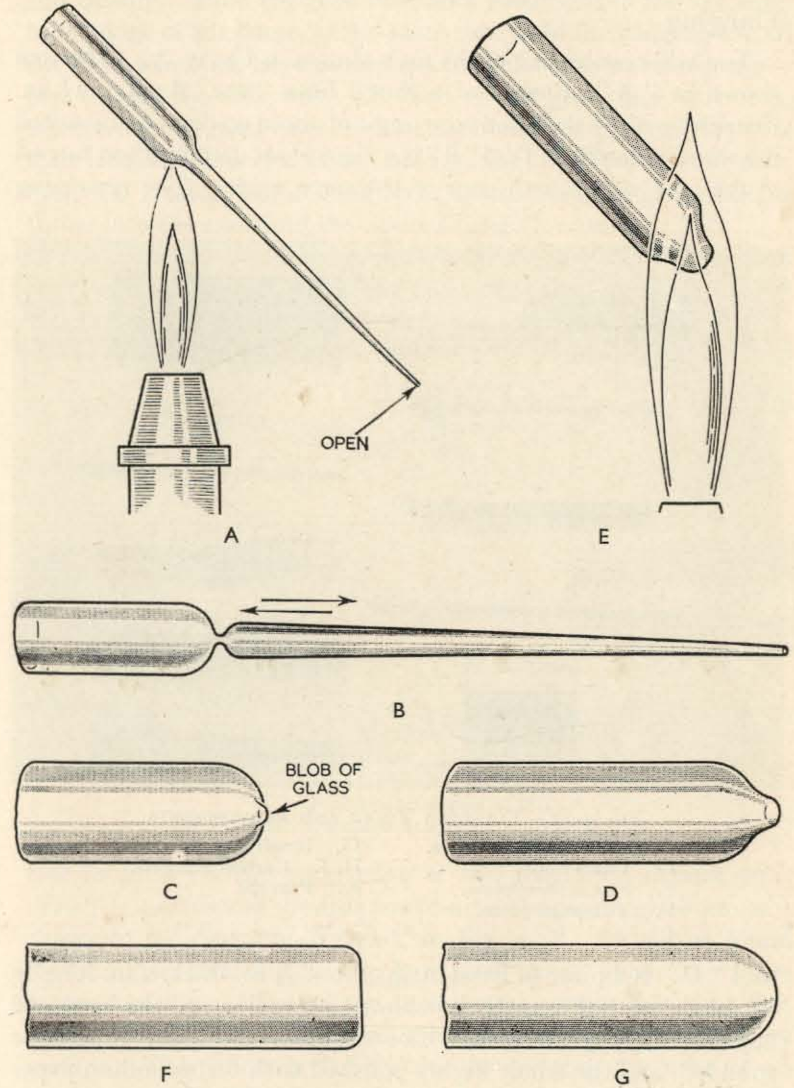


FIG. 4-16.—METHOD OF MAKING CLOSED ENDS

A. Position of tube for drawing off point.
B. Appearance of tube before pulling off smaller tube.
C. A blob of glass is left after pulling off the point.
D. Small bubble blown out.
E (*top right*). The bubble being reheated in the flame to produce a flat end.
F. End collapsed flat.
G. Completed round end.

Flanging

You will require one of the tools shown in Fig. 4-17. The tool shown at "A" consists of a fluted brass cone, about 1–1½ in. diameter with an included cone angle of about 90 degrees, mounted in a wooden handle. Tool "B" is a piece of arc-lamp carbon turned at the end to a smooth cone of the same angle. The remaining

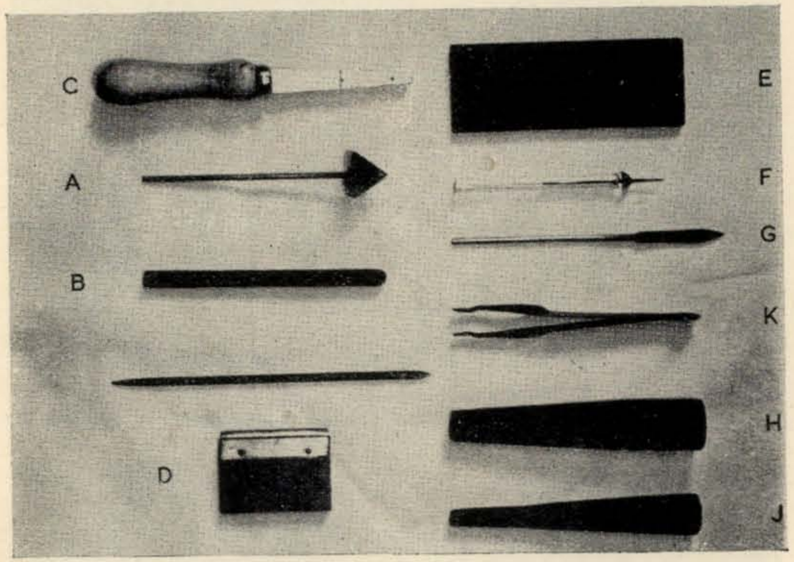


Fig. 4-17.—Flanging Tools and Requirements

A, B, C. Flanging tools.
D. Glass knife.
E. Flat carbon plate.
F. Tungsten point.
G. Small flat reamer.
H, J. Carbon reamers.
K. Forceps.

tool "C" is a piece of brass strip, about $\frac{1}{16}$ in. thick, 2 in. long in the blade, with the small end about $\frac{1}{8}$ in. radius and the large end approximately $\frac{1}{2}$ in. wide. The edges of the blade should be rounded, and the whole highly polished with carborundum paper after mounting in a suitable wooden file handle.

The first two tools are the easiest to use, but have the disadvantage that their use is restricted to tubes of fairly small diameter; of course, they will only "flare" the tube, and will not give a wide out-turned flange which is sometimes necessary.

The tube to be flanged must have the open end cut off squarely

and cleanly. Hold the glass tube and, rotating it in the left hand in the edge of the flame, at the same time hold the flanging tool in the right hand just beyond the tip of the flame to warm slightly—just to take the chill off. The end of the glass tube will melt, thicken slightly, and turn inwards as shown in Fig. 4-18(A); it is then removed from the flame (still rotating the tube) and the cone tool, also rotated, but at a different speed from the glass tube, is thrust into the end until the desired flange is obtained.

The use of the flat flanging tool is not so easy. Heat the glass tube as before, and when in the right condition, insert the metal

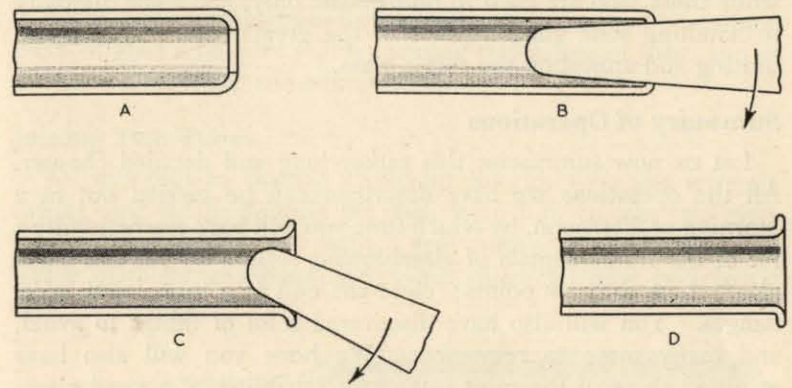


Fig. 4-18.—Flanging the End of a Tube

A. End collapsed inward.
B. Starting position of tool.
C. Finishing position of tool.
D. Finished flange.

tool to press on the inner edge of the glass tube nearest you; draw it outwards and towards you to draw the plastic glass out, as is shown in the diagrams B and C in Fig. 4-18. It will be found that the glass tube will have to be rotated slowly about four times to produce a good flange, and it is almost certain that your first flange will not be nice and smooth, but will have a ridged or bumpy surface. This effect is largely due to rotating the tube at an irregular speed, using rather too much pressure on the tool; a few trials may be necessary before you get the proper feel of the tool.

Incidentally, most glassblowers keep a lump of beeswax on their bench, on which they wipe their warm metal tools to keep them from sticking to hot glass; you can see such a piece in the background of some of the photographs.

Proficiency in joining glass tubes is very essential, and, like learning to ride a bicycle, success comes suddenly after a lot of practice. When you have mastered these operations with soda glass, repeat them all using borosilicate, which you will find somewhat easier, as the glass will be less likely to crack if it is not properly annealed, and rather greater liberties can be taken when heating.

It may seem more logical to practise on borosilicate first, but over many years we have found that glassblowers who have been used to working in soda glass can get used to borosilicate easily; while those who are used to borosilicate only, find some difficulty in handling soda glass because of the greater care necessary in heating and annealing the softer glass.

Summary of Operations

Let us now summarise this rather long and detailed chapter. All the operations we have described can be carried out in a morning or afternoon, by which time you will have learned quite a lot of the fundamentals of glassblowing:—how to cut and clean glass; how to draw points; close the end of a tube; and make flanges. You will also have discovered a lot of things to avoid, and many more to remember. We hope you will also have acquired three of the most important attributes of a good glassblower, which may be called *preparation*, *patience*, *and perseverance*.

Finally, remember the following points:—never put dirty glass tube into a flame; always keep glass rotating while in the flame; do not blow glass while in the flame; and finally, never be satisfied with an imperfect job.

CHAPTER 5

JOINING GLASS TUBES AND BULBS

By the time you have completed the exercises described in the last chapter, you will feel much more confident in handling glass in the blowpipe, and having got used to the "feel" of hot, plastic glass, you will wish to go on and make something.

So far, our manipulations have been confined to work on a single piece of glass; now we will try joining two pieces of tube, and at the same time make something useful.

Joining Two Tubes

We will start by making a calcium chloride tube and a thistle funnel, and in the process we shall learn how to join two glass tubes. Provide yourself with a few pieces of soda-glass tube 6 mm. diameter, and also some 15-mm.-diameter tube, both being about 8 in. long.

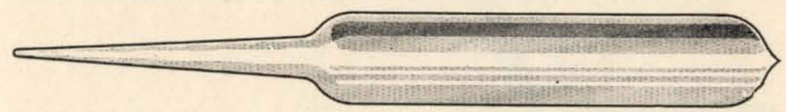


FIG. 5-1.—TUBE READY FOR JOINING OPERATION

Draw a point on each end of one of the pieces of larger tube. Draw off the surplus glass from one end, as in making a round-end tube (see Fig. 4-16(B)) and blow a small bubble (Fig. 4-16(D)). Do not bother this time if a small excess of glass is left on the closed end. The tube will be as shown in Fig. 5-1. Adjust the blowpipe to give a small, hot flame, and heat the extreme tip of the bubble until the glass is quite molten; then quickly blow sharply into the open end to produce a large, thin bubble as in Fig. 5-2.

With the glass knife, cut the bubble away, using "hacking" strokes, leaving the edges rather jagged (Fig. 5-3). Inspect the rough stub to see if it is of the same size as the tube you are to join on to it. If the stub is too large in diameter, heat it in the flame until it shrinks down to the required size; if too small, heat in the flame, and when soft open out, using a small flat brass strip.

Now comes the more difficult part. Seal the tip of the " point " of the larger tube in the flame. Hold the larger tube in the left hand, and the smaller tube in the right hand, and rotate each

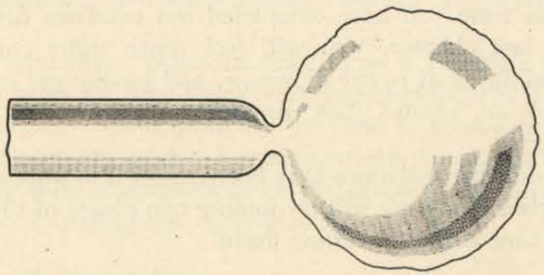


FIG. 5-2.—BUBBLE BLOWN INTO TUBE.

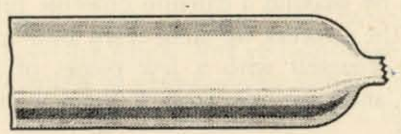


FIG. 5-3.—BUBBLE CUT AWAY LEAVING JAGGED EDGES

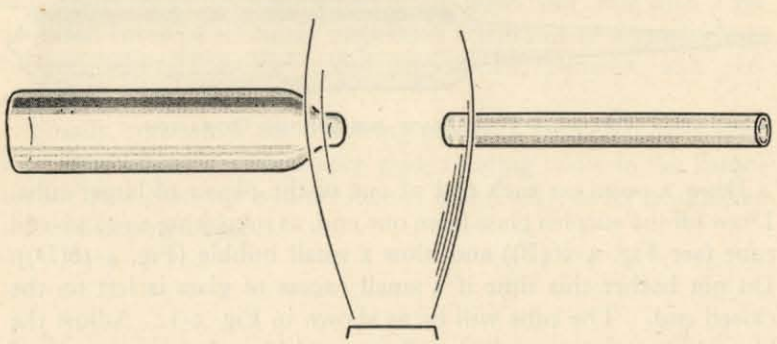


FIG. 5-4.—ROTATING TUBES BEING PRESSED TOGETHER IN FLAME

evenly and at the same speed in opposite edges of a fairly large flame. When the glass is hot enough, press the two tubes together, taking care that they are held quite squarely. Remove from the flame and blow gently into the open end of the small tube. If the glass has joined properly there will be no small leaks; if any are found, replace the tube in the tip of the flame till

soft, press together gently to thicken the glass, again remove from the flame and blow gently, slightly pulling the tubes apart if the glass joint appears too thick (Fig. 5-5).

You will probably find that the tube is very misshapen, and that the small tube is not joined on centrally. If the job is not too bad

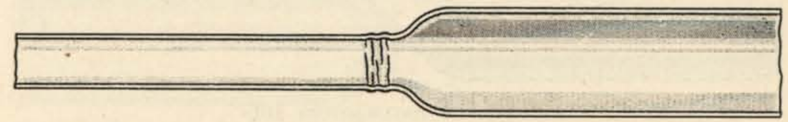
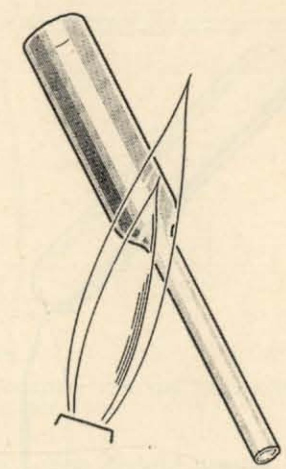


FIG. 5-5.—THE GLASS JOINT SHOWN IS TOO THICK, AND THE TUBES MUST BE PULLED SLIGHTLY APART

we can proceed to the next stage, but if it appears hopeless, throw it away and have another try.

When you have a satisfactorily joined tube, reduce the flame to about $\frac{1}{2}$ in. diameter and, holding the tube at an angle of 45 degrees in the flame (see Fig. 5-6) heat slowly; note that the larger tube

FIG. 5-6.—HEATING TUBE BEFORE BLOWING TO PRODUCE WELL-SHAPED END



is wholly in the flame and that the joint itself is just inside the hot edge. When the glass is hot enough (make sure the glass is really hot and molten) remove from the flame and blow, at the same time pushing the two tubes together so that a well-shaped end is formed there, as illustrated in Fig. 5-7.

Hold the tube in the flame again, and reduce the air supply to the blowpipe fairly rapidly until a yellow, smoky flame is obtained —keep your glass rotating all the time until the hot portion has cooled considerably; then stand aside to cool completely.

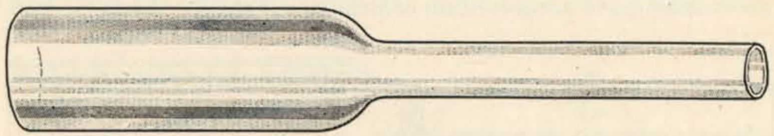


FIG. 5-7.—A SATISFACTORY JOIN

Instead of using a plain tube, we can use one of the round-bottom tubes left from our exercises described in the previous chapter.

Using Round-bottom Tube

The method of procedure in general is as described above. Adjust the blowlamp to a very small flame, and hold the round end of the tube as shown in Fig. 5-8 until a small spot in the end

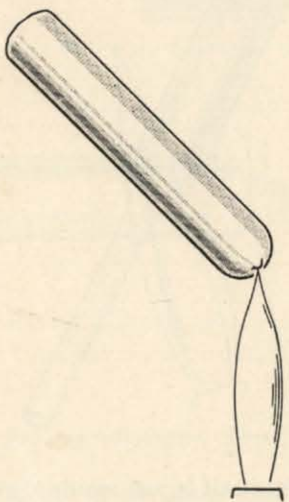


FIG. 5-8.—PREPARING FOR JOINT IN ROUND-BOTTOMED TUBE

is hot enough to collapse. Blow into the open end of the tube to make a small bubble (as in Fig. 4-16(D)). Reheat the bubble, and blow hard to make a thin glass balloon as in the previous example; then proceed as already described, but in this case the bubble is

cracked off close to the round end as in Fig. 5-9, leaving only a little projection.

Close the end of the small tube with a cork, and using a large flame, heat the end of the tube and also the small-diameter tube,

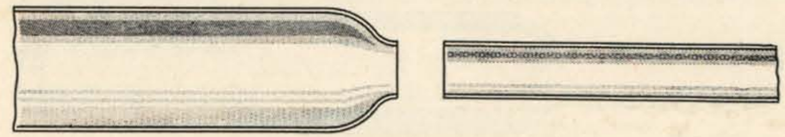


FIG. 5-9.—BUBBLE CRACKED OFF CLOSE TO ROUND END

and press gently together. Immediately reduce the flame to a fine point, and heat fairly strongly. The tube will shrink in as illustrated in Fig. 5-10.

Blow gently into the tube until the joint swells a little, but do not pull the tube when blowing; this is a fault which is rather difficult to overcome, and some considerable practice will be

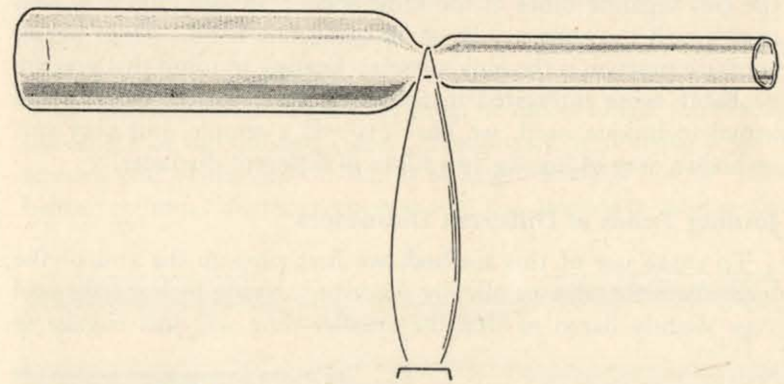


FIG. 5-10.—THE TUBES ARE PRESSED TOGETHER AND THE TIP OF THE FLAME IS SHRINKING THE JOIN

required before the knack is gained. You should always push gently when blowing into hot glass joints unless you definitely wish to narrow down, and the tube should be kept rotating all the time, otherwise the lower side will blow more than the upper side, and a lop-sided effect will be obtained.

When you have managed to make a reasonably good joint, warm the tube and finish as shown in Fig. 5-6.

If at this stage the tube is overblown as in the next figure (5-11) it should be heated again, and the tube pulled while blowing gently —but make sure that the glass is hot enough before you do this, otherwise the small tube, instead of the large, will pull out. When you have got the joint to your satisfaction, anneal in a cool flame.

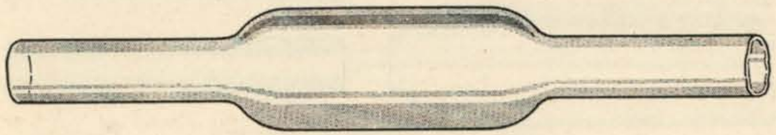


Fig. 5-11.—An Overblown Tube

When making joints between glass tubes the aim is so to work the glass that the walls of the tube and of the joint are of uniform thickness, the joint then being almost invisible. The hot joint must be blown up and slightly pulled, or allowed to thicken in the flame and slightly blown to achieve this.

It is most probable that you will find great difficulty in rotating the two separate tubes at the same speed; in fact, you may find it awkward to rotate a tube at all using one hand. Once again, constant practice is the only answer; bearing in mind that you are probably more interested in achieving good results than in the actual technique used, we have evolved a simple, but very unorthodox, way of joining two tubes of different diameter.

Joining Tubes of Different Diameters

To make use of this method, we first prepare the end of the large-diameter tube as already described, trying to leave the end very slightly flared so that the smaller tube will just engage as

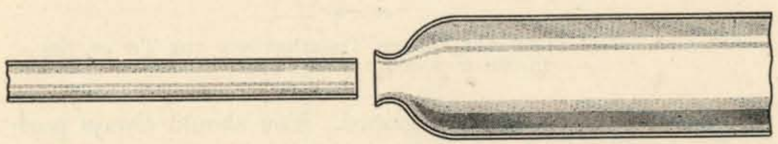


Fig. 5-12.—Tube Shown Slightly Flared to Engage Smaller One

shown in Fig. 5-12. The actual joint is made by holding the two tubes in contact while cold, and introducing into the flame. By this means you will find that each tube supports the other, making the action of rotating very much easier. As the tubes are pushed together during heating, you will find that the original joint is

rather thick, so blow it up gently to make the wall thickness uniform, and pull out in line. We have found this a very easy and speedy method.

Still another method, frequently used by glassblowers when a number of similar joined tubes have to be made, is to neck down

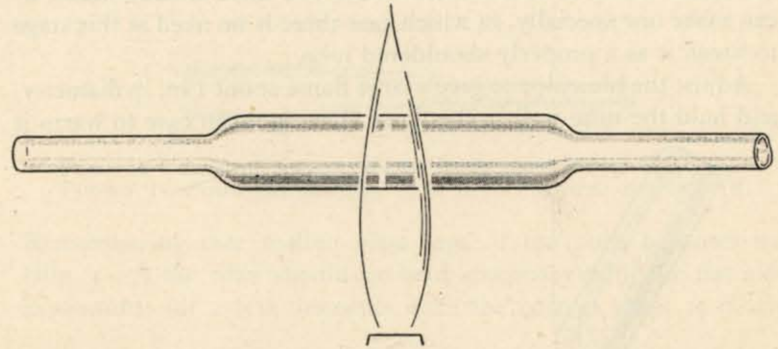


Fig. 5-13.—Heating Being Applied to the Neck Portion

the larger tube in the flame in order to make the " stub " for joining to the smaller tube.

In this method the larger tube must be rather longer than twice the length of the finished piece. Commence by drawing a point at each end of the tube if this is of large diameter; with tubes below 15 mm. diameter, points are not necessary unless the

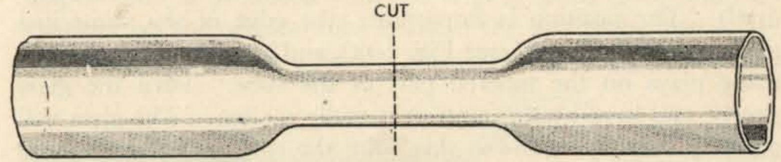


Fig. 5-14.—The Tube, When Cool, Is Cut in the Middle

finished tube is too short to handle. Now hold the centre of the tube in a small flame, rotating slowly, at the same time trying to avoid either pulling or pushing the two ends. As the glass melts it will thicken and reduce in diameter. When the wall has appreciably thickened the soft glass can be pulled slightly to reduce the wall thickness. Continue heating until the necked-down portion is the same diameter as the smaller tube to which it is to be joined. This is shown in Figs. 5-13 and 14. When the tube is cool cut it in the middle, and join the small piece to one of the ends by one of the methods already described.

Making a Calcium Chloride Tube

You should now be able to make a calcium chloride tube. You can either use one of the joined tubes you have already made, or can make one specially, in which case there is no need at this stage to finish it as a properly shouldered tube.

Adjust the blowpipe to give a large flame about 1 in. in diameter, and hold the tube well in the flame (having taken care to warm it

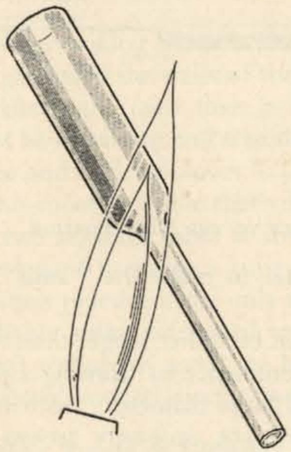


FIG. 5-15.—ONE-THIRD OF THE FLAME PLAYS ON THE TAPERED PART OF THE TUBE

first!). The position is important; the edge of the flame just plays on the joint itself (see Fig. 5-15), and about one-third of the flame plays on the tapered part of the tube. Turn the glass slowly, and keep heating until it is really molten. The glass will get very " flabby ", and at this point the rotation becomes more difficult. Watch the glass carefully—molten glass sags very quickly, and must be rotated in the flame in such a manner that it does not droop towards one side. Melt evenly; turn evenly; and get really molten. While turning, push the ends together gradually so that the glass " gathers " as the glassblower calls it. Be careful not to push too hard, otherwise ripples will form. The glass tube at this stage should look like Fig. 5-16(A), not like Fig. 5-16(B). The diameter and thickness of the small tube should not be altered. When this stage is reached, take the tube out of the flame and blow through the small end, rotating the tube

meanwhile. You will find that, with the tube in your mouth for blowing, you get a very good idea of the symmetry of the bulb.

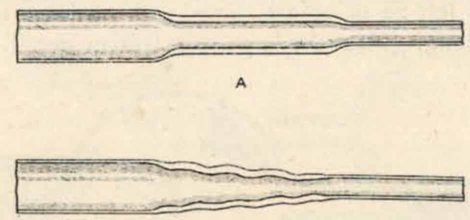


FIG. 5-16.—CORRECT APPEARANCE OF TUBE AFTER EDGES HAVE BEEN PUSHED TOGETHER (A), RIPPLES HAVE BEEN ALLOWED TO FORM (B)

Remembering that molten glass sags, if the bulb becomes flat (Fig. 5-17) the tube should be held stationary with the flat side downwards for a few moments until the correct shape is nearly

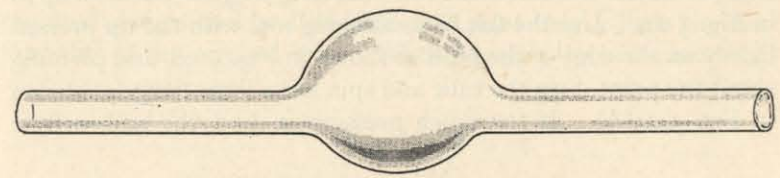


FIG. 5-17.—A BADLY SHAPED BULB

restored, and blowing and turning recommenced until a good-shaped bulb is produced—not too large; about three times the diameter of the original tube is about the maximum that is safe.

Anneal the bulb in a smoky flame: cut the larger tube to a

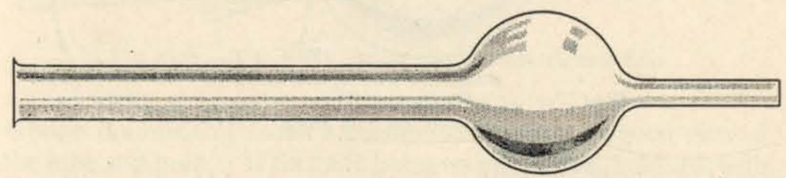


FIG. 5-18.—A CALCIUM CHLORIDE TUBE COMPLETED

length of about 4 in., and the smaller tube to about $1\frac{1}{2}$ in. long. Flange the larger tube slightly as described in the previous chapter, and flame polish the end of the small tube by holding in the flame until the edges just melt, and you have a complete calcium chloride tube (Fig. 5-18).

Making a Thistle Funnel

A thistle funnel is made in the same manner, except that the small tube is left 20 or 30 cm. long, and the large tube is cut to about 2 cm. long. Heat the large tube (taking care not to heat the

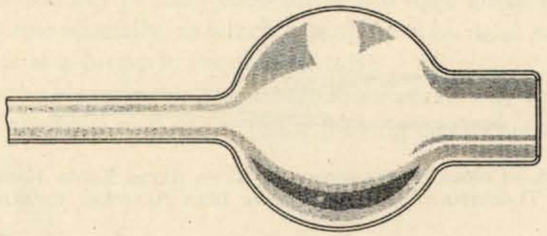


FIG. 5-19.—THE LARGE TUBE IS HEATED UNTIL THE END MELTS IN A LITTLE AND THE GLASS THICKENS

bulb) until the end melts in somewhat and the glass thickens up as in Fig. 5-19. Use the flat brass flanging tool with the tip pressed lightly on the edge of the bulb as shown in Fig. 5-20, and pivoting about the point, turn the tube and spin out a large flange as shown in Fig. 5-21(A). If too much pressure is used, the bulb will be

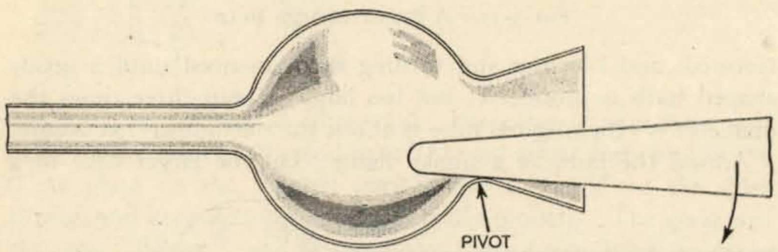


FIG. 5-20.—THE TIP OF A FLANGING TOOL IS PRESSED LIGHTLY ON THE EDGE OF THE BULB

turned in as in Fig. 5-21(B). The flanging should be done without having to reheat the glass, so be sure that it is hot enough before you start spinning it out.

The operation of blowing a bulb on the end of a tube requires perhaps rather more dexterity in handling hot glass with one hand. One of the round-end tubes you have made will be excellent for practising this operation. A large flame will be required, and the

tube should be held in the right hand. Heat strongly till the end of the tube shrinks and thickens. The tube should be rotated slowly, and the angle at which it is held in the flame must be varied

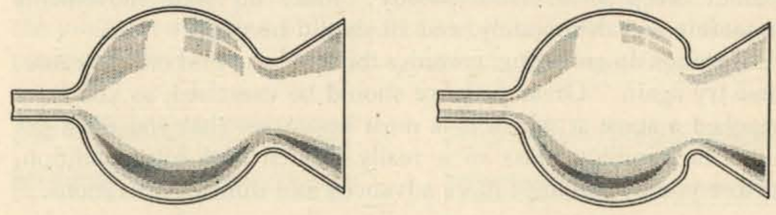


FIG. 5-21.—THE CORRECT APPEARANCE OF FLANGE (A), TOO MUCH PRESSURE HAS BEEN USED (B)

as required to keep the molten end as straight and symmetrical as possible. A little experience will soon enable you to judge just how far to let the glass thicken in order to blow a bulb of the required size, with a wall thickness at most only a little thinner than that of the original tube. When blowing the bulb, hold the

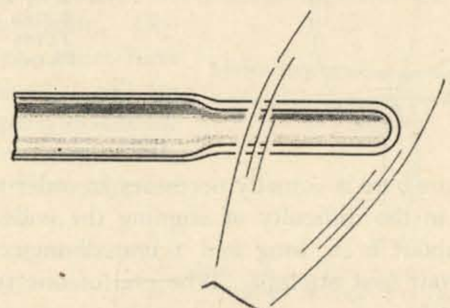


FIG. 5-22.—THE TUBE BEING HEATED UNTIL THE END SHRINKS AND THICKENS

tube in the mouth in such a position that you get a good view of the tube and bulb. If the bulb becomes misshapen, hold still with the flatter side downwards (without blowing) to let the molten glass flow under gravity, and continue to rotate when of the correct shape, varying the speed of rotation as necessary to preserve the symmetry.

When the bulb has been blown to your satisfaction do not forget to reheat in a soft flame, reducing the air supply gradually to a smoky flame to cool the glass slowly and relieve strain.

During the operation you will doubtless have been surprised, and perhaps a little scared, by the glass suddenly becoming really flabby and intractable when molten. Resist the temptation to panic; keep your hands steady; make all your movements smoothly and deliberately, and all should be well.

If things do go wrong, consider the fault and find out the cause, and try again. Great patience should be exercised, as you have reached a stage at which it is most important that you must get used to handling glass in a really molten and soft condition, before you can attempt more advanced and difficult operations.

Joining Tubes of Similar Diameter

Although at first sight the joining of two tubes of similar diameter may seem to be more easy than the operation just

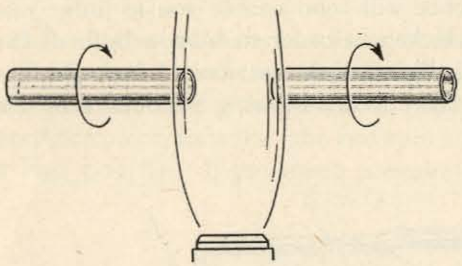


FIG. 5-23.—FLAME ADJUSTED FOR JOINING TUBES OF SIMILAR DIAMETER

described, more care is actually necessary in order to make a neat joint, owing to the difficulty of aligning the ends of the tubes. Two tubes about 6 in. long and 1 cm. diameter will be convenient for your first attempt. The end of one tube should be closed by a cork.

Adjust the blowlamp to give a flame about the same diameter as the tube you are to use, and holding a tube in the proper manner in each hand (the corked tube being in the left), rest your elbows on the bench and get into a comfortable position—steadiness of the hands is most important. Rotate both tubes slowly, and bring them into the opposite edges of the flame; heat the edges of the tubes until fairly hot—but not hot enough to shrink in diameter. Stick the tubes together; you must be sure that the tubes are in line at the first attempt—a result like Fig. 5-24(B) is almost impossible to rectify at this stage. Quickly reduce the flame to about 1 in. long, and heat the joint all round in the tip of the

flame until the glass is really molten and the joint contracts (Fig. 5-25), at the same time gently pressing the tubes together. Blow the joint up, at the same time pulling slightly to maintain the original diameter of the tube. Increase the flame size, and reheat the joint, blowing and pulling until the joint itself is smooth and practically invisible. To make a good job, you must be sure that the glass at the joint really melts, and that you keep the tubes in line all the time.

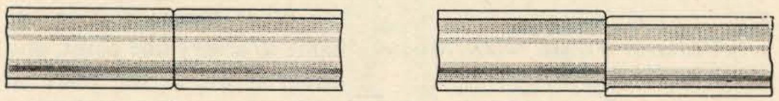


FIG. 5-24.—A GOOD JOINT (A) SHOWING TUBES IN LINE WITH EACH OTHER. A BAD JOINT (B)

When you have mastered the technique of joining small tubes, you can try your hand on larger tubes—about 40 or 50 mm. diameter. With these large tubes, however, you will require tube rests, and you must use a large flame in the preliminary " sticking " operation. Obviously, when the tubes have been lightly joined it will not be possible properly to fuse the joint all round in one operation, at least until you have achieved considerable skill.

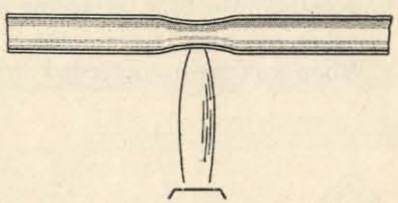


FIG. 5-25.—THE JOINT IS HEATED ALL ROUND IN THE TIP OF THE FLAME

The art here is to keep the whole tube fairly hot by repeated warming in a larger flame, and to melt and blow the joint a little at a time, gradually working right round the tube. By this time you should be very familiar with your blowpipe, and should be able to increase or decrease the size of the flame without any interruption of the work.

When the joint has been melted and blown all round, the whole tube is heated in a large flame and reblown just as you did with the smaller tube; it is finally annealed in a cool flame.

T-joints

The next operation we should master is that of making joints on the side of a tube—T-pieces are an example of this. A convenient size of tube to practise on is one of 1 cm. diameter. Cut two pieces of this about 6 in. long, and close the end of one piece with a cork. One end of this piece should be slightly flared—only slightly, as shown in Fig. 5-26.

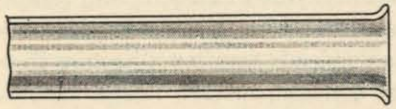


FIG. 5-26.—THE END OF ONE TUBE IS SLIGHTLY FLARED WHEN MAKING A T-JOINT

Now warm the centre of the other piece; reduce the flame to a very fine point, and direct it on to the place at which the joint is to be made, and blow a small bubble (see Fig. 5-27) about the size of the tube which is to be joined on. Then heat the centre of the bubble and blow out. The aim is to make the hole the same size as the side tube; if too small, the hole can be opened with a small brass strip; if too large, it can be shrunk a little by heating in the flame. However, it is difficult to shrink the hole without the tube collapsing inwards, and care must therefore be taken not to get it too large.

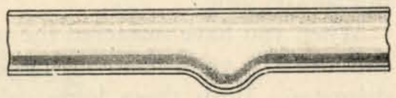


FIG. 5-27.—A SMALL BUBBLE IS BLOWN IN THE TUBE TO BE JOINED

When you have succeeded in getting the main tube to your satisfaction, turn the blowpipe flame up to about 1 in. diameter, and hold the main tube in the left hand at an angle of 45 degrees (holding by the upper end) so that the edge of the flame plays on the upturned edges of the hole, and hold the side (flanged) tube in the other edge of the flame until the glass is hot enough to stick.

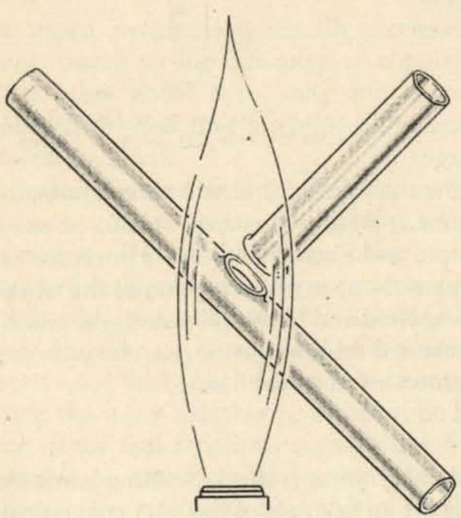


FIG. 5-28.—THE FLAME PLAYING ON THE EDGES OF THE HOLE AND ON THE SIDE FLANGED TUBE

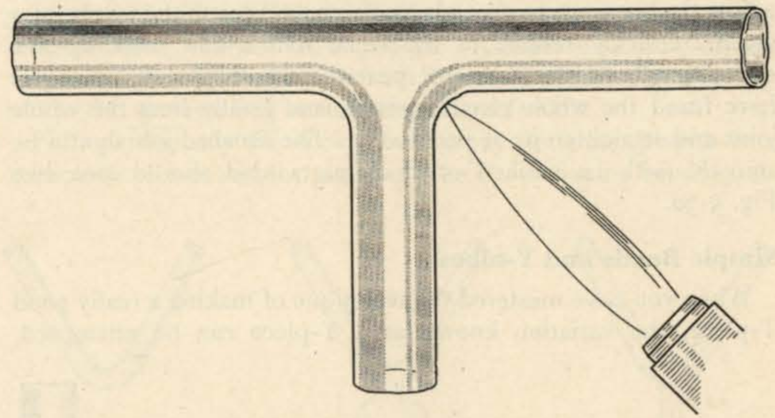


FIG. 5-29.—THE REDUCED FLAME IS USED TO FUSE THE JOINT

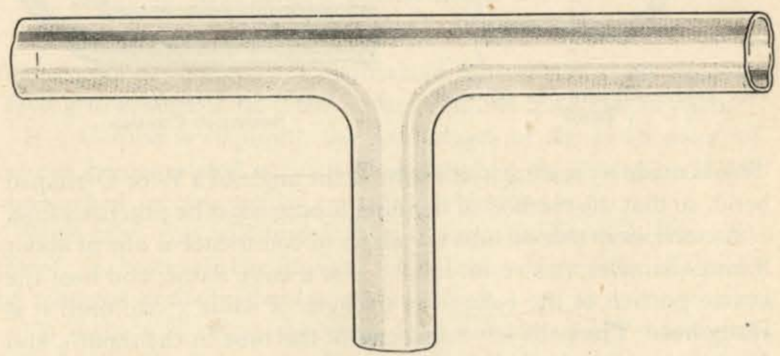


FIG. 5-30.—THE COMPLETED T-JOINT

The correct position is shown in Fig. 5-28. Press the side tube on to the main tube, taking care to get it properly placed.

The joint now has to be properly made. Cork both ends of the main tube. Reduce the flame to a very fine point, and heat one side of the joint (Fig. 5-29) until the glass is molten, working over about one-quarter of the circumference of the joint, blowing up gently until the glass is completely united. It is very important to keep the whole job warm during these operations, so occasionally adjust the blowpipe to give a large flame, and warm the whole joint again. Quickly reduce to the small flame, and work up the opposite side of the joint. Repeat the whole process until you have fused the whole circumference, and finally heat the whole joint and straighten up if necessary. The finished job should be smooth, with no sunken or thick parts, and should look like Fig. 5-30.

Simple Bends and Y-tubes

When you have mastered the technique of making a really good T-piece, the variation known as a Y-piece can be attempted.

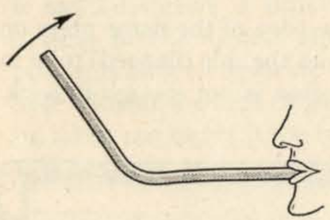


FIG. 5-31.—METHOD OF MAKING A BEND

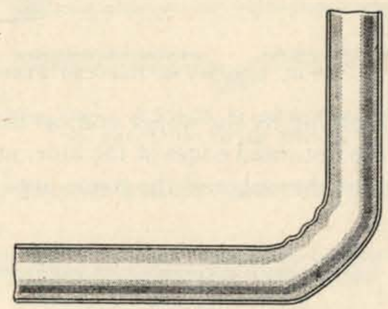


FIG. 5-32.—AN UNSATISFACTORY BEND SHOWING CREASES

This is made by sealing a side tube at the angle of a V- or U-shaped bend, so that the method of bending tubing must be practised first.

A convenient size of tube on which to commence is one of about 8 mm. diameter and 10 in. long. Use a large flame, and heat the centre portion of the tube over a length of some 5 cm. until it is really hot. Place the left-hand end of the tube in the mouth, and closing the other end with the forefinger of the right hand, bend the tube by raising the right-hand end as shown in Fig. 5-31, at the same time applying a slight air pressure, by blowing steadily into the tube, to keep the diameter at the bend uniform.

In this case a small, steady air pressure is required, not a violent puff, the pressure being varied according to the state of the bend. By holding the tube in the position described during the bending

operation, you will find it very easy to control the speed of bending and the tendency of the tube to flatten.

If the glass is not hot enough, or it is bent too quickly, the outer part of the bend will flatten, and creases may be formed on the inner portion; as shown in Fig. 5-32. A malformed bend of this nature in tube smaller than 10 mm. diameter is difficult to rectify unless the operator has attained considerable skill.

Note particularly that tube should always be bent upwards in a vertical direction, and the glass must be blown during bending, so

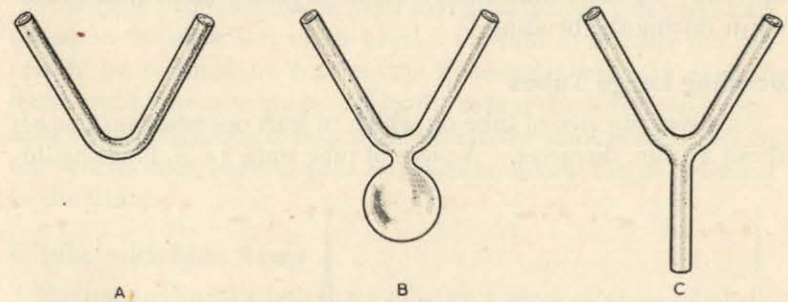


FIG. 5-33.—THE FORMING OF A Y-PIECE

A. Y-bend in main tube.
B. Hole blown in outer surface.
C. Side tube joined and the whole annealed.

that a uniform diameter is maintained during the whole process. Trying to reblow a flat bend never produces a satisfactory job.

If a U-tube is required, the final stages of the bend must, of course, be completed without blowing when the return bend has approached inconveniently near to the blowing end.

With care, you will find it easy to keep the bend in the same plane; if, however, the finished job is somewhat twisted it should be reheated and adjusted before annealing.

To make a Y-piece, the main tube is bent to a V having an included angle of about 60 degrees. A hole is then blown in the outer surface of the bend, using the method described in the previous section, and the side tube joined on in the usual manner, as shown in Fig. 5-33. The whole piece must be carefully annealed when completed.

CHAPTER 6

LARGE TUBES AND INTERNAL SEALS

In the last chapter we described the method of bending tube of 10 mm. in diameter or less. Larger tubes require a rather different technique; while the manipulation of larger tubes is obviously the more difficult, it is easier to rectify faults which may occur during the bending.

Bending Large Tubes

A convenient size of tube on which to start operations is one of about 25 mm. diameter. A piece of tube some 15 in. long should

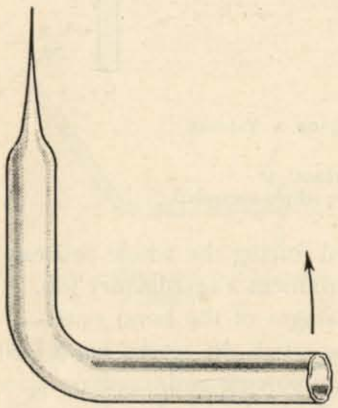


Fig. 6-1.—The Tube is First Bent to a Right-angle

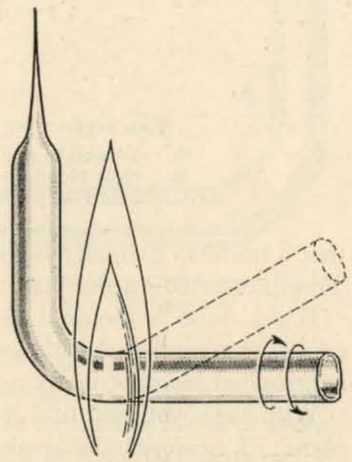


Fig. 6-2.—The Rotating Tube Is Heated and Bent to Make the Other Half of the U.

be cleaned, and the ends drawn to points, one of which should be sealed, the other being left open.

The blowpipe should be adjusted to give a large flame, and the tube heated to the softening point over a length of about 3 in., located left of the centre of the length. When in a fit condition, bend and blow the tube in the same manner as for the smaller

tube, but in this instance the bend is corrected by a series of quick puffs, as it will be found very difficult to exert a steady pressure of sufficient force to blow tube of this size. Do not bend the tube through more than a right angle.

Now hold the bend, shown in Fig. 6-2, with one limb in the left hand, the point of the other limb being held in the usual manner in the fingers of the right hand. By rotating the tube backwards and forwards with the left hand, heat uniformly all round, again for a length of about 3 in., and bend the tube to make the other half of the U-tube (Fig. 6-2).

It is quite probable that at your first attempt you will produce a crease on the inner side of the bend. On tube of this size this can readily be rectified by heating the distorted portion in a small flame and blowing to shape. Finally, reheat the whole, and carefully bend both limbs to be parallel and in the same plane. When the bend is completed to your satisfaction, do not forget to anneal in the flame.

U-tube with Side Arms

Having produced a satisfactory U-bend, we may as well make it into something useful by finishing it off as a U-tube with side

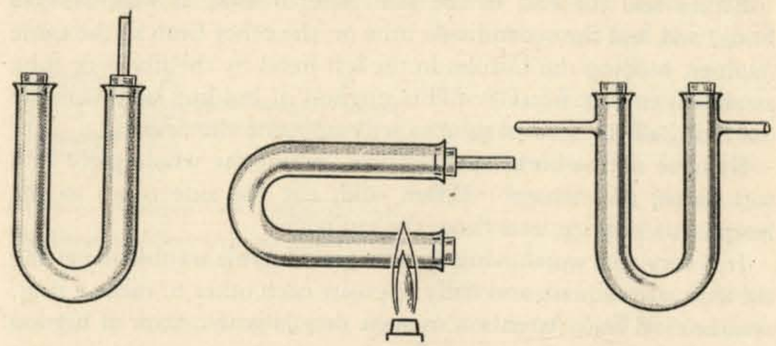


Fig. 6-3.—Method of Making a U-tube with Side Arms

arms. With a grease pencil, mark the limbs of equal length and crack off in the flame, finishing with a small flange. While the tube is cooling after this operation, prepare two side arms of 6-mm. tubing about 100 mm. long, not forgetting to slightly flare one end of each.

Close one limb of the U-tube with a solid cork and the other with a one-hole cork through which is passed a short piece of small tube through which you will blow as required. These corks should project not more than 1 cm. into the tubes. Please note particularly that when closing tubes for blowing operations, corks must be used—never rubber stoppers—as if the latter get too hot, they melt and burn into the glass, whereas cork only chars and does not adhere.

With a grease pencil, mark a short line 1 in. from the top of each limb where the side tubes will be joined. Until you have become more experienced, it is wise to make a vertical line through each mark to indicate the centre of the side tube, taking some pains to get your marks exactly opposite on each limb.

Using a medium-size flame, hold the tube with the limbs horizontal, and warm all round one limb in the region of your mark. Then reduce the flame to a fine point and blow a hole exactly on your mark, as directed in the previous chapter. Take one of your prepared side tubes, and, after replacing the tubulated bung by a solid one, seal the side tube in position by the usual method, making sure that it is square in all directions. These operations are illustrated in Fig. 6-3.

Either seal the end of the side tube or close it with a small bung, and seal the second side tube on the other limb in the same manner, holding the U-tube in the left hand by the first side tube as shown in Fig. 6-3(C). This method of holding will facilitate the fixing of the second tube exactly opposite the first.

Remove all the corks and closures, reheat the whole piece in a soft flame, and anneal. When cold, cut the side tubes to the length you require, and flame the cut edges.

It is very well worth while to take considerable trouble in getting the side arms square and truly opposite each other to make a neat, symmetrical fit. Attention to such details is the mark of a good glassblower.

When you are sufficiently skilled to be able to bend a large tube in exactly the right place, a U-tube can be made by first cutting and flanging the ends of the main tube and bending in the middle instead of trimming and flanging after bending—considerable saving of tube can be effected by this method, but there is always danger of making a lop-sided tube if the bend is not made accurately.

Whichever method is adopted, however, the side tubes must always be fused on after bending, as it is almost impossible to get these accurately aligned if they are first fused to the straight tube; some degree of twisting in one place or the other is inevitable when bending.

Internal Seals

A type of construction which is often required is one in which a small tube is sealed through a larger one, as shown in Fig. 6-4. This style of construction is termed an internal seal, or ring seal, and may be made by either of two methods, according to the design of the finished product.

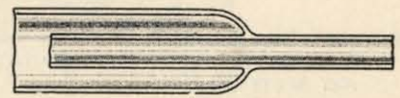


FIG. 6-4.—TUBE WITH INTERNAL SEAL

We will, as usual, start with a simple example. Using a piece of 25-mm.-bore tube about 6 in. long, fit one end with a cork and blowing tube, and close the other by blowing a round end, which should be rather flat, not hemispherical. Blow a slightly tubulated hole to accommodate the smaller tube which is to be sealed through it. This small tube should pass through the tubulure with a little room to spare, and the tubulure should be just slightly flared, and finished off square by pressing a flat carbon plate against the hot glass (not forgetting to keep your tube rotating meanwhile); see Fig. 6-5(A).

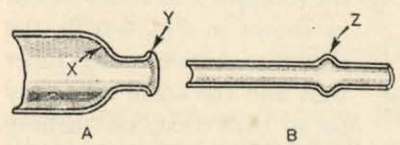


FIG. 6-5.—MAKING THE INTERNAL SEAL
The flared tubulure (A), the smaller tube with the ridge (B).

Now take the small tube and cut it to the length you require. Use a small flame, and heat the tube over a narrow band at the point at which you wish to seal it into the large tube. When sufficiently hot, press the tube together axially to throw up a small ridge as shown in Fig. 6-5(B). This ridge should be just large enough to rest in the tubulure Y of the large tube. Taking the large tube in your left hand, and the small one in the right, heat both tubes (rotate!) and when warm, but not soft, pass the small tube through the hole, until the ridge rests on the ridge of the tubulure, taking care to get it central, as shown in Fig. 6-6(A). Continue heating till the glass just adheres, and after reducing the size of the blowpipe flame, heat the junction of the two tubes until the glass melts and flows together. You must watch the inner portion of the small tube, and vary the speed of rotation of the glass so as to keep the tube straight. Blow the joint in the usual

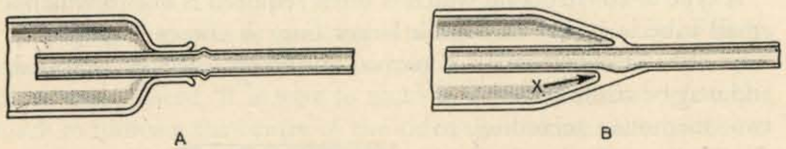


FIG. 6-6.—THE SMALL TUBE PLACED INSIDE THE LARGER ONE SO THAT THE RIDGE RESTS ON THE TUBULURE (A), THE ROUNDED END MUST NOT BE TOO ACUTE (B)

manner (after sealing the outer end of the small tube) until you get a nice smooth joint as in Fig. 6-4. Heat the whole of the end of the large tube and joint, and blow out to a proper hemispherical end, adjusting the straightness of the small tube meanwhile.

You will now see the reason why a somewhat flattened end is required on the large tube at the beginning of our operations. If the rounded end is too acute, as shown in Fig. 6-6(B), the clearance between the inner wall and the small tube may be so little that, on melting the joint, the glass may collapse on to the inner tube, as seen in the lower part of the diagram, preventing the making of a good seal. For the same reason, the joint must be carefully watched while it is being heated, and the end should be gently blown out if it shows any signs of collapse.

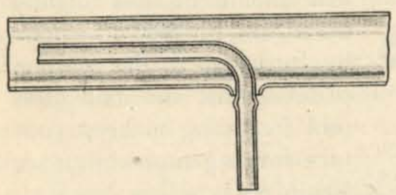


FIG. 6-7.—A SMALL TUBE THREADED THROUGH THE SIDE OF A LARGER ONE READY TO SEAL.

Occasionally it is necessary to seal a tube through the side of a larger one. If the length of the inserted tube permits, it is possible to thread it into the larger tube as in the previous example. This is shown in Fig. 6-7. The technique is the same as for the joint we have just made, but it may be found more difficult to prevent the

inner tube from bending out of position. You should by now, however, be sufficiently experienced in the manipulation of plastic glass to overcome this difficulty.

A good example of this method of construction is the making of a splash head illustrated in Figs. 6-8 and 6-9. The first figure shows the completed job, and the second the stages during blowing. As you should be well practised in the operations

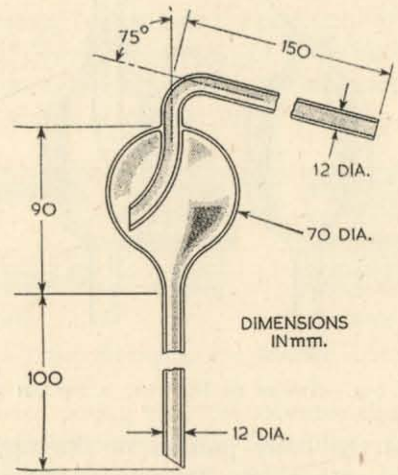


FIG. 6-8.—A SPLASH HEAD

described in earlier chapters, details will not be repeated, unless there are special points which require mention.

We commence by rounding the end of a suitable length of 50-mm.-diameter tube, and sealing the inlet (lower) tube on to this end (Fig. 6-9(A)). A point is then drawn on the other end, but in this instance, contrary to our usual practice, we deliberately make an abrupt point, with an obtuse internal angle as shown in the figure, and we should take care to maintain the wall thickness of the tube at least to the point X. The internal tube should be ridged, and the lower end bent only to the required angle. Make the bend after, not before, forming the ridge.

Now make the tubulated opening in the large tube to fit the inner tube, which can then be fused into position. If you have not made the " point " really obtuse you will almost certainly experience difficulty here, as the surface tension of the melted joint will draw the inner tube towards the side of the bulb.

Having made a satisfactory seal, heat the whole piece until sufficiently plastic, and blow the bulb and manipulate it into the correct pear shape, which will necessitate blowing first to a spherical bulb, after which the lower end is pulled out to the final shape.

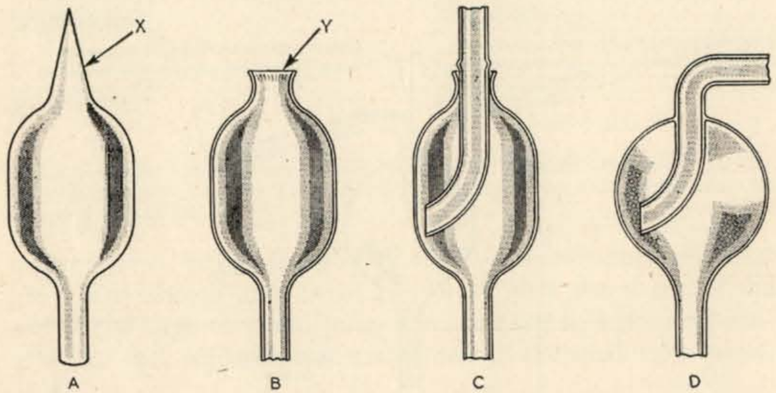


FIG. 6-9.—STAGES IN BLOWING A SPLASH HEAD

Finally, bend the outer portion of the upper tube to the requisite angle, and cut off. Do not forget firstly to melt the ends of the cut tubes in the flame, and secondly, to anneal the completed job.

You will note that for the first time, dimensions have been given in Fig. 6-8, and an attempt should be made to work to these. If an error in dimensions is made, however, do not let this worry you now.

Another Method of Making Ring Seals

The second method of making through or ring seals, though somewhat more difficult than the first, is one of much wider application, and for this reason no effort should be spared to master it.

This method must be used, for instance, when the internal and external portions of the through tube are of different diameters; when the internal portion is long or heavy and requires extra support during blowing; or when the internal tube has to be

sealed on at both ends, as in the construction of a Leibig condenser, illustrated in Fig. 6-14.

We will start in the simplest manner by sealing through one end of a piece of plain tube. First make a round-end tube of 25 mm. diameter, about 6 in. long. Then prepare two pieces of 8-mm. tube; cut off square and slightly flange at one end as already described. One piece can be some 30 mm. shorter than the length of the outer tube; the other may be any convenient length.

Bore a short piece of cork to take the plain end of the inner tube, and paper or file it down to be an easy fit in the outer tube. Wrap asbestos paper round the other end of the inner tube, not too tightly, to keep this end central while blowing. Assemble as

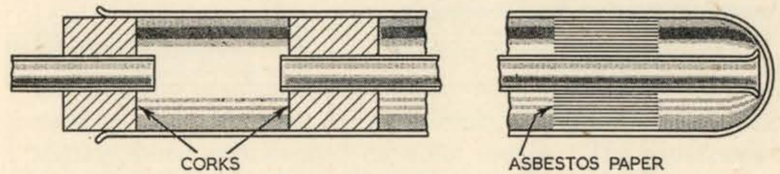


FIG. 6-10.—TUBES ASSEMBLED FOR MAKING A RING SEAL

shown in Fig. 6-10, noting that the asbestos should be at least $\frac{1}{2}$ in. away from the proposed seal. Carefully adjust the tube so that the flanged inner tube presses against the closed end of the outer tube and the whole lies perfectly central. Fit the open end of the tube with a cork and short blowing tube.

Using a medium-size flame, heat the end of the tube, rotating slowly, and holding it at an angle of 45°, so that the flame plays on the end until the tube collapses inwards somewhat. Reduce the size of the flame, and heat all round the junction of the two tubes until the glass melts, blowing as required to make the glass unite completely all round the seal (Fig. 6-11(A)).

The next operation is to blow the end open in the usual manner, as for making a joint. You will find that with a small, well-directed flame there is no danger of spoiling the joint you have already made. Still keeping the job warm in the flame, heat the end of the outer tube you are going to seal on, and make the joint as if joining two tubes. You must, of course, either replace the cork and blowing tube by a solid cork or, more conveniently, place the finger over the small tube while blowing up the joint. Finally, the whole joint is warmed, blown up to a nice hemispherical end, and straightened up before annealing.

Occasionally it is necessary to seal a tube through the side of a larger tube, as in Fig. 6-12. Exactly the same technique is required, but in this case much greater care must be taken in the

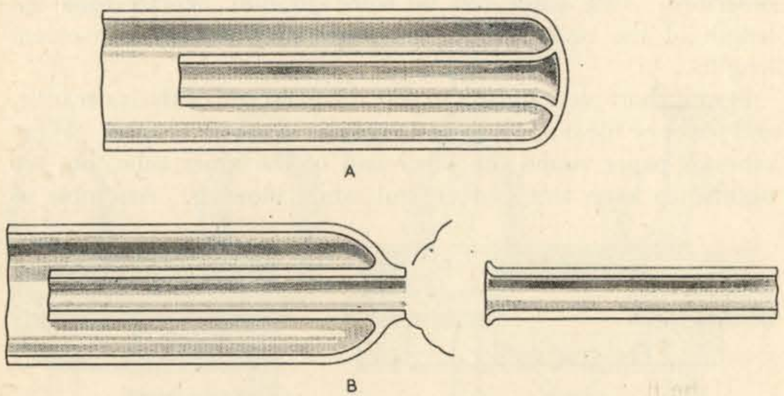


FIG. 6-11.—BLOWING OPERATIONS FOR A RING SEAL

A. The glass is made to unite round the seal.
B. End blown open to make the joint.

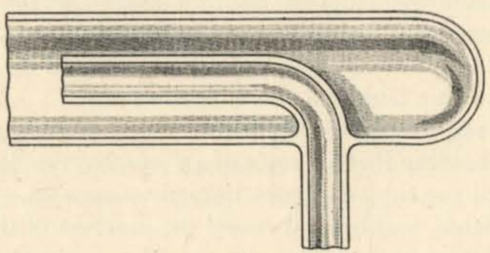


FIG. 6-12.—A TUBE SEALED THROUGH THE SIDE OF A LARGER ONE

location of the inner tube, particularly if the tube is joined at both ends—it is absurdly easy to fit your corks and packing in such a way that they are not removable when the job is done!

If this unfortunate state of affairs should ever happen to you, do not throw the job away in a temper; the situation can be rectified with care. If a cork has to be removed, fill the glass with concentrated nitric acid and leave for a few hours until the cork has disintegrated; and wash out the bits with plenty of water.

If the offending material is asbestos paper, fill with water and leave overnight, so that the material is well sodden. Shaking the tube should break the asbestos up sufficiently to allow it to be extracted with a notched piece of wood—do not use a metal hook.

A very useful method of holding and locating the inner tube is shown in Fig. 6-13. A piece of smaller tube is wrapped at one end

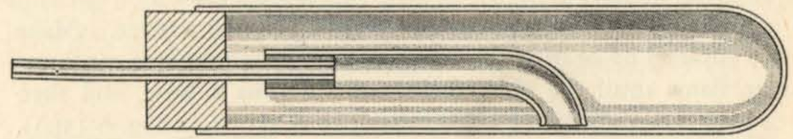


FIG. 6-13.—METHOD OF CONTROLLING THE INNER TUBE

with a strip of asbestos paper about 1 in. wide to make it fit tightly into the inner tube. To the other end of the tube is fitted a short cork of a size to suit the outer tube. Note especially that the cork must be short, and that the short end of the inner tube must be slightly flared and finished off quite square. The squareness of the ends of tubes to be sealed by this method is most important.

You will see that by manipulating the holding tube in and out, and rocking the cork, the position of the inner tube can be controlled with ease and certainty.

Constructing a Leibig Condenser

Having succeeded in making a good job of all the exercises described so far, you should be able to make the condenser shown

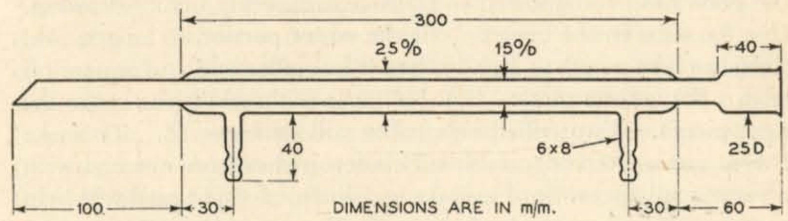


FIG. 6-14.—DIAGRAM OF A LEIBIG CONDENSER

in Fig. 6-14. Try to keep to the dimensions quoted as far as you can, and proceed in an unhurried manner. Operations already described will not be repeated in detail, but note carefully the sequence and, particularly if you are working in soda glass, be careful to keep the job hot—at least the end you are working on—by warming up in a large flame from time to time until the job is finished, and anneal the joints carefully before proceeding to the next operation.

We start by preparing the various pieces of glass which will be required to form the finished article. Make all these before you commence joining up, so that you will not have to interrupt the job of assembly.

First select, clean, and cut all the tube you will require. Make the cup end by heating the centre of a piece of tube in a medium-size flame until the glass melts and thickens a little, and then draw it down slowly for a short distance as shown in Fig. 6-15(A).

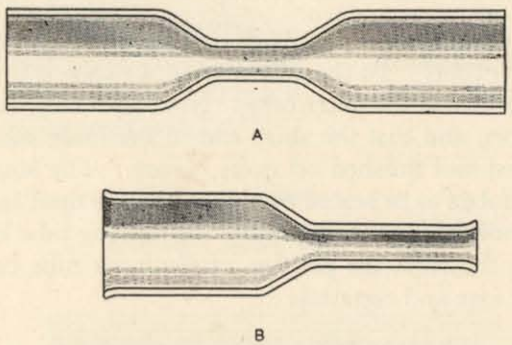


FIG. 6-15.—THE MAKING OF THE CUP END

The centre of the drawn-down portion should be nearly parallel if the glass has been allowed to thicken sufficiently before drawing. Cut the tube in the centre; cut the wider portion to length, and flange to take a cork; slightly flare the smaller end and square off with a flat carbon plate. Set this piece aside while you make the next pieces. Two riffled side tubes will be required. To make these, heat a piece of suitable tube a few inches from one end with a very small flame, until it sinks in a little; a slight pull will help to produce a sharp neck as shown in Fig. 6-16(A). The process is repeated at a point about 8 mm. away from the first neck, and again if required to produce the effect shown at (B). Cut the tube in the centre of one of the necked portions and flame the end to produce the riffled end shown at (C). Cut this tube to the length required for your side tube, and flare and square the plain end.

If a riffled tube is required to accommodate rubber pressure tube, the shape of the riffle must be different to allow the comparatively inelastic tube to slide on easily. The riffles are made, just as described above, but the last riffle is pulled out to a pear shape, as seen in Fig. 6-17, and cut at X. Generally, only one neck will be required, as shown.

Next prepare the inner tube by cutting to length, flaring and squaring both ends for sealing; a short length of tube to form the lower end of the condenser will also be required. Finally, make the outer jacket tube by selecting a length of tube some 4 in.

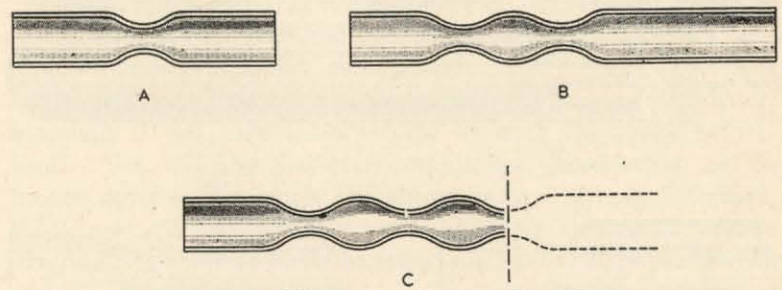


FIG. 6-16.—MAKING THE RIFFLED SIDE TUBES

The necked portions are shown in (A) and (B), and the riffled end in (C).

larger than the finished jacket, and make a round closure at one end.

All our pieces are now ready, and we are able to start the assembly and joining. Fit a small blowing tube to the inner tube as described under Fig. 6-10, and fix in the outer jacket with a cork, so that the free end is in contact centrally with the closed end of the jacket. Make the seal, blow the end open, and seal on the cup tube. While this end is still warm, seal one of the side tubes in position. You will find it most convenient to close the end of the side tube with the finger and blow through the blowing tube; this will obviate the danger of a nasty burn, which might occur if you attempt to blow through the side tube at the hot end of the assembly.

Now remove the cork and blowing tube, and any packing you may have used inside the jacket. Wait until the tube has cooled sufficiently to handle, and holding the sealed end in the left hand, draw a point at the other end, pulling the glass down so as to just

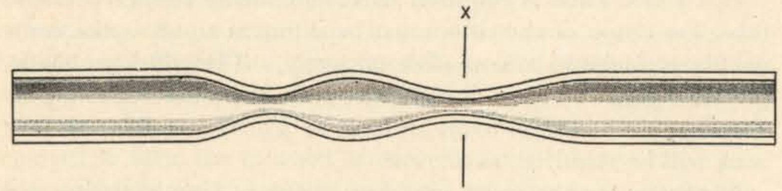


FIG. 6-17.—TUBE WITH LAST RIFFLE PULLED OUT TO ACCOMMODATE PRESSURE TUBE

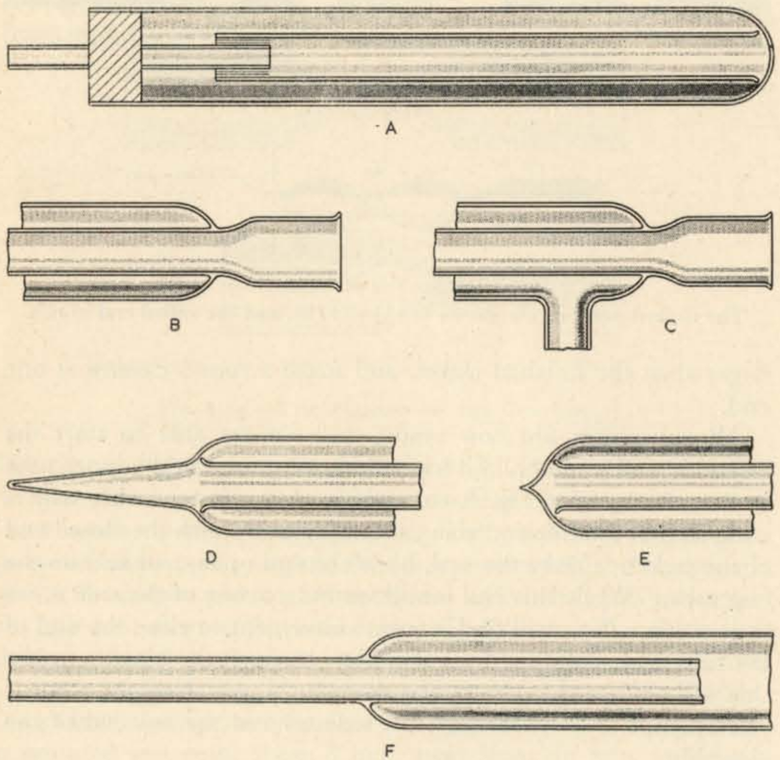


FIG. 6-18.—STAGES IN THE ASSEMBLY AND JOINING OF A LEIBIG CONDENSER

clear the end of the inner tube. These stages are illustrated in Fig. 6-18.

You must take care that the thickness of the wall is maintained and that the shoulder is very oblique, for reasons we have already mentioned earlier. The inner tube must not touch the jacket. Heat the end until the glass collapses on to the inner tube. At this stage excess glass may be drawn off, leaving the end in the condition shown in Fig. 6-18(E). Work up the seal, open the end, and join the exit tube. Finish the job by sealing on the remaining side tube, either exactly in line with the first one or exactly opposite it, at the lower end.

Finally, reheat and anneal the whole job. When cool, it will be very instructive to check the dimensions with Fig. 6-14 and consider why mistakes, if any, came about.

The making of such a condenser should give you confidence, especially if you have mastered the separate operations beforehand. You will find that even complicated glassblowing can be broken down to the simple operations we have already described. While some other, more advanced methods still remain to be described, they are all based on those you have already performed.

CHAPTER 7

CAPILLARY TUBING

It is generally considered much more difficult to work with capillary tube than with tube of ordinary thickness. This is not in fact the case if certain precautions are taken. The difficulties are caused by the amount of glass which has to be got completely hot enough to work, without allowing the bore to collapse and also to the care which must be taken in annealing.

Joining Process

To get the " feel " of capillary tubing during working, it is best to start by joining a piece of $1\frac{1}{2}$-mm.-bore by 8-mm.-outside

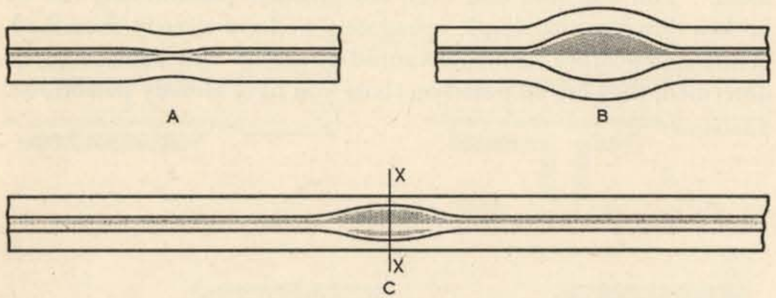


FIG. 7-1.—METHOD OF PREPARING A CAPILLARY TUBE FOR JOINING

diameter tube to a piece of ordinary 8-mm. tube. You will find it best to commence by heating the centre of an 8-in. length of capillary in a small, hot flame, taking care that the glass is completely molten right through the thickness of the wall. The tube will shrink as shown at Fig. 7-1(A), but do not let the bore close too much. Closing the bore of the tube with the finger of the left hand if necessary, blow a small bulb as seen in (B), and pull the tube out gently so as to restore the outside diameter as shown at (C). Allow to cool, and cut in two at *X*, making sure that the tube is broken off quite square. The standard-wall tube to which it is to be joined must be cut off square, not flared as you have done previously. One end is corked, and is held in the left hand while

making a joint in the usual way. A small flame must be used, and care exercised that it is not allowed to play too near the capillary bore.

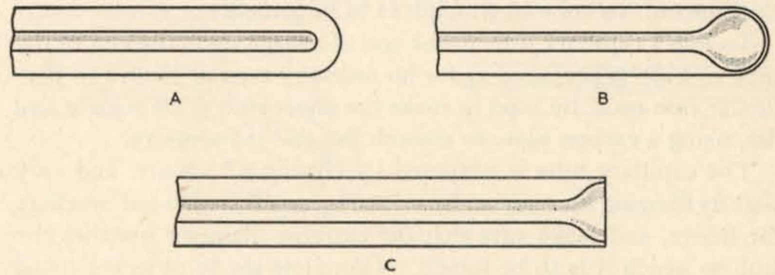


FIG. 7-2.—ANOTHER METHOD OF PREPARING THE END OF A CAPILLARY TUBE

Another method of preparing the end of the capillary tube is to heat one end until the bore is closed (Fig. 7-2(A)). Continue to heat the end and blow out to a diameter equal to that of the tube,

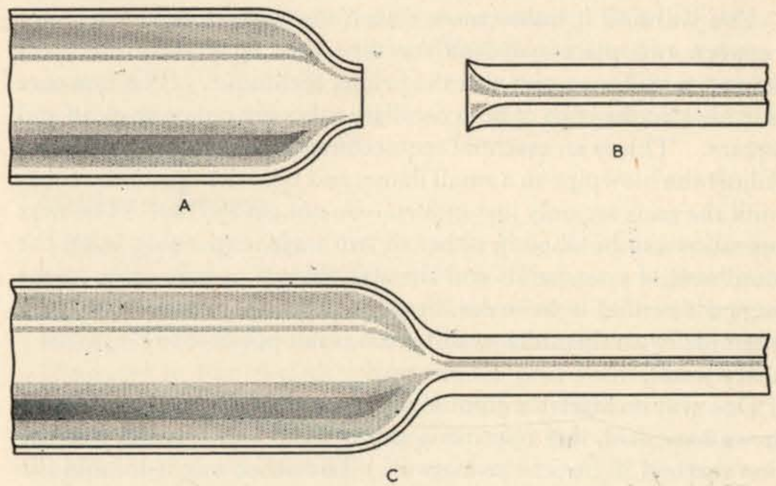


FIG. 7-3.—METHOD OF JOINING CAPILLARY TUBE TO A LARGE TUBE

as seen in sketch B. Then heat the end of the bulb in an extremely small flame, and blow out completely. Clean off the excess glass, heat in the flame until the end is flat and square, and seal to the ordinary wall tube as described in the previous chapter.

This method, however, is not so good as the first described, as the edges of the tube are likely to be too thin to make a satisfactory joint. In the first method the thickness of this part can be controlled, and after a little practice can be adjusted to match the thickness of the tube to which it is to be joined.

To join a capillary tube to the end of a large tube, the end of the tube or bulb is prepared as for an ordinary type of joint, but particular care must be used to make the short stub quite square and flat, using a carbon plate to smooth the end if necessary.

The capillary tube is prepared by cutting off square, and very slightly flanging the end, as shown in Fig. 7-3(B). Do not overflare the flange, and make sure that the extreme diameter matches the stub to which it is to be joined. Complete the joint in the usual way, not forgetting to keep the blowpipe flame clear of the capillary bore. Make sure, by melting and blowing, that a nice smooth joint is obtained, nowhere thinner than the wall of the main tube, and with no "lumps" or rough places.

Butt Joint

You will find it rather more difficult to make a good butt joint between two pieces of capillary tube, but again care and perseverance will soon give you the proper technique. The first care is to see that the ends of both capillary tubes are cut quite clean and square. This is an essential requirement for making a good joint. Adjust the blowpipe to a small flame, and heat the tips of the tubes until the ends are only just molten—do not get too hot. The next operation can be done in either of two ways, depending upon the steadiness of your hands and the straightness of your eyes, as the second essential is to make the joint properly in line at the first attempt; with this thick-wall tube it is not possible to "untwist" a wry joint.

One way to start the joint is simply to butt the ends together; as we have said, this requires a steady hand and eye, but it is the best method if you can manage it. The other way is to hold the two tubes at an angle, and then to bring together at one edge, as in Fig. 7-4(A), closing the two tubes together like a hinge, without squashing at the original contact. Note that the two tubes at the junction must only be hot enough to just stick together. If the glass is too plastic the ends will bulge up and the bore may close.

Immediately heat the junction of the tubes in a very small flame,

as you did when preparing a tube for the first exercise, and when the glass is heated right through, and the bore is not less than half its original diameter, as in Fig. 7-4(B), press the joint together to produce a very small bulb (C), blowing if necessary to prevent the bore closing. Heat again to thicken up the wall of the tube, and

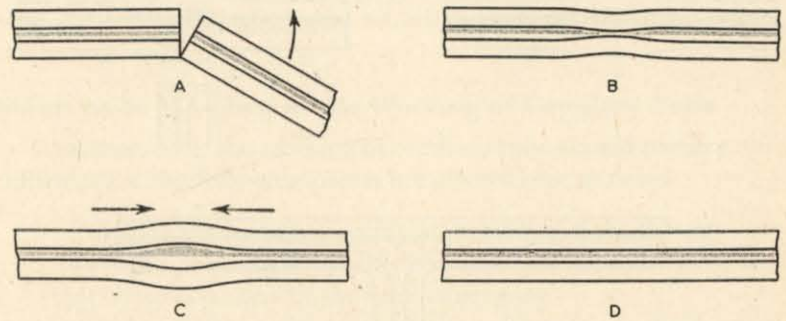


FIG. 7-4.—MAKING A BUTT JOINT

when the inside diameter of the bulb is about twice the diameter of the original bore, pull the tube out slowly. The object is to restore the original bore and wall thickness at the same time, as shown at (D). You will probably find that several attempts have to be made before you can make a nice clean butt joint, in which the joint itself is almost invisible.

Making a T-piece

When you can make a butt joint to your satisfaction, the next step is to make a T-piece in capillary. Prepare a slightly flared piece of tube for the side arm, and blow a small bulb in the centre of the main tube, just as you did when making a butt joint; this is illustrated in Fig. 7-5(A). Now reduce your flame to a very fine point, and blow out one side of the bulb as shown in Fig. 7-5(B). As in all capillary work, take great care not to heat the tube beyond the part you are actually working. Seal on the side tube, working round the joint just as in any other T-piece, until you obtain a nice smooth joint like Fig. 7-5(C).

For certain apparatus, such as gas burettes, pipettes, or viscometers, the joint between the capillary and the bulb must be very gentle, so that the contained liquid (usually mercury) can flow freely without danger of the gas being trapped at the shoulder joint. This is easily effected by preparing the capillary tube rather differently from the usual manner. Start by blowing a bulb in a piece of capillary tube, in this case blowing up to about twice the tube diameter; then pull the tube out to its original diameter, so that a gentle conical enlargement of the bore is obtained as

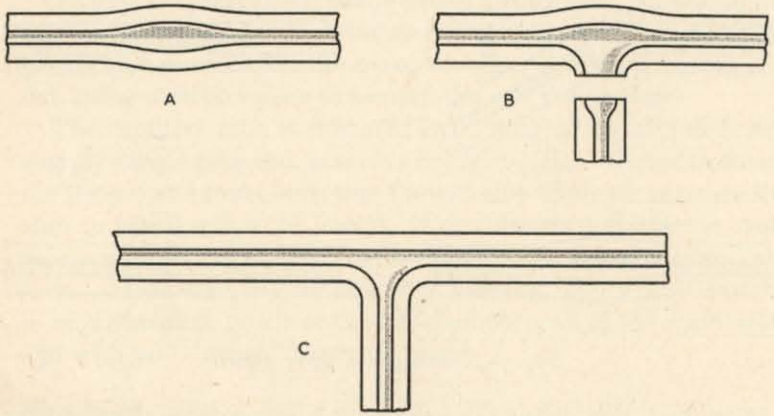


FIG. 7-5.—MAKING A T-PIECE IN CAPILLARY TUBING

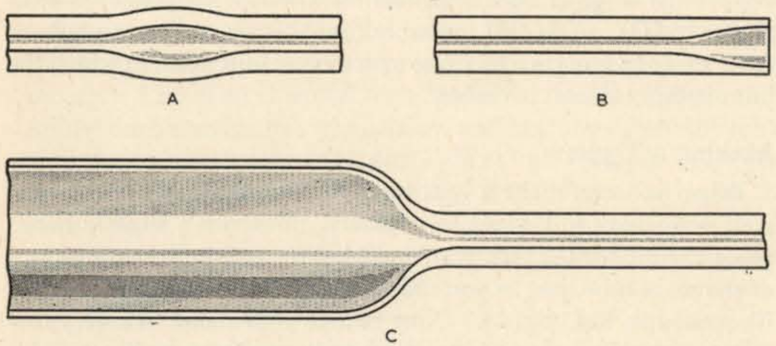


FIG. 7-6.—MAKING A "GENTLE" JOINT FOR AN INSTRUMENT TO CONTAIN MERCURY

shown in Fig. 7-6(A). Cut the tube in half to obtain two pieces like sketch (B). The thickness of the wall at the end of the tube should be the same as that of the bulb to which it is to be joined.

Prepare the end of the bulb in the usual way, and join on to the capillary. When the joint is completed, heat the end of the bulb, avoiding the capillary, and pull out to a conical form, so that the

wall of the tube slopes gently and continuously into the bore of the capillary as drawn in Fig. 7-6(C).

Bending capillary tube presents no difficulty, providing that the glass is melted right through over a sufficient length to make the bend with one heat. Small-bore tube will not need blowing when bending, but with larger-bore capillary, a gentle air pressure should be maintained by the mouth to prevent the bore from collapsing.

Points to be Watched in the Working of Capillary Tube

To recapitulate, the working of capillary tube should present no difficulties if the following points are always kept in mind:

(*a*) The glass must be completely molten right through.

(*b*) The tube must not be allowed to shrink too much, so that there is danger of the bore closing up.

(*c*) At all times the bore of the tube must be kept uniformly smooth, without lumps or ripples.

(*d*) When being worked, the tube must be kept warm, and when the job is complete it must be thoroughly annealed.

Making an Absorption Pipette

At this stage it will be very helpful if you blow a piece of glassware which incorporates many of the operations you have prac-

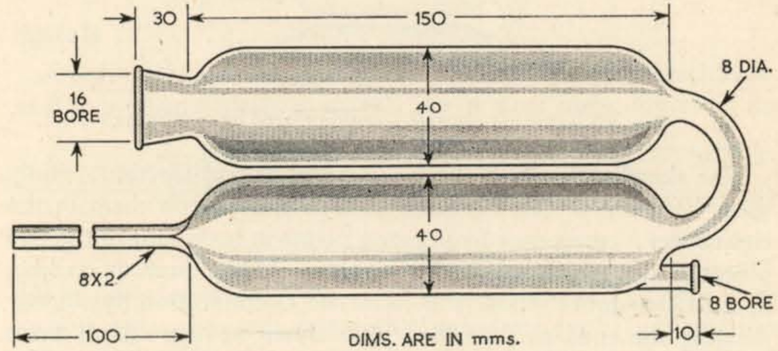


FIG. 7-7.—DIMENSIONAL SKETCH OF AN ABSORPTION PIPETTE

tised. An absorption pipette of the type used in Orsat gas-analysis apparatus is a very good example to select; a dimensional sketch is given in Fig. 7-7.

Start by selecting and thoroughly cleaning the tube you will require, and set to work, keeping to dimensions as accurately as you can. In this connection, it is well to use a wood rule, not a metal one, for measuring; some glassblowers check their work by laying the glass on the drawing while working and adjusting. This is certainly a help, provided that you have checked the drawing to make sure that it is in fact full size, and accurately to scale.

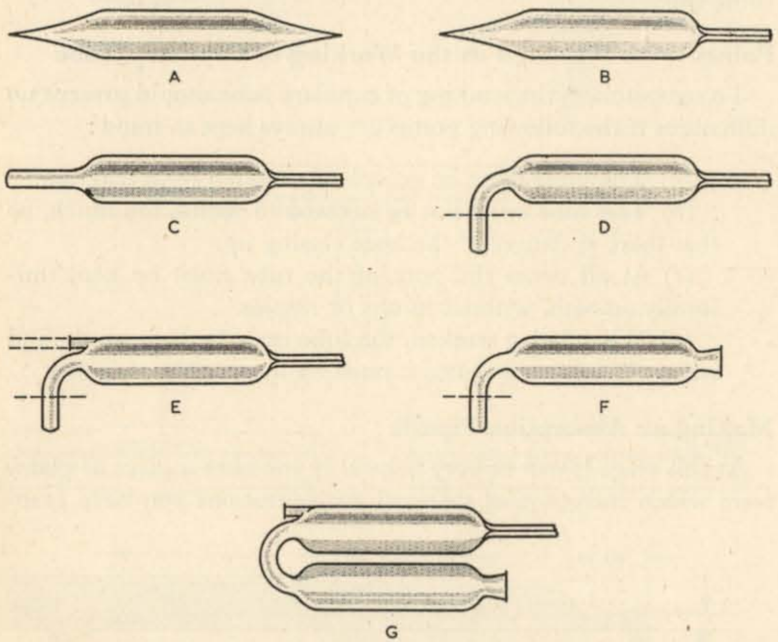


FIG. 7-8.—STAGES IN THE CONSTRUCTION OF A PIPETTE

The sketches Fig. 7-8 show the stages of construction; study these before you start blowing, so that you can do them in the right order; commence by drawing points at both ends of the two pieces of tube which will form the bulbs. While these are cooling, prepare two tubes which will form the U-connection by slightly flanging the ends as described in Chapter 6; leave both these tubes about 6 in. long. Also prepare one end of the capillary tube with a tapered entry as detailed in Fig. 7-6.

Now seal the capillary tube to the end of one of the body tubes (Fig. 7-8(B)), taking care to make the shoulder sufficiently smooth and acute to allow liquid to rise in the bulb and capillary tube

without trapping gas. To the other end of the bulb seal one of the larger connecting tubes (Fig. 7-8(C)) and after the seal is made, while the glass is still warm, bend the tube at right angles as shown at (D). Cork the end of this tube, and blow a flanged hole to take the lower filling tube, shown in Fig. 7-8(E). Close the capillary tube with a rubber cap; if one is not available, a short piece of rubber tube closed by a small cork can be used. Seal on a piece of tube to form the filling tube; this will require very careful manipulation, as not only is the seal on the shoulder of the rounded end, but it is also very near the other seal you have just made. The flame must be so directed that it does not heat too large an area, and blowing must be done at intervals to maintain the proper shape of the end. Before annealing, warm the whole end of the tube and adjust the position of both tubes.

Set this piece aside while you make the other half of the pipette, shown in Fig. 7-8(F). This is similar to the first piece, except that the capillary is replaced by a wide, short neck, tapered to receive a standard cork, and there is no filling tube on the bottom. When both pieces are completed, cut the filling tube to about 20 mm. long, flare the end and slightly cone to take a cork (Fig. 7-8(F)). Cut the bend on both pieces as shown by the dotted line, so that the end projects only about 1 mm. beyond the diameter of the bulb, and seal the two bends together to make the final job shown in Fig. 7-8(G).

Spirals

A well-made spiral is a delightful piece of glasswork which looks as if it is most difficult to make. As in most cases, however, the

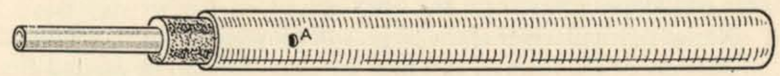


FIG. 7-9.—MANDREL FOR MAKING A SPIRAL

job is fairly easy when the right method is used. There is no need to make or buy an expensive " spiral winder "; a plain piece of brass tube, if necessary covered with asbestos paper, will do all that is required. The brass tube, or former, should be about 18 in. long; one end is provided with a tight-fitting cork bored to take a piece of glass tube about ½ in. diameter and 6 in. long to serve as a handle. The assembly is shown in Fig. 7-9, which also shows the position of the hole which must be bored near the handle, to take the size of glass tube from which the spiral is to be made.

Before starting to wind a spiral the bench must be set out with the necessary room and apparatus. The actual operation is shown in the photograph Fig. 7-10. You will notice that the former is held in the left hand. Most glassblowers prefer to stand instead of sitting. The free end of the former is supported in a

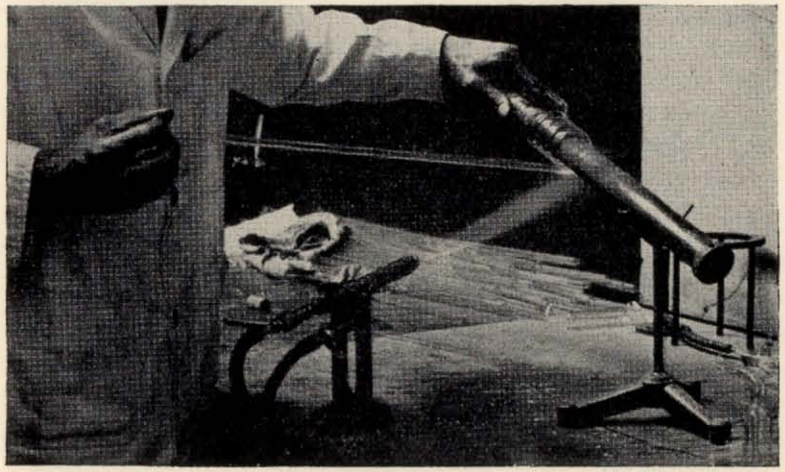


FIG. 7-10.—THE FORMER SHOWN IN THIS ILLUSTRATION IS AN ELABORATE TYPE AS USED IN A PRODUCTION GLASSBLOWING SHOP

V-rest, adjusted to such a height that the former is inclined downwards towards the right at an angle of nearly 45 degrees, and the free end slopes away from the body.

Notice particularly that the large, soft blowpipe flame is arranged to pass under the former, and that the glass tube to be wound lies along the top of the flame, so that it is heated and softened before it reaches the winding position.

Having arranged these matters to your satisfaction and comfort, select a complete 5-ft. length of the tube you wish to wind (we suggest 6 mm. diameter to start with), and make sure that the end will enter the hole in the former. If it does not, draw the end of the glass down until it fits snugly; hold the former in the correct position, and after warming the end of the glass tube to the softening point, push the end into the hole; immediately rotate

the former in an anti-clockwise direction so that the glass tube winds on to the underside of the former. Supporting the free end of the glass tube in the right hand, hold it along the top of the flame, and turn the former slowly with the left hand to wind the glass evenly upon the brass tube. Do not wind the tube too rapidly, or the glass will not remain in the flame long enough to acquire the proper degree of softenness to wind nicely; and do not drag the free end of the glass tube, or a flattened spiral will be formed. A few minutes' experiment will soon give you the feel of the glass, and you should experience little difficulty.

You will notice that as the spiral is wound, the former must be moved upwards towards the left so as to keep the glass in the flame; for this reason it is as well to wind only a few turns at the first attempt. As you get a little experience you will find it

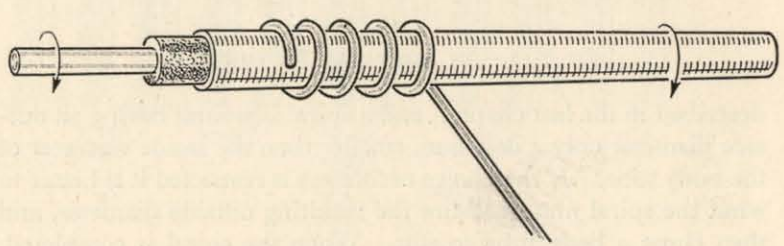


FIG. 7-11.—WINDING A SPIRAL

easy to co-ordinate your movements so as to wind a nice even spiral, which retains the proper circular shape of the tube. When the spiral is completed, put the whole thing aside to cool thoroughly. When everything is completely cold the anchored end can be cut or broken off, and the spiral will slide off the former. The ends of the spiral are then cut or bent to the requisite form.

To make a good spiral, you must continuously bear in mind certain points. First, be sure to get yourself into a comfortable position, with lots of elbow room before you start; it is very annoying to get a spiral half-wound and find that the former is in an impossible position. Secondly, do not let the flame play on the former, as if this gets too hot the glass may stick to it. You must synchronise the speed of turning to the plasticity of the glass, so that the soft tube is wound on the former without any pull or drag on the free end.

A Spiral Condenser

A good example of an internally fitted spiral is the condenser Fig. 7-12. No dimensions are given here, as this type of condenser is generally made to suit special requirements.

The body tube, side tubes, and ends are to be prepared as

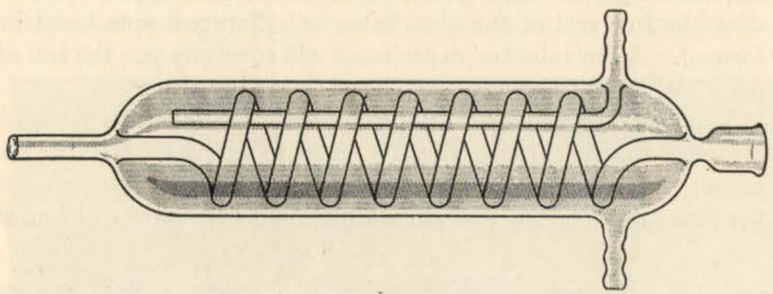


FIG. 7-12.—AN INTERNALLY FITTED SPIRAL

described in the last chapter, and a spiral is wound having an outside diameter only 4 or 5 mm. smaller than the inside diameter of the body tube. If the choice of formers is restricted it is better to wind the spiral first, measure the resulting outside diameter, and then chose a body tube to suit. When the spiral is completed, finish the ends as shown in Fig. 7-13, ready for sealing. Do not

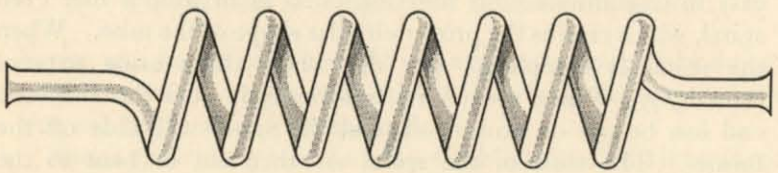


FIG. 7-13.—THE ENDS OF THE SPIRAL SHOWN READY FOR SEALING

make the straight portions too short, as otherwise you may run into difficulty when forming and sealing the ends of the body.

In order to locate the spiral in the body, pips are formed on it, at least two rows of three being required. These pips are made by first drawing out a piece of small tube and melting a small portion of glass on to the spiral using a small flame—see Fig. 7-14. To do this, the spiral is heated locally in the flame at the point where the pip is required, and the tip of the drawn-out tube just stuck on.

The flame is then shifted about 5 mm. along the tube, which is melted off at the point, leaving a short piece of the glass attached to the spiral. The point of attachment is reheated, and the spiral gently blown to retain the circular section of the tube at this point; at the same time the pip will melt down slightly and fuse to the spiral. Attach the other pips in the same manner, checking from time to time that the spiral will just slide into the body tube.

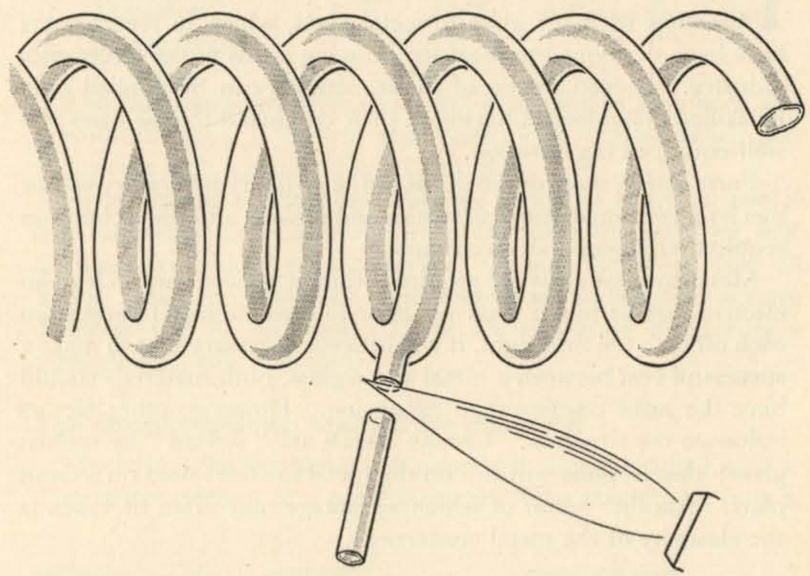


FIG. 7-14.—MAKING THE PIPS TO LOCATE THE SPIRAL

Next slide the spiral in position (no packing will be required as the pips will be sufficient location). Seal the spiral in position, join the cup end to the body tube, and then one of the side tubes. Draw off the other end of the body tube, seal the spiral at this end, and complete the condenser.

All these operations are exactly as described under the heading " Leibig Condenser " in Chapter 6, which should be referred to if you are not quite certain of the correct procedure. The main point to watch is that when fitting an internal spiral the clearance at the closed ends is very small, and care must be taken that the tube does not collapse on to the spiral during the operation.

CHAPTER 8

METAL-TO-GLASS SEALS

In a book on elementary glassblowing it is neither possible nor desirable to deal with the large number of methods and materials used for glass-to-metal seals, which in recent years have been developed to meet the growing needs of the electronics industry. Indeed, many of these methods can be applied only by skilled glassblowers having at their command the facilities of a well-equipped organisation.

Fortunately, most of the needs of the ordinary laboratory can be met by a very small range of metals and glasses, and the techniques required are comparatively simple.

Metal-to-glass seals are required when it is necessary to lead an electric current into a glass vessel or to insulate metal parts from each other. On first sight, it would seem necessary that to make a successful seal between a metal and a glass, both materials should have the same coefficient of expansion. However, other factors influence the situation. Certain metals are " wetted " by molten glass; that is, glass will run on the metal as water does on a clean plate. Another factor of which advantage may often be taken is the elasticity of the metal concerned.

Suitable Metals

The first metal used in making glass-to-metal seals was platinum, used in conjunction with soda glass, and this combination is still used for a wide range of chemical apparatus. The high cost of platinum has led to the development of other materials for use in lamps, valves, and other mass-produced items.

It should be noted that whereas the coefficient of expansion of metals is nearly uniform over the whole temperature range, that of glass passes through a transition point. Considerable strains are, therefore, inevitable in any glass–metal seal unless care is taken in design and construction; advantage can be taken of the elasticity of the metal by suitable shaping. Naturally, all these seals must be very thoroughly annealed, and in use care must be exercised not to subject them to violent changes of temperature.

The table of coefficients of expansion shown below for various commonly used metals also shows the types of glass to which they can be sealed successfully.

Platinum . .	9×10^{-6}	Soda and lead glass
Steel . . .	10·5	Soda and lead glass
Nickel . . .	13·0	Soda and lead glass
Copper . . .	18·0	Soda and lead glass; Borosilicate glass
Tungsten . .	4·0	Borosilicate glass
Molybdenum . .	5·0	Borosilicate glass

The anomalous property of copper in sealing to both soda and borosilicate glass is due to the elasticity of this material, and to the ease with which it is wetted by glass.

Since platinum–soda glass seals are probably the most useful and the easiest seals to make, it is advisable to make our first attempts with these two materials. A few inches of No. 28 S.W.G. platinum wire and a quantity of soda-glass tube 6 mm. diameter will be required. There are two ways of making a through seal with platinum.

The Shrinking-down Method for Platinum

The first is the shrinking-down method, illustrated in Fig. 8-1. The centre portion of a piece of 6-mm. tube about 3 in. long is

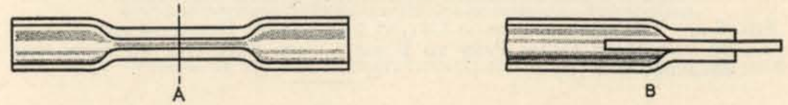


Fig. 8-1.—The Shrinking-down Method of Making a Platinum–Glass Seal

shrunk down in the flame (as described in a previous chapter) until the bore will just accept the platinum wire. When it is cold, cut the tube in the centre, as shown at (A); slide a piece of platinum wire, 30 mm. long, through the tube, allowing an equal amount to project out at the end of the tube and in the large-diameter portion. Rotate in a small flame until the glass shrinks down into close contact with the metal, and blow very slightly to make sure that there are no leaks; straighten the wire, using a pair of forceps. During these manipulations, see that the inside end of the wire does not touch the hot glass, otherwise it will stick and ruin the seal. The resulting seal is shown in Fig. 8-1(B).

The sealed tube is then cut off at the larger diameter to the requisite length; it can then be sealed to the main glass part in the usual way, to give a side seal, as in Fig. 8-2(A), or an end seal as required.

Making a Mercury Cup

A variation of the type of seal is used when it is desirable to make an easily removable electric contact, using a mercury cup to

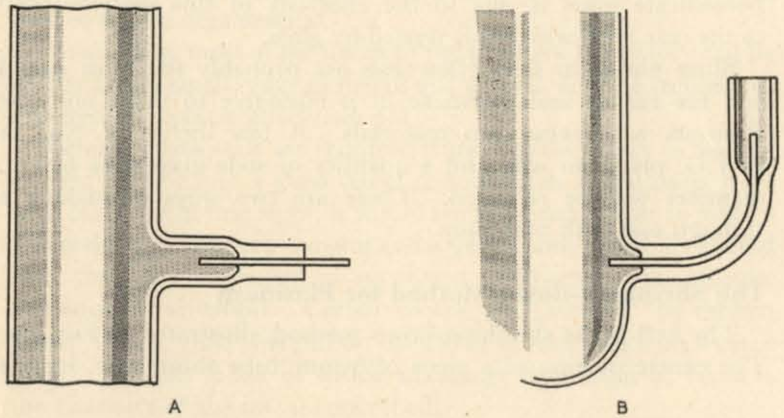


FIG. 8-2.—THE SEALED TUBE IS CUT AT THE LARGER DIAMETER AND SEALED TO THE MAIN GLASS PART TO FORM A SIDE SEAL (A), TO MAKE THE MERCURY CUP (B)

give a positive, low-resistance seal. The procedure is very similar to that just described, except that the tube Fig. 8-1(A) is not cut in the middle, and the wire is threaded in and sealed so as to leave a length of wider tube at each end of the seal. When complete, one end is cut to leave 6 mm. of plain tube, and the whole sealed in position. Immediately the glass-to-glass seal is made, the platinum seal is heated and bent upwards (see Fig. 8-2(B)) to make the mercury cup.

In making these seals, do not forget that there is a considerable thickness of glass around the platinum, so that the finished seal must be cooled very slowly in the flame to avoid strain.

The Bead Method

The second method of making a platinum–glass seal is the bead method. This is very useful where the seal must be small, with the minimum strain.

A piece of platinum wire about 20–25 mm. long is required. This is best held in a small pin vice, but if one is not available the wire can be thrust into a small cork which will serve as a handle.

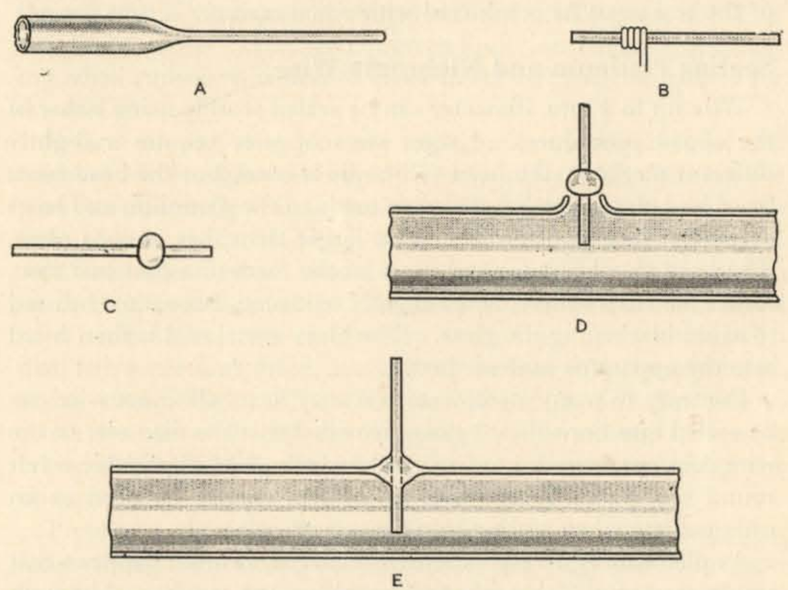


FIG. 8-3.—STAGES IN MAKING A PLATINUM–GLASS SEAL BY THE BEAD METHOD

Now draw out a small glass tube or rod (which can be either soda or lead glass) down to a diameter of about 1 mm. (Fig. 8-3(A)). Heat the centre of the platinum wire in a small flame, and keeping it in the flame, touch the centre with the tip of the glass rod. When the glass adheres, wind on two or three turns (Fig. 8-3(B)) by rotating the wire. Cut off the glass in the tip of the flame, and heat the wire and spiral until the glass melts and flows into a bead on the centre of the wire as Fig. 8-3(C).

The glass to which the seal is to be fused is prepared by blowing a small hole in the usual way in the required position. This hole must be just a little smaller than the bead, which should sit in it as shown in Fig. 8-3(D). Using a small, hot flame, fuse the bead to the glass, blowing the joint carefully to make a smooth joint; forceps will be found very useful to adjust the position of the wire, which should be done quickly while the glass is hot; the resulting seal should be like Fig. 8-3(E).

It must be stressed that the annealing of these platinum-to-glass seals must be conducted with care, as not only must the seal be heated uniformly, but undue softening must also be avoided, otherwise the weight of the wire will cause the seal to sag. The cooling of the seal must be conducted with equal care.

Sealing Platinum and Nichrome Wire

Wire up to $\frac{1}{2}$ mm. diameter can be sealed readily using either of the above procedures. Larger sizes of wire require a slightly different method; the bead technique is used, but the bead must be of lead glass, which fuses more easily to the platinum, and has a coefficient of expansion somewhat larger than that of soda glass. The bead should be formed more in the form of a flattened disc, rather than as a sphere, and a slightly oxidising flame must be used to avoid blackening the glass. The glass–metal seal is then fused into the apparatus as described.

Contrary to many statements you may hear, platinum wire can be sealed into borosilicate glass, provided that the diameter of the wire does not exceed 0·015 in., and as little glass as possible is left round the wire. Lead glass, of course, cannot be used as an intermediate when sealing into borosilicate glass.

As platinum is a very expensive material, it often happens that stocks are not available when required for urgent jobs. Although special 50% nickel–iron wire is made for sealing to glass, it is perhaps not generally known that the nichrome type of wire can be sealed into soda glass if extra care is taken in annealing. We have successfully sealed nichrome up to 1 mm. in diameter into soda glass, though wire of this size requires very great care in manipulation. If a small copper-plating bath is available, or can be made in a beaker, plating of the nichrome wire will greatly facilitate the making of the seal The technique in this case will be similar to that described below for Dumet wires.

Tungsten Pyrex Seals

As will be seen from the table on page 95, tungsten has very nearly the same coefficient of expansion as Pyrex glass, and good

tungsten-to-Pyrex seals can be made if precautions are taken to control the oxidation of the metal.

Tungsten has a melting point of well over 3000° C., and for this reason wire is formed by sintering and forging. Consequently, tungsten wire has a very fibrous structure; as by the process of manufacture the fibres are aligned in a longitudinal direction, ordinary wire has channels which may leak if sealed into a vacuum system. A special kind of wire is made to avoid this trouble; the material is very densely compacted and finally ground. This wire is ordered as " Ground Tungsten Rod ", and to avoid splintering when cutting, it is best to order in the cut length required for the seal.

Before use, the tungsten wire must be thoroughly cleaned and oxidised to the right condition. This is achieved by heating the wire to a dull red heat in the blowpipe flame, and melting on to it a little sodium nitrite, KNO_2—note, not nitrate. The nitrite will melt into a bead which should be run up and down the wire two or three times to deoxidise the metal surface. The deoxidised wire is allowed to cool and is then washed free from nitrite with distilled water and dried, leaving the surface a uniformly clean, satiny steel colour. After cleaning, care must be taken not to touch the material with the fingers—for this reason, it is most convenient to hold the wire in a pin vice during the whole of the operation.

Prepare a sleeve of Pyrex tube about 15–20 mm. long, just large enough to allow the wire to thread through. The next operation requires strict care and attention. The wire is drawn through the flame, if necessary several times, watching the change in colour on the surface, which passes through the range: straw; vivid blue; blue-green; slate. The oxidation must be stopped between the last two stages; if the wire is not oxidised enough a very poor seal will result, as glass only wets the oxidised surface. If the wire is oxidised to the black condition, the seal will not be vacuum tight. The only true guide is experience, but we have found that it is best to under-oxidise, as further oxidation takes place while making the glass seal.

While the wire is still hot, slip the sleeve on to the middle of the wire (Fig. 8-4(A)) and, using a fine flame, melt the glass on to the wire, commencing at one end and proceeding steadily along the length of the sleeve, so that the air is driven out ahead of the seal.

When the metal is properly sealed to the glass, it appears larger, so that the progress of the operation can be followed easily; see Fig. 8-4(B).

When cold, the seal is inspected for air bubbles and complete contact of glass and metal. A good seal is orange or copper bronze in colour, and free from large bubbles in contact with the metal.

A dark seal, which will be useless, is the result of too much pre-oxidation of the metal. If this result is obtained, the glass should

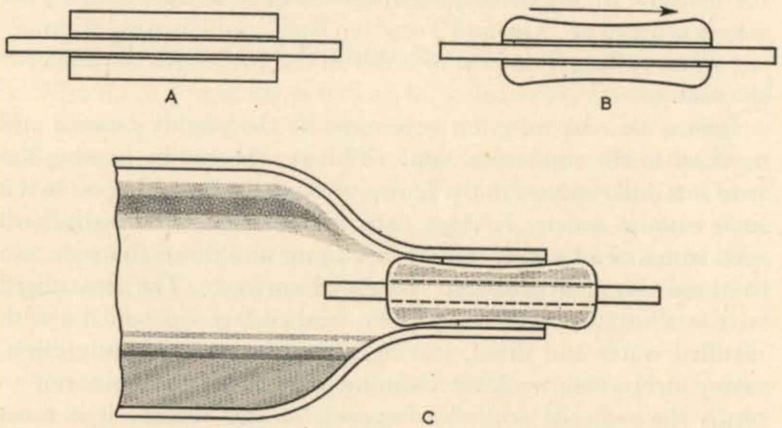


FIG. 8-4.—THE PROCEDURE FOR MAKING A TUNGSTEN PYREX SEAL

be broken off the wire, which is then cleaned with sodium nitrite and used again.

The sleeved seal is then fused into a small tubulure blown in the apparatus as shown in Fig. 8-4(C).

It is very important to get the metal in the right condition before fusing to the glass sleeve, and experience can be the only guide, as it is impossible to exactly define these conditions. The unprofessional author has made a large number of good seals after only a very little practice, so it cannot be very difficult.

Incidentally, copper or nickel leads can be hard soldered to tungsten in the usual manner, if the wire is first cleaned with nitrite—do not use soft solder with this material.

Molybdenum Seals

Molybdenum can also be sealed to Pyrex and other borosilicate glasses; the technique is the same as for tungsten, but as molybdenum oxidises very rapidly, the risk of a poor seal is very great, and the use of this material is avoided whenever possible.

Dumet Seals

The earliest electric lamps used seals of platinum, but as this was very soon found to be too expensive, much thought and research were expended to provide a cheap substitute. As noted above, nickel–iron alloys can be sealed into glass; however, they suffer from the disadvantages of high electrical resistance and in not being readily wetted by the glass.

These troubles were largely overcome in 1915 by an American, B. E. Eldred, who invented a composite wire, which is known as "Dumet" (two metals), consisting of a 40% nickel–steel wire of comparatively low electrical resistance, coated with a layer of copper, which occupies about 20% of the cross-sectional area. Seals of this material owe their success to the tenacious bond between the copper coating and the glass, and to the low yield point of the copper, which, to a certain extent, limits the strain put upon the seal.

Dumet is sealed into soda glass in the same manner as platinum, except that it is usual to make the bead of lead glass, which affords a better seal. Although much cheaper than platinum, this material is still very expensive, so it is usual to use only the minimum length of Dumet required to make the seal, wires of nickel or copper being butt welded or brazed to each end of the Dumet wire.

The method of using this material in pinch seals for electronic devices will be described later in this chapter.

Copper-to-glass Seals

Copper-to-glass seals are unique by reason of the large difference in the coefficient of expansion between the two materials. Such seals are possible because the low yield point and high ductility of copper enables us so to design a seal that the maximum stress set up by the metal is less than the ultimate strength of the metal-to-glass joint. Four main types of seal are possible, and examples of each will be described.

Copper wire cannot be sealed straight into glass unless it is of very small diameter, when there is considerable danger of melting the wire while heating the seal. Quite large-diameter wire can be sealed, however, if the portion actually in contact with the glass is not more than 0·002 in. thick. This is accomplished by flattening the central portion of the lead (as shown in Fig. 8-5) by hammering on a steel plate or anvil.

For a first attempt, a piece of 18 S.W.G. copper wire should first be cleaned with emery paper, and the central portion, about 1 cm. long, is flattened by hammering, taking care that the flat portion is symmetrical (Fig. 8-5) and that the edges of the flattened portion are sharp. The thickness of the flat should be checked with a micrometer to make sure that it does not exceed 0·002 in.

Now prepare a piece of borosilicate tube in the usual way by melting down and flattening one end until your wire will just enter. Before the copper is sealed into the glass, it must be lightly

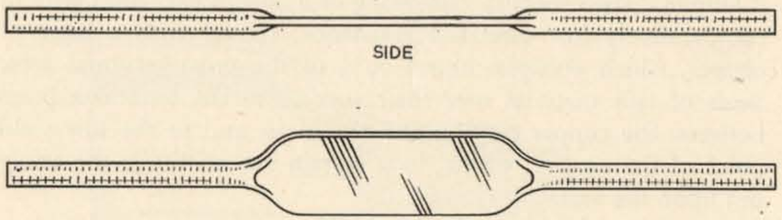


FIG. 8-5.—METHOD OF SEALING LARGE-DIAMETER COPPER WIRE INTO GLASS

oxidised and coated with borax, or borated as it is called.

Hold the cleaned piece of copper in tweezers or a pin vice (not the fingers) and heat for not more than two or three seconds in the tip of the flame, to a dull red heat, keeping the copper moving all the time. Allow to cool, and dip into a strong solution of borax; then dry in the flame, first holding the metal a little above the flame, so that it dries gently, otherwise the borax will spit and spatter away.

Not only does the coating of borax so obtained protect the copper from over-oxidation, but it is also probable that a certain amount of copper borate is formed, which forms a kind of intermediate seal between the copper and the glass. This technique was developed in 1923 by W. G. Housekeeper; hence these copper–glass seals are known as " Housekeeper " Seals.

" Housekeeper " Seals

Put the copper lead in position and heat the glass until it is quite soft; you will observe that the flattened portion of the metal is

wholly enclosed by the glass (Fig. 8-6). This is to give the round portion of the wire some support, to take the bending strain off the strip portion, and also to protect the strip from direct contact

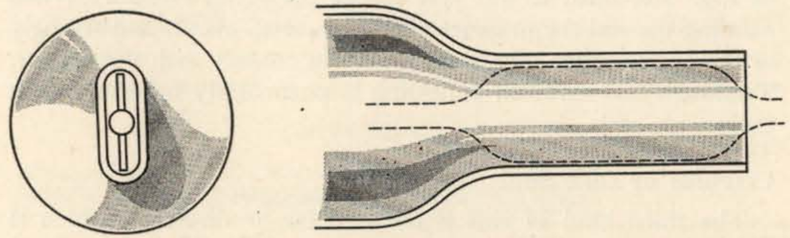


FIG. 8-6.—A " HOUSEKEEPER " SEAL

with the flame. When the glass is quite soft, either pinch it strongly with a pair of flat-ended forceps, or by pressing on your carbon plate with a carbon rod so that the metal is forcibly pinched in the hot glass. The finished seal is shown in Fig. 8-6, and it

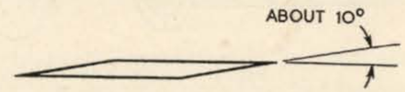


FIG. 8-7.—THE EDGES OF THE RIBBON ARE BEVELLED FOR A RIBBON SEAL

should be noted that the seal is made only on the flattened portion of the wire. The assembly must then be carefully annealed.

When a fairly large lead is required to carry heavier current than is possible with the wire seal described above, a ribbon seal may often be used. Copper ribbons of 20 mm. or more in width can be

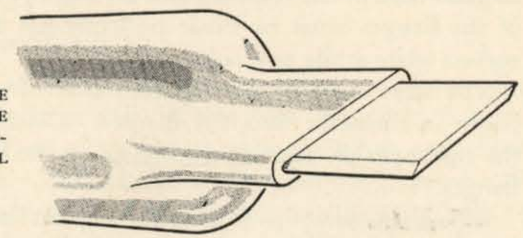


FIG. 8-8.—SHOWING THE PREPARATION OF THE GLASS TUBE TO ACCOMMODATE THE METAL RIBBON

sealed if the thickness does not exceed 0·010 in. The procedure is exactly as for the wire seal, except that the edges of the ribbon must be bevelled with a file to present a knife edge to the glass. This is shown in Fig. 8-7. Use a soft flame, both when borating the ribbon and when sealing into the glass; during the latter operation take care that the flame does not play directly upon the copper strip, which is very easily melted.

The glass tube is prepared by melting the end and pinching flat as Fig. 8-8, until it will just accept the metal ribbon. When forming the seal the pressure must be exerted evenly and strongly to force the molten glass everywhere in contact with the copper. Thorough and uniform annealing is particularly necessary with these wide seals.

Circular or Disc Seal

The third kind of seal is the circular or disc seal, which is extremely useful when very heavy gauge copper wires or rods must

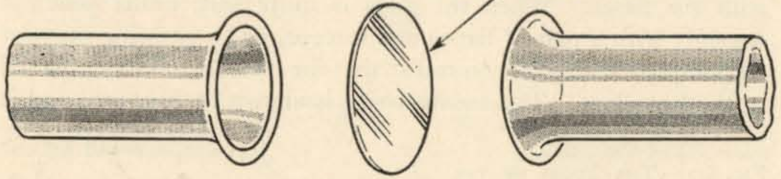


Fig. 8-9.—Exploded View of Copper Disc Seal

be sealed into glass vessels. Copper sheet, in the form of flat discs about 28 S.W.G. (0·0148 in.) can be butt sealed on to the end of either soda or borosilicate tubes, provided that the glass is not allowed to spread over the edges of the disc. An exploded view of such a seal is shown in Fig. 8-9. The ends of two pieces of glass tube of the required size are slightly flanged, and the faces of the flanges must be made perfectly flat by pressing against a carbon plate while still soft.

The next stage is to prepare a disc of copper about 6 mm. larger in diameter than the flanges. Clean, oxidise, and borate the disc over an annular area equal to the thickness of the glass flanges.

Adjust the blowpipe to give a small, hot flame and, gripping the disc in a symmetrical position between the flanged glass tubes, rotate in the flame until the seal is completed. A little practice will be necessary to gauge the correct amount of axial pressure to apply to the tubes while sealing, so that the glass is forced into contact with the disc on both sides, without unduly spreading the flanges.

Do not attempt to seal the disc to one tube only; if such a seal is required, the second tube must be cut off close to the disc, as seen in the next figure, so that a band of glass is left fused to the open face.

To complete the lead, drill the copper disc in the centre, and hard solder the wire or rod through the disc, using a very small pin-point flame and as little solder as possible. Complete the

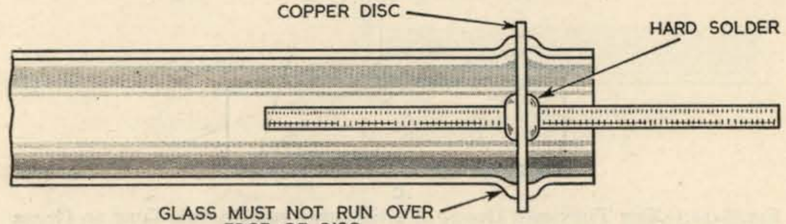


Fig. 8-10.—Copper Disc Seal in Position

operation quickly, so that the copper is not overheated, and anneal in the usual manner.

If very heavy copper leads to carry considerable current are required, it is best to hard solder the lead through the disc before making the glass seal, taking care to flatten the disc after soldering, if it has been distorted during the operation, before sealing to the glass. These heavy leads may require supporting by corks in the glass tube to keep the disc in position, but make sure that if used, the corks are an easy sliding fit, so that proper pressure can be applied to the glass during the sealing process.

Copper-tube-to-glass Seals

The Housekeeper-seal technique can be used to seal copper tube to glass tube. Quite large seals of this type are, or have been, used in the fabrication of special thermionic tubes and other experimental devices. Short lengths of copper tube can also be used in place of a graded glass seal to join borosilicate to soda or lead glass—a trick which is often useful in setting up complicated trains of apparatus for gas or vacuum work.

In making these seals, the glass may be either on the inside or the outside of the copper tube, which must be prepared accordingly. As in other copper–glass seals, the metal must be thinned down to only a few thousandths of an inch in thickness where it is to be joined to the glass. Remembering that it is the elasticity and yield of the metal which is important, this thinning down must be gradual, as shown in Fig. 8-11(A) or (B), not sudden as at (C).

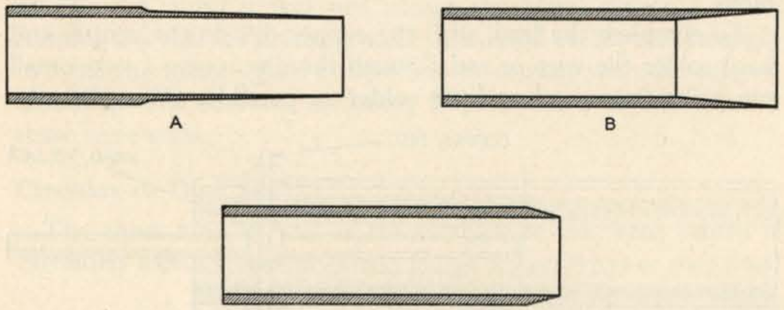


FIG. 8-11.—THE THINNING DOWN OF THE METAL FOR COPPER TUBE TO GLASS SEALS MUST BE GRADUAL, AS IN (A) AND (B), NOT SUDDEN AS IN (C)

This should be done in a lathe, taking care to get the edge square and of uniform thinness. For an outside glass seal, the copper tube is prepared as Fig. 8-11(A), and for an inside glass seal as

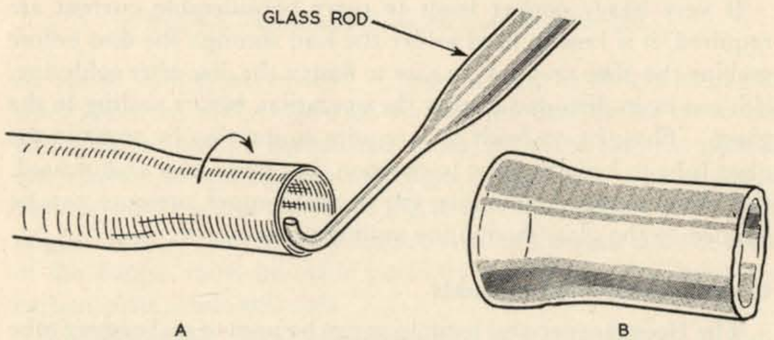


FIG. 8-12.—THE PARTS REQUIRED FOR MAKING A COPPER TUBE TO GLASS SEAL

Fig. 8-11(B). As the copper will get very hot during the glass-blowing operation, it should be fitted into a glass-tube handle by means of asbestos papers.

First considering an outer glass seal, chose a glass tube which fits over the copper, and flange as sketched in Fig. 8-12(B). Prepare a piece of suitable glass rod or tube by drawing down to about $1\frac{1}{2}$ or 2 mm. diameter.

The first step is to oxidise the copper tube by heating to a dull

red heat for only a few seconds, and immediately borating as previously described. Reheat the copper and fuse the glass rod on in a ring inside the tube, taking care to keep the glass about 1 mm. inside the edge of the copper—do not let it flow up to or over the edge. Get this glass well fused on to the copper, as its

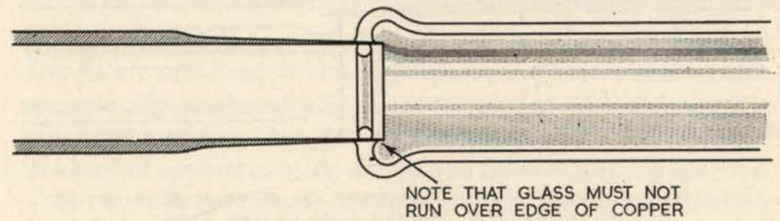


FIG. 8-13.—THE COMPLETED JOINT

purpose is to provide additional support to the thin metal, and to equalise the strains inside and outside. Beware of getting the copper over-oxidised, by using as small a flame as possible, and directing it only on the glass–metal joint (see Fig. 8-12(A)). While everything is still hot, shrink the flanged outer glass tube down on to the copper as depicted in the sectional view Fig. 8-13, and, again using a small flame, fuse to the metal, blowing the joint in the usual manner to make a good and even seal.

Owing to the danger of over-oxidising the copper, experience is required before a good job can be made, but once the knack is acquired, the method is easy.

Internal Glass Seal

To make a seal with the glass inside, first fuse a ring of glass on to the outside of the copper tube, and then fuse a slightly outward-flanged glass tube inside as shown in Fig. 8-14.

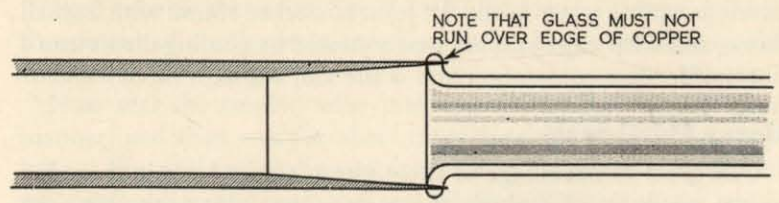


FIG. 8-14.—AN INTERNAL GLASS SEAL

This type of internal glass seal is neither so easy to make as the external glass type, nor is it so satisfactory; this construction should therefore be avoided unless the design of the apparatus cannot be altered to obviate it.

When the glass tube to be used has a wall thickness of over 2 mm., it is possible to make the seal by thrusting the feather edge

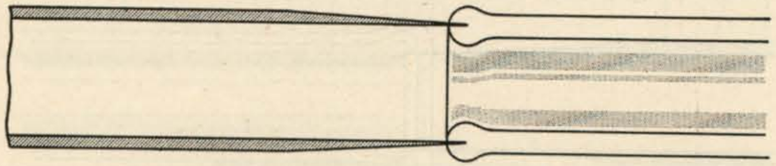


FIG. 8-15.—A SEAL MADE BY THRUSTING THE FEATHER EDGE OF THE COPPER INTO THE MOLTEN EDGE OF THE TUBE

of the copper into the molten end of the tube as shown in Fig. 8-15; a very steady hand is required for this, as it is necessary for the pressure to be evenly applied all round the face of the joint during the sealing operation.

A short section of copper tube can be used to make a soda-to-borosilicate joint as shown in Fig. 8-16. Both joints should be completed without allowing the assembly to cool.

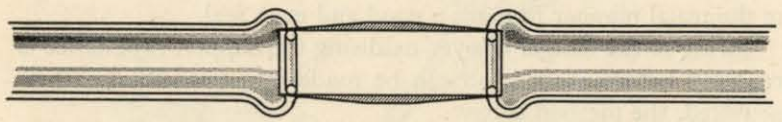


FIG. 8-16.—USING A SHORT SECTION OF COPPER TUBE TO MAKE A SODA-TO-BOROSILICATE JOINT

These copper-to-glass seals can be made as large as the ease of manipulation will allow; care must be taken, however, to keep the whole assembly warm while the joint is worked round with a small flame, and such large jobs are best annealed by placing direct into a hot muffle after completion and while still warm.

Heavy Metal Seals

The great disadvantage of these Housekeeper seals is that, due to the necessity of making the metal–glass joint very thin, the mechanical strength of the assembly is very weak. For certain applications strength is very important, and special alloys of nickel–cobalt–chromium–iron have been developed which have

coefficients of expansion which will allow massive joints to be made to special glasses. As these are special applications, they will not be described here. Details can be obtained from the makers of these alloys.

Pinch Seals for Thermionic Devices

Experimental lamps, discharge tubes, and other thermionic devices are often required in the laboratory; items such as these are normally produced in a factory equipped with elaborate and expensive machines, but it is not difficult to make small pieces of this kind of apparatus using only the equipment already described.

The simplest electronic device is perhaps the vacuum discharge

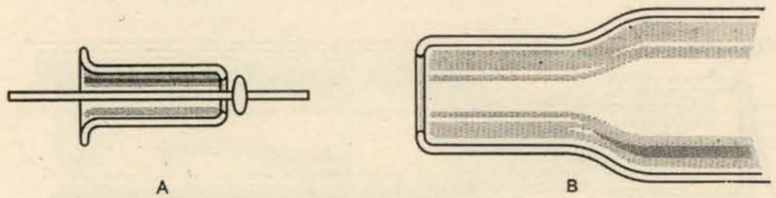


FIG. 8-17.—MAKING A VACUUM DISCHARGE TUBE WITH A SINGLE ELECTRODE AT EACH END

tube, having a single electrode at each end. To make the seal, first bead a piece of platinum or brightray wire as described earlier in this chapter. Then prepare two soda-glass tubes 6 mm. diameter and 25 mm. long, by closing one end to just take the bead (see Fig. 8-17(A)) and make a good-size flange at the other end.

Then make the discharge tube body of 20-mm.-diameter tube, about 6 in. long, by necking down each end to take the short flanged tube as shown in Fig. 8-17(B), and seal a 6-mm. tube in the centre of the larger portion to form the connection to the vacuum pump.

Now seal the beaded wire into the short tubes in the usual manner, and then seal the short tubes into the ends of the main tube. You will find that an engineer's small pin vice a very useful tool for holding the wire and seal while performing these manipulations.

It is usual to finish seals of this nature with a small metal cap sealed over the glass neck with plaster of paris, or one of the newer plastic resins, the wire lead passing through a small hole in the cap, to which it is secured with soft solder, as illustrated in Fig. 8-18.

When more than one wire has to be sealed through the glass in a small space the pinch or press seal is used. The compound seal wires must first be prepared. These, as shown in Fig. 8-19(A), are made of a piece of Dumet wire, to one end of which is hard soldered or spot welded a length of thin copper wire or copper braid. To the other end is similarly fixed a piece of nickel or hard copper wire about 20 S.W.G. diameter.

The piece of Dumet wire is only about 1 cm. long; the thin wire or braid 5 or 6 cm., and the hard nickel 25 mm. long. Note that the ends of these latter wires are turned over and nearly

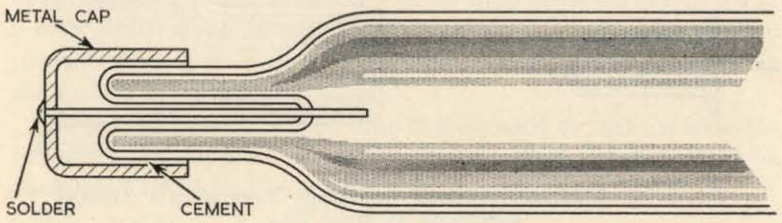


Fig. 8-18.—The Seal Is Finished with a Small Metal Cap

closed together, as shown in Fig. 8-19(A). Two of these compound wires will be required, together with another length of nickel wire only.

To make the pinch, take a length of 20-mm. soda or lead glass tube, cut one end quite square, and heat this end in a medium-size flame until it is quite soft. Now pinch the end with flat-ended forceps (which should first be slightly warmed in the flame) and close the glass down until the wire seal can just be slipped through (Fig. 8-19(B)).

Instead of purchasing special forceps, these can be made sufficiently effective for this job by bending a 12-in. length of hard brass some 20 mm. wide by 18 S.W.G. thick into a U-form, like a pair of sugar tongs.

Cut the tube off about 25 mm. behind the flattened portion, and flange this end out as shown in Fig. 8-19(B), taking care to make the flange slightly larger than the maximum width of the intended filament.

At this stage the bulb or outer envelope of the lamp should be made. In this example the exhausting tube can be attached to the rounded end of the bulb, as in old-fashioned valves. The prepared envelope is shown in Fig. 8-19(E). The open end of the bulb should be turned inwards and adjusted so that the flange of the pinch will just enter (Fig. 8-19(D)—dotted).

The next step is to cut a flat piece of cork to hold the wire in position while sealing. The nickel ends of the wires are thrust through this cork as illustrated in Fig. 8-19(C), and the ends

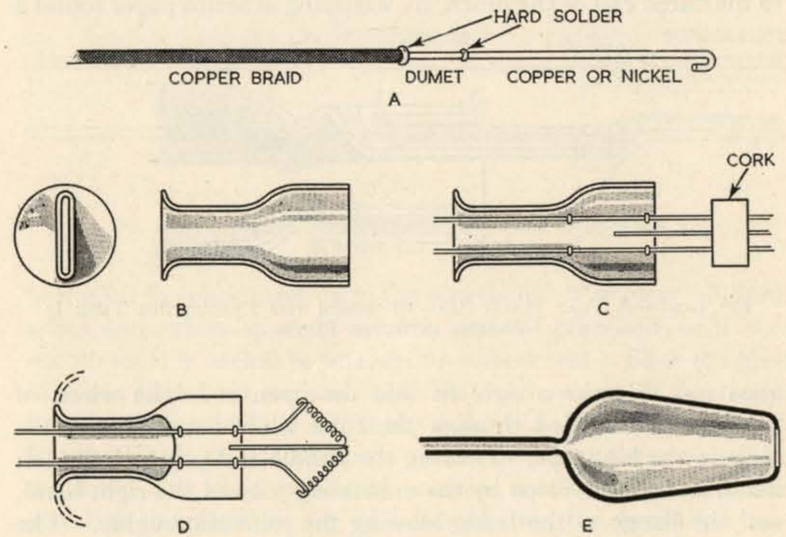


Fig 8-19.—Making a Flat Pinch or Press Seal

adjusted to the pinch to get them in the proper positions. Note that the Dumet wires must be completely inside the pinch, while the central nickel wire only just enters the pinch.

Another pair of sheet-metal forceps only 8 mm. wide will be required for the next operation. Slip the wire assembly into the pinch, carefully check the position, and heat the flat glass part uniformly until it is quite molten; then with the forceps press the centre of the pinch together firmly, so that the Dumet wire is forced into contact with the melted glass. This pinching should be done quite deliberately and with considerable pressure in one operation. If you have done the job properly, the Dumet wire will be firmly sealed, while the wires at each end of the seal, and the central wire, will be lightly gripped and supported by the glass. Anneal the pinch thoroughly.

The details of the tungsten filament will not be described here; the methods of winding and attaching to metal supports will be found in several of the excellent books on practical physics. Harnwell and Livingood's book on *Experimental Atomic Physics* contains much valuable information on the methods of making electronic devices.

When you have fitted the filament, a glass handle must be fitted to the flared end of the pinch, by wrapping asbestos paper round a

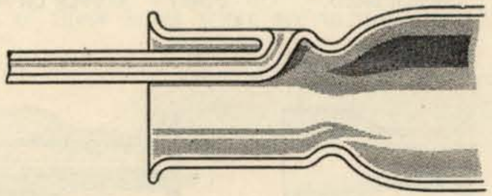


FIG. 8-20.—A FLAT PINCH SEAL IN WHICH THE EVACUATING TUBE IS SEALED INTO THE PINCH

glass rod to make a tight fit into the open end—the wires, of course, are threaded through the tube while manipulating the glass in the blowpipe. Holding the handle and pinch in the left hand, and the envelope by the evacuating tube in the right hand, seal the flange to the bulb, blowing the joint thoroughly. The lamp can then be sealed to a vacuum pump and evacuated in the usual manner.

This type of flat-pinch seal can, of course, be made to accommodate any reasonable number of leads. When the design will not allow the evacuating tube to be sealed on to the bulb, it can be sealed into the pinch as in Fig. 8-20. This construction, however, is very fragile, and, at least for experimental purposes, should be avoided wherever possible.

Glass to Porcelain

Porcelain is, in ordinary circumstances, an infusible material, but it is often possible to join it to borosilicate glass. Although success cannot always be guaranteed, we have found that the following method is very useful.

Cut the porcelain or mullite tube and grind square by using a grinding-wheel of the kind used in workshops for tool grinding; it is not possible to cut porcelain tube with a file or knife as you would glass.

Prepare a thin tube or rod of borosilicate glass as you did when making a Housekeeper seal, and heat the end of the porcelain gently in the blowpipe; although the material is infusible, it will often crack and break if heated suddenly. Wind a ring of glass round the tube about 3 mm. wide (Fig. 8-21(A)), and continue to

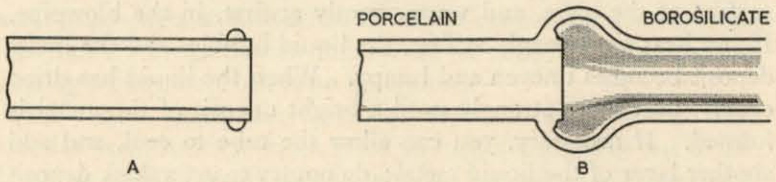


FIG. 8-21.—METHOD OF JOINING UNGLAZED PORCELAIN TO BOROSILICATE GLASS

heat until the glass fuses on to the porcelain. The glass will form a flux and adhere strongly to most kinds of porcelain—if it does not do so, it is useless to attempt to make a seal. Blow the glass tube out slightly at the end, and flange inwards to fit the ringed porcelain, to which it is fused, making a glass-to-glass joint. Let the whole joint cool slowly in the blowpipe flame to relieve the strain, and when quite cold, examine the finished job to make sure that the glass has not pulled away from the porcelain.

We have found that the technique is generally satisfactory with unglazed porcelain tubes; with glazed tubes, however, it is often impossible to make a joint, as the glaze cracks off when the tube is cold.

" Liquid Metal " Seals

Finally, there is a method of making glass-to-metal joints which is not strictly glassblowing; it is very useful where the joint, once made, is not afterwards subjected to heat.

The method consists in depositing on the glass a coating of silver or platinum; the solution used is made by certain firms under the name of " Liquid Silver " or " Liquid Platinum ", which is a colloidal suspension of the metal in a volatile essential oil.

Whenever possible, the joint should be so designed that the glass is inside the metal tube, into which it fits rather easily, so as to allow room for the solder which will later be applied to the joint.

It is best to prepare the metal tube first, by turning it inside for a length of about 20 mm. Next select a glass tube to fit, and slightly roughen a similar length of the outer surface with a fine grinding-wheel or carborundum powder.

You will find that the liquid metal is very thick, so the bottle must be shaken very thoroughly to make the contents uniform. With a small brush, paint the liquid, not too thickly, on the ground surface of the glass, and warm, gently at first, in the blowpipe. If you heat too strongly at first, the liquid bubbles and the metal deposit becomes uneven and lumpy. When the liquid has dried evenly, heat more strongly until a bright deposit of the metal is formed. If necessary, you can allow the tube to cool, and add another layer of the liquid metal; do not try to get a thick deposit by applying the solution too liberally.

While still hot, apply a coat of solder or Wood's metal to the metallised surface, either by melting the solder directly on to the tube or by dipping into molten solder.

Keep the tube warm, and heat the metal tube in the blowpipe. Push the glass tube into the turned metal tube, and cool slowly in the flame until the joint has set. The layer of solder between the glass and the metal is sufficiently ductile to take up the difference in expansion between the two materials.

This method is very useful for joining silica to metal, and also silica to glass.

CHAPTER 9

STOPCOCKS

THE numerous laboratory supply houses list a very wide variety of stopcocks, but occasions will always arise when the one you want is not available, and it has to be made.

At first sight this would seem to be a very difficult thing to make; however, as we said in an earlier chapter, all glassblowing jobs can be broken down to a series of simple operations, and making a glass stopcock is no exception.

For many years, the taper of stopcock tap keys has been standardised, and is now settled at an included angle of one in ten. It is now possible to obtain pressed solid key blanks in a number of standardised sizes; a table of these keys is given in Appendix A. Specification of various types of taps and sizes of keys is given in British Standard Specification 1751 : 1952.

A few special tools will be required; these are shown in the photographs Fig. 4-17 (page 48). The most important tool is the flat reamer, (C) in the photograph. This is made from a piece of $\frac{1}{16}$-in. steel or brass sheet—preferably the former. The metal blade is shaped accurately to an included angle of one in ten, and the edges are rounded and smoothed. The length of the blade should be such that the whole range of key sizes is covered by not more than two reamers. An examination of Fig. 4-17(C) will reveal two small holes in the blade; these holes indicate the length of the tap barrel required to accommodate the No. 3 key blank, which is the size mostly used for general work. If other size keys are to be used, additional holes can be made to suit; a number of holes, however, lead to confusion, and if special sizes are only occasionally used it is sufficient if the blade is marked with ink for the special dimensions.

The next tool we shall require is shown in Fig. 4-17(F). It consists of a piece of 1-mm. tungsten wire, about 30 mm. long, sealed into a piece of Pyrex tube 8 mm. diameter and 100 mm. long. The end of the tungsten wire should be ground to a point.

Used in conjunction with this tool is a small reamer, Fig. 4-17(G). This consists of a blade of brass, some $\frac{5}{16}$-in. wide at the widest point, and $1\frac{1}{2}$ in. long, fitted to a metal handle $\frac{1}{4}$ in. diameter. The blade is about 18 or 20 S.W.G. thick, and the end is shaped to a point of about 60 degrees included angle. The tool is used to ream out the small holes in the tap barrel.

A flat carbon plate, shown in Fig. 4-17(E), will also be required; one or two carbon reamers, shown at (H) and (J), are also useful for trueing up the tap barrels after fitting the side tubes; they are not essential equipment, however.

Essential Requirements of a Good Tap

Before describing the method of making stopcocks, let us consider the essential requirements of a good tap, as shown in Fig. 9-1.

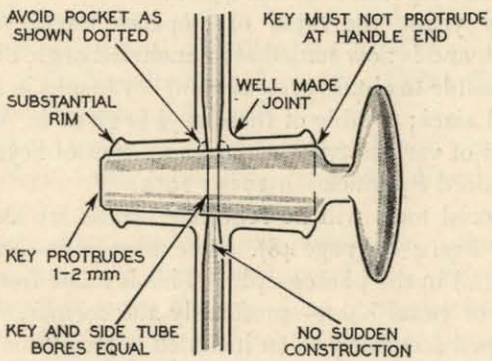


FIG. 9-1.—THE ESSENTIAL REQUIREMENTS OF A GOOD TAP

Perhaps the first thing to note is that the key should protrude beyond the small end of the barrel, but *should not protrude* through the large end. This is necessary to prevent a ridge forming on the key during the grinding operation, or later due to wear. The guide holes in your reamer must, therefore, be placed accordingly.

Next, notice that not only must the side tubes be well joined to the barrel, but that care must also be taken to see that the bore of the side tubes does not shrink unduly during the sealing operation. Care must also be taken to avoid enlargement of the holes in the barrel, which will form pockets for grease and dirt, and give rise to leaks.

Success in stopcock making depends very much on careful preparation, and orderly, systematic procedure; so commence operations by deciding the size of key you wish to use. If a new

solid key is not available, use a ground key from an old stopcock for your first attempt at making a barrel. The stopcock or tap barrel is always made from thick-wall tube; a wall thickness of $2\frac{1}{2}$ or 3 mm. is usual. Select a piece of this tube of such a bore diameter that the small end of the key will just not enter. You will also require two pieces of tube for the side tubes, having the bore rather larger than the proposed bore of the key; a 6-in. length of 8-mm.-bore tube; and a similar length of 5–6-mm. rod or tube.

The Stopcock Making Procedure

Having got all these ready, as well as the tools already described, a start can be made on the stopcock. First prepare the side tubes by thickening up and flaring the ends as shown in Fig. 9-2. Be careful to make the flare thicker than the main-tube wall, so that a sufficient mass of glass will be available when sealing. Put these tubes aside in your tube stand. Next cut the end of the barrel tube quite straight and make a square flange, taking care to get the face of the flange perfectly flat and perpendicular to the length of the tube by flattening with the carbon plate. These two stages are shown in Fig. 9-3(A) and (B). Remember that as the tube you are now using is very thick, a blowpipe flame hotter and rather larger than usual must be used.

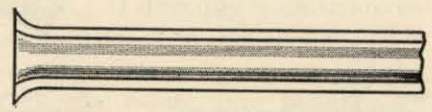


FIG. 9-2.—THE STOPCOCK SIDE TUBES

When you are satisfied that the flange is flat and square, bevel the edge, using a flat carbon plate, being careful to keep the rim quite substantial (Fig. 9-3(C)). The bevel is made, not by pushing the square flange back over the body of the tube, but by causing the molten glass to flow gently in the required direction—hence the glass must be really hot. Note particularly that the bevelled edge does not extend to the bore of the tube—a rim of the original square flange, about 1 mm. wide must be left to reduce the risk of subsequent chipping when grinding the tap. Now take a piece of 8-mm.-diameter standard-wall tube and flange out one end to fit the bevelled end of the barrel; this is shown in Figs. 9-3(D) and (E). This flared tube should just fit the bevel at its edges as shown; heat both the tube and the barrel, and "tack" the two together, so that the two are properly in line. Do not make a

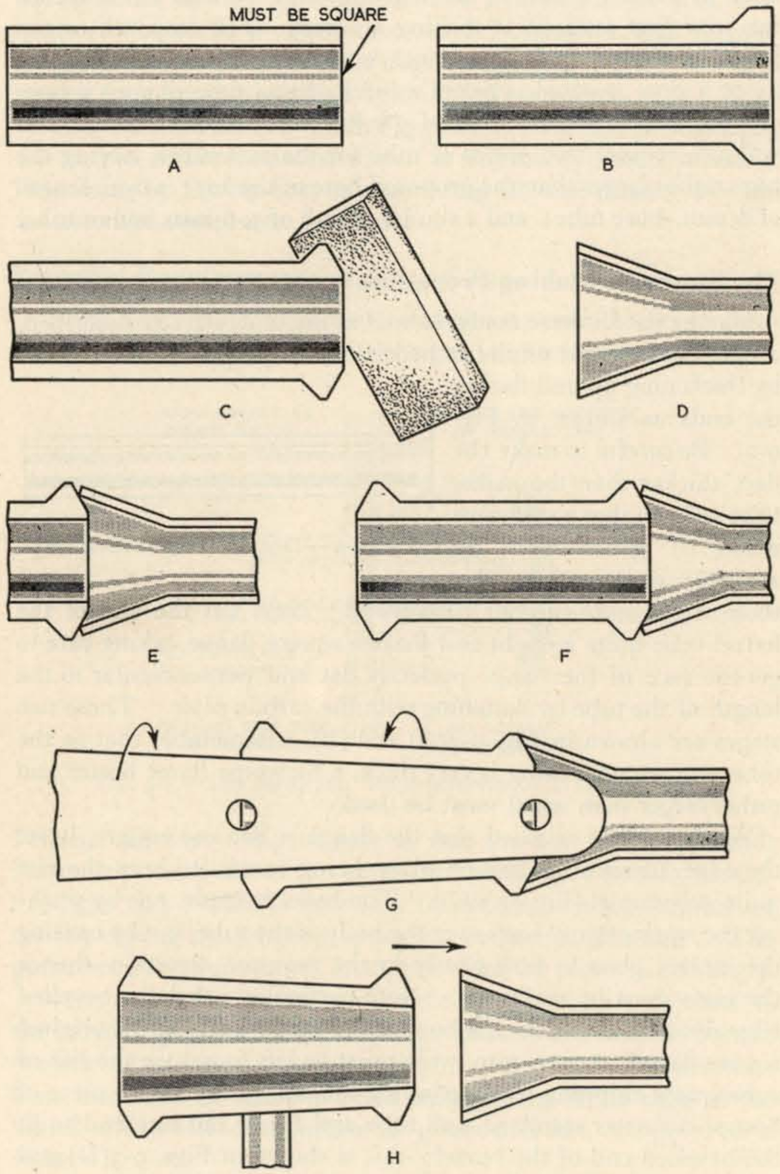


Fig. 9-3.—Procedure for Making a Stopcock Barrel

proper fused joint, as you will have to break it later on. Using this tube as a handle, held in the left hand, cut the barrel tube to a length about 5 mm. longer than you require the finished piece, and flange and bevel this end as you did the other one (see Fig. 9-3(F)).

You now have to ream out the barrel to the proper taper, so, using a large flame, get the barrel piece really hot. Rotating the barrel steadily, carefully insert the (warmed) reamer into the tube and gently push it in until the two holes in the blade coincide with the ends of the barrel (Fig. 9-3(G)). Do not use force, or the bore will become ridged and misshapen. The feel of the reamer in the tube will be the best guide to the speed with which the taper can be formed: if things are going properly the tool just slides forward with little resistance. If difficulty is encountered it is generally an indication that the glass is not hot enough.

When you have formed the taper successfully, and while the barrel is still warm, tack the piece of 6-mm. tube in the exact centre of the barrel. Again, do not force the tube in position. Now warm the end joined to the handle; a sharp tap on the handle tube should break it off. If necessary, reheat the bevel and smooth it with the carbon plate (Fig. 9-3(H)).

The next operation is to pierce the barrel and fit the side tubes. This is shown in Fig. 9-4. Adjust the blowpipe to give a small, very hot flame, and heat the barrel at a point exactly opposite the temporary side tube. When the small area of glass is molten apply the end of the tungsten point (Fig. 4-17(F)), and immediately draw out a pip, pulling slowly so as to form a point about 10 mm. long (Fig. 9-4(B)). With the glass knife, cut the point off as near the barrel as possible, and with the small reamer (Fig. 4-17(G)) open the hole out to a diameter slightly larger than the hole which is to be made in the key. Be very careful during reaming that you do not force a ridge of glass inwards into the bore of the barrel, and smooth the outside of the hole with the edge of the carbon plate so that it does not project.

Now take one of the side tubes and, holding the barrel in the edge of the blowpipe flame so as to heat the area adjacent to the hole, join on the hot side tube. Immediately reduce the flame to a fine point, and fuse the joint as you did when making a T-joint described in Chapter 7; in this case, however, the joint is not blown, so you must see that the glass is properly fused and joined all round. The side tube may be slightly wriggled about to facilitate this operation; finally, pull the tube gently to restore the bore, and straighten before allowing to cool.

When the joint has cooled enough to be rigid, the temporary tube on the other side can be cracked off by a smart tap. The barrel on that side is pierced exactly opposite the finished side

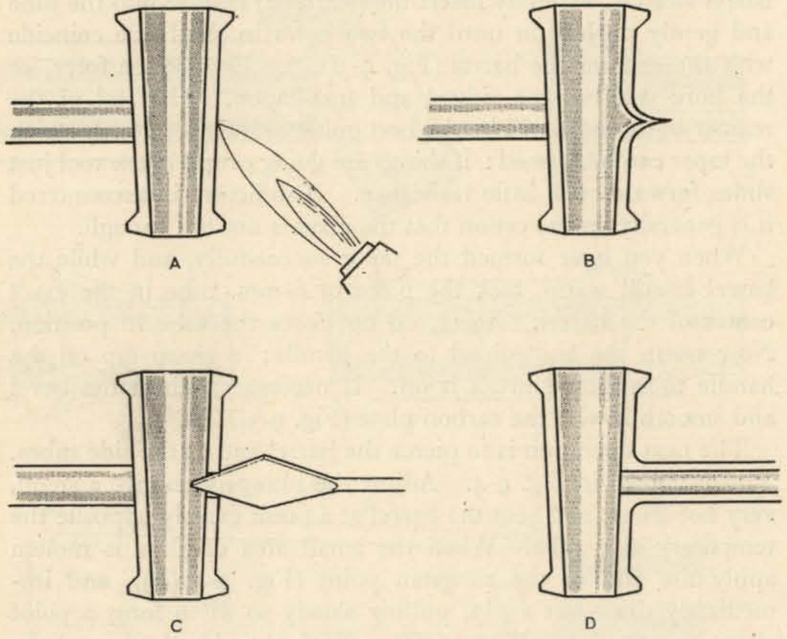


FIG. 9-4.—METHOD OF PIERCING BARREL AND FITTING SIDE TUBES

tube, reamed out, and the second tube fused on. Finally, the bore may be finished by using a carbon reamer such as that shown in Fig. 4-17(H) and (J). The idea of using these reamers is to smooth the bore and make it truly circular; you must be careful that the reamer is not applied with sufficient force to enlarge the bore of the barrel.

Before putting the barrel aside as complete, make sure that both side tubes are exactly in line, otherwise the hole in the key will not line up properly when the stopcock is open. The grinding and drilling of the key and barrel will be described in the next chapter.

Barrel for Double Oblique Stopcock

The barrel for what is known as the double oblique stopcock, Fig. 9-5, is made in exactly the same manner, except that it is longer to accommodate the twin-bore key. When making the barrel, be sure to get the single side arm exactly central between the other two side arms. The hole for the single arm should be made first; then make one hole on the other side, and measure its distance from the first hole. Next make the pip for the third

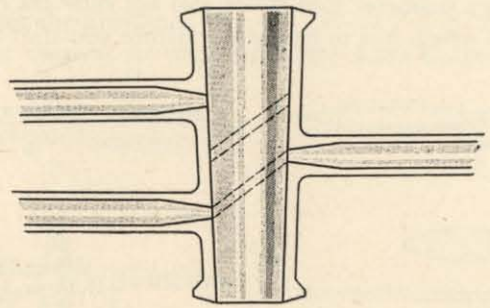


FIG. 9-5.—BARREL FOR DOUBLE OBLIQUE STOPCOCK

hole and check, and if necessary, adjust its position before completing the hole. When fusing on the two adjacent arms you will not have much room between them, so be very careful where you direct the flame; finally, line up both the side arms at the same time; you can do this quite easily by holding both tubes together between the fingers and thumb, adjusting them parallel and square by gentle manipulation.

When stopcocks with capillary tubes are required, the method of making is similar, but do not forget to take the usual precautions to prevent closing of the capillary bores.

Stopcocks of Special Sizes

On those occasions when a suitable tap key is not available, or when a stopcock of special size is required, it is necessary to make a hollow key from glass tube. It will save time and inconvenience if the handle part is made first. This is made from 8-mm.-diameter tube; the various stages in the procedure are shown in Fig. 9-6. Using a fairly large flame, draw a short point on the end of the tube, and about 30 mm. from the start of this point draw the tube down to a fairly substantial tube of some 3 mm. diameter. This small tube is cut to a length of approximately 6 in., as shown at (A). Now bend the small long tube end back so that it is parallel to the handle part (see sketch (C)), and then bend back away from the handle as shown dotted in the figure so that the out-turned portion is in the centre of the handle. Next pull and blow the larger-diameter portion to a nice oval shape, and seal off the short point (B).

For the key body you will require another piece of thick-wall tube of such a diameter that it will *just not enter the larger end of* the barrel in which it is to be used. Before you start the blowing

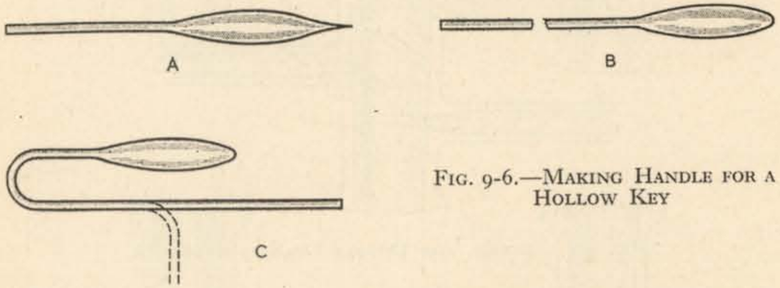


FIG. 9-6.—MAKING HANDLE FOR A HOLLOW KEY

operation get a piece of paper or, better still, asbestos paper or sheet if you have any, and rule on it two heavy convergent pencil lines, to give a taper of one in ten. Make the lines 8 mm. apart at the closer end, and some 6 in. long. This will form a good guide for the taper of the key. Also have handy a short length of tube of the correct size to form the bore of the key.

Using a large flame, draw out a point on your piece of thick-wall tube, and draw off again to another point at the opposite end so as to leave a portion of original parallel tube between the points. Make sure that you have the ruled piece of paper handy, and heat the tube until the glass is soft; slowly draw the tube down to the correct taper, holding it above the ruled lines as a guide. The process is really like drawing out a very long point, keeping the wall thickness of the tube as great as possible. The glass should look like Fig. 9-7(A). Before proceeding farther, check the taper of the barrel and the key by means of a caliper gauge—or if these are not available a visual comparison can be made.

Select (either by using calipers or by the use of ruled paper) the

portion of the taper tube which will match the barrel. This is done by placing the barrel on the convergent lines and sliding it along until the bore coincides with the ruled taper. With a pencil, mark the position of each end of the barrel. Now measure the centre of these two marks, and make another mark here. Now put the taper tube on the lines, adjust to coincidence, and transfer the centre mark on to the barrel with a grease pencil. Measure a length 4 mm. *larger* than on the barrel, from the grease-pencil line towards the larger end of the cone, and mark on the taper tube. This will give you the finished length of the key, with the necessary allowance for the grinding.

The next stage is to neck down the tube at the upper mark

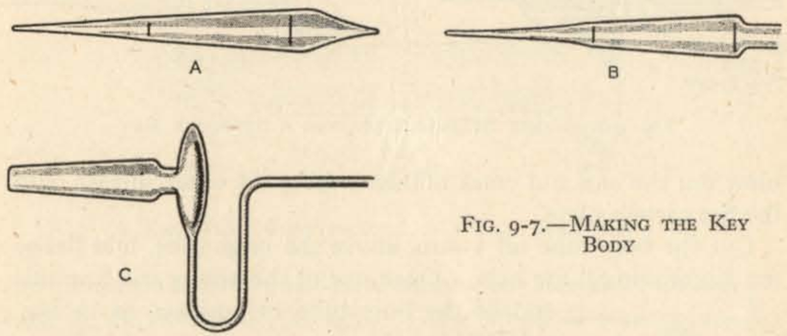


FIG. 9-7.—MAKING THE KEY BODY

(Fig. 9-7(B)); make the shoulder quite sharp; the diameter of the necked portion is the same as the largest part of the handle you made earlier. Instead of making this portion by necking down, if you wish you can make a closed end at the proper point on the tube and join the neck piece on in the usual manner.

Whichever method you adopt, the next step is to cut the neck some 8 or 10 mm. long, and join the handle piece, as shown in Fig. 9-7(C). At this stage leave the bent part of the piece in position, if necessary adjusting it so that the bent portion lies on the axis of the coned tube.

Align the tap key alongside the barrel, so that the mark at the small end projects about 2 mm. beyond the end of the barrel, and mark the position of the side tube. Using a small pointed flame, pierce a hole in the key in exactly the same way as you did for the barrel (Fig. 9-8(A)) and ream out the hole to let the small-diameter bore piece slide through, as shown in Fig. 9-8(B). See that both ends of the key piece are closed, and fuse the bore tube to the blank side of the key. This stage is shown in Fig. 9-8(C); blow the joint well (through the bore tube) and when it is completed

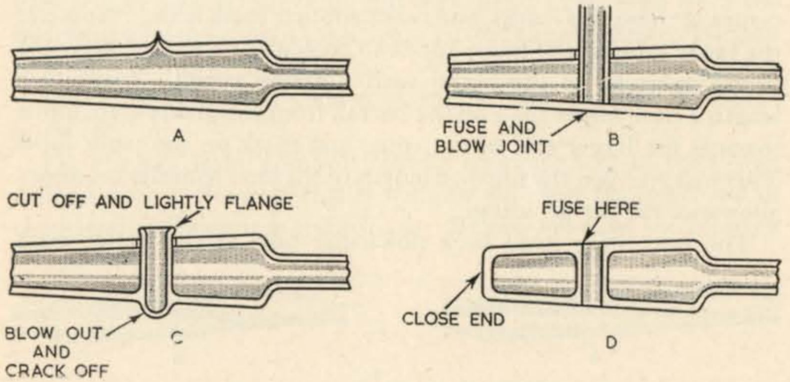


FIG. 9-8.—FINAL STAGES IN MAKING A STOPCOCK KEY

blow out the end and crack off, smoothing the outer surface with the flat carbon plate.

Cut the bore tube off 1 mm. above the large tube, and flange out slightly to fill the hole. Open one of the points and fuse this end of the bore tube in position, as in Fig. 9-8(D).

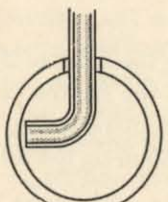


FIG. 9-9.—SECTION THROUGH HOLLOW KEY WITH RIGHT-ANGLE BORE

Next, draw the point off at the mark on the small end of the key, making a flat end (Fig. 9-8(D)). Smooth the outside of the cone by reheating and applying the carbon plate, at the same time clearing the bore tube with the small reamer if you find that the edges have closed in during the sealing operation. Finally, remove the now surplus bend from the handle, and your stopcock key is complete.

It is not necessary to close the end of the key, though it makes a much neater job to do so. Instead, the key may be cut off at the proper length, and the cut edge just melted, or flamed.

Not all stopcocks, of course, have a straight-through bore. A right-angle-bore hollow key is constructed in the same manner as the key described above, except that the bore tube is bent before insertion, in the manner shown in the section view, Fig. 9-9.

You will probably have to make the hole rather larger than the diameter of the cross tube, to allow the bend to be inserted; when this is cut off to fuse the open end to the key, take care to flange over to meet the edges of the hole before sealing together.

Tail Stopcocks

Another variety of hollow-key stopcock is what is known as a tail key. This is used either to make a connection to air or to enable a sample to be taken off through a rubber tube.

The bore may be either straight or right angled, and a hole is

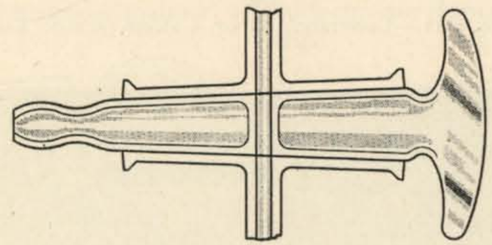


FIG. 9-10.—CONSTRUCTION OF A TAIL STOPCOCK

drilled in the required position to connect the side arm of the stopcock to the hollow of the key. The method of construction is obvious from the sketch Fig. 9-10; instead of removing the point at the small end of the key, it is worked to a rubber-tube connection, as described in Chapter 6.

Vacuum Stopcocks

The method of constructing a high-vacuum tap such as Fig. 9-11 employs generally similar operations. The barrel is to be finished with a cup at one end and a bulb at the other—the latter is required to accommodate the ends of the reamer and the grinding-tool.

Commence by drawing a point at one end of the barrel tube; cut the tube to the length of the barrel plus the cup, and flare the cup at the open end. Mark off the length of the barrel and blow a bulb, leaving the point on as shown dotted in Fig. 9-11(A). Next ream the barrel to the proper taper, and pierce. Close the cup with a cork (blow through the point) and attach the side tube or tubes. If two side tubes are fitted, fuse off the point and finish the bulb in the usual way. If you wish to make the type of stopcock with one side tube and one vertical tube the latter is fused to the end of the bulb as shown dotted in the figure.

The key portion is drawn taper and measured for fit as already

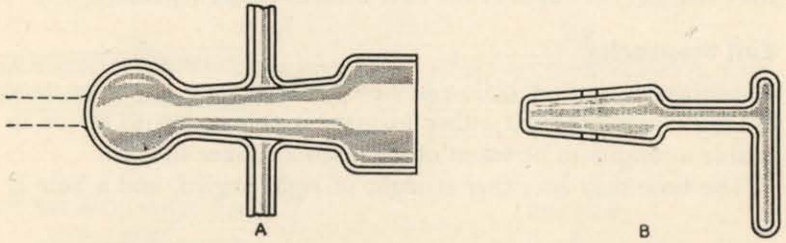


FIG. 9-11.—CONSTRUCTION OF A HIGH-VACUUM TAP

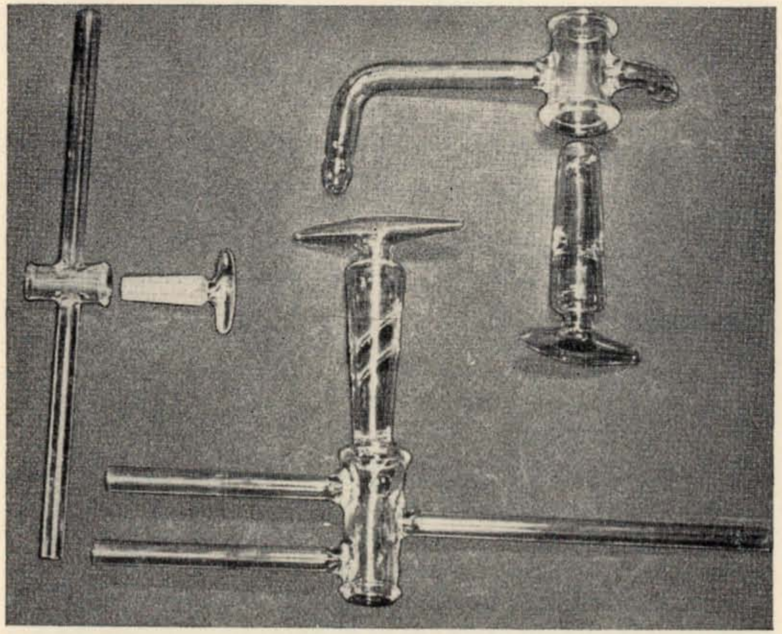


FIG. 9-12.—TYPES OF STOPCOCK, INCLUDING A SOLID KEY, A HOLLOW KEY, DOUBLE OBLIQUE, A STRAIGHT-THROUGH STOPCOCK WITH A HOLLOW KEY

described. In this kind of stopcock no cross-bore tube need be fitted, and the end may be left open. Note that the neck of the key has to be made long enough to clear the cup, and substantial enough to withstand the turning strain, which can be considerable

when the key is lubricated with stiff vacuum grease. Instead of a T-handle, high-vacuum stopcocks are generally fitted with a stout asymmetrical handle about 2 in. long, similar to that shown in Fig. 9-11(B).

The stopcocks, made as described, will look as illustrated in the photograph Fig. 9-12, which shows a solid key stopcock; a hollow key; double oblique stopcock; and an ordinary straight-through type, also with a hollow key.

Stoppers

A stopper may be regarded as a special form of hollow key, and is made in a similar manner. Two forms are shown in Fig. 9-13

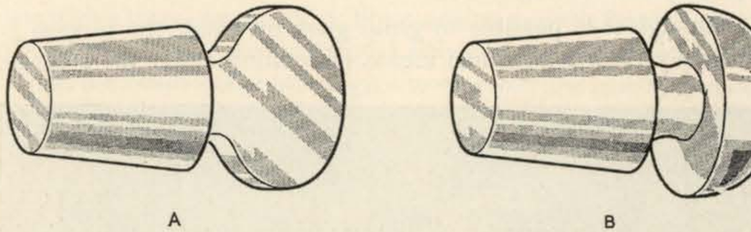


FIG. 9-13.—A STOPPER WITH A FLATTENED ROUND HANDLE (A), AND STOPPER WITH FLAT TOP (B)

(A) and (B). The first shows a stopper with a flattened round handle. The taper portion is first formed, a bulb blown at the large end, and flattened by using flat-nose tongs; the small end is either left open or closed as desired. The second stopper has a flat top, made as before by blowing a bulb and flattening with a carbon plate.

If a replacement stopper is required for a piece of apparatus the correct taper can be found by cutting a piece of card to fit the female portion, and then drawing this taper by two convergent lines on a piece of asbestos paper, as already described earlier in this chapter.

CHAPTER 10

GRINDING AND DRILLING STOPCOCKS

BEFORE the stopcocks described in the last chapter can be put to use, they must be finished by grinding, until the key and barrel are a close, non-leaking fit. The equipment needed is simple, and the technique easily acquired; at least sufficient to enable you to make a good stopcock.

Equipment

Although it is possible to grind glass by hand, the process is extremely laborious; some means of rotating either the glass or

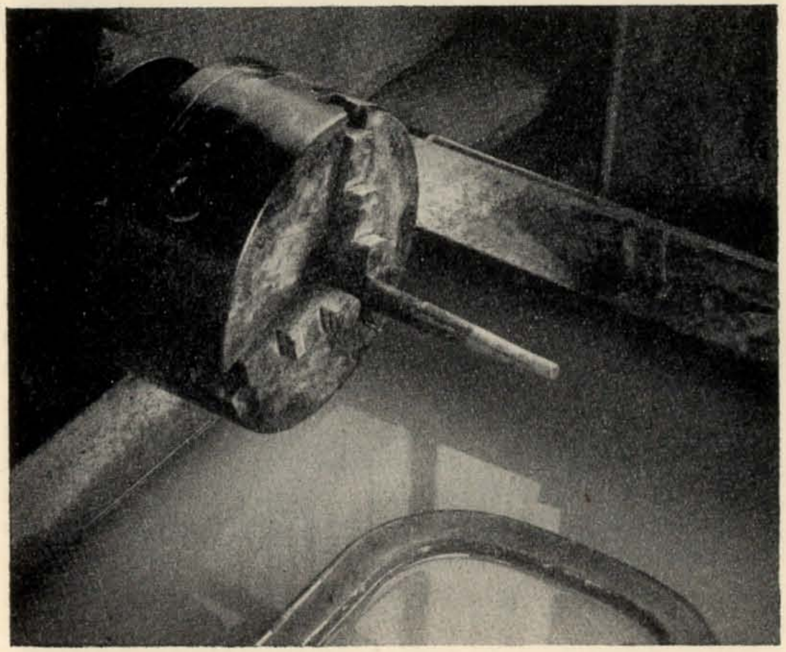


FIG. 10-1.—A SUITABLE HEADSTOCK FOR GRINDING GLASS

the tool is therefore desirable. For this purpose, an old lathe headstock is generally used. It can be mounted on the bench

and be driven by a small electric motor at some 200–300 r.p.m. Such a headstock is shown in Fig. 10-1. Note that the motor is well shielded from water and flying grinding material, and that a tray is placed under the chuck; this should be made to contain water.

The carborundum powder we use for grinding is an extremely abrasive material, and a little in the wrong place can do a lot of damage, so that care should be taken to locate the grinding-bench in an out-of-the-way corner, as far as possible from the glass-blowing bench and glass store. Any rigid bench or table can be utilised; an old lathe headstock can be obtained from almost any scrap-machine dealer for a small sum. Be careful, however, to choose one which is not too worn, and try to get a headstock complete with a three-jaw chuck. The machine must be firmly bolted to the bench top; two substantial strips of wood can be placed to raise the headstock, both to give more room and also to enable the locating strip, usually found on the base of the head, to clear the bench.

Be sure to fit a good-quality and well-insulated switch to control the motor, as your hands generally will be very wet; a badly insulated switch may give you a very nasty, if not fatal, shock.

The fittings required for the headstock are a chuck; a taper mandrel; a hollow taper mandrel, and a grip for the stopcock key. These are shown in detail in Fig. 10-2 and in the photograph Fig. 10-3. The mandrel *A* is made of brass, and is about 6 in. long. It is turned to an included taper of one in ten, being about $\frac{5}{16}$ in. diameter at the small end. This mandrel will accommodate all but the largest stopcock barrels.

Several female mandrels *B* will be required to cover a range of keys; the internal taper must be bored so that a standard key handle will project far enough to clear when the key is ground. A saw slot, about $\frac{1}{8}$ in. wide, must be cut through to the central hole. These mandrels also should be made of brass.

If only a little grinding is contemplated you need not provide these female mandrels; use instead sheet-metal " butterflies " to be described in a later paragraph.

The clamp, or key grip *C* in Fig. 10-2, is made from a piece of hardwood about $1\frac{1}{4}$ in. square. One end is turned to 1 in. diameter and 2 in. long, for holding in the three-jaw chuck. The square portion is slotted as shown in the drawing, the grooves

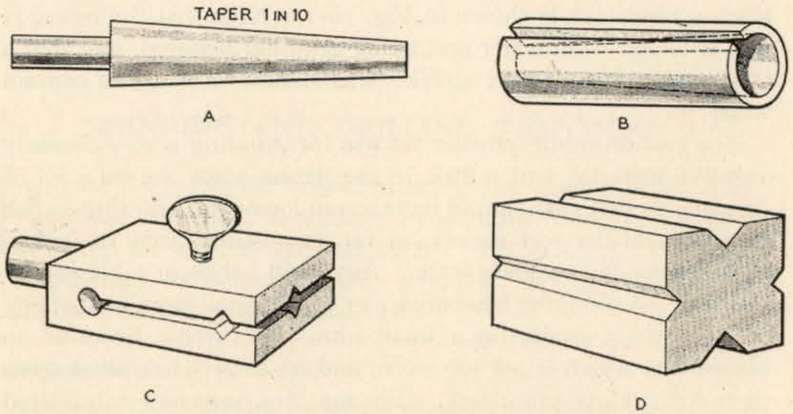


FIG. 10-2.—THE HEADSTOCK FITTINGS

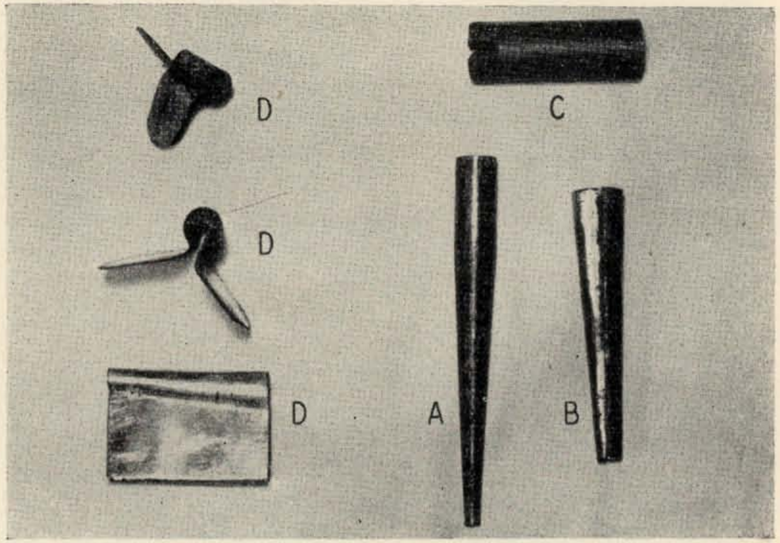


FIG. 10-3.—TOOLS USED IN GRINDING STOPCOCKS

A and B. Mandrel and metal sleeve.
C. Clamp or holder for key.
D. Sheet metal " butterfly ".

being located so that a stopcock key can be held rigidly by the handle with the whole of its cylindrical portion projecting. The cross hole should be large enough to give the jaws plenty of spring, and the thumbscrew must be long enough to clamp the largest key you wish to use. A piece of brass can be screwed to the lower jaw, and tapped to suit the clamping screw.

An additional useful device, not illustrated, is a brass plate about 6 in. diameter, fitted with a spigot for holding in the chuck, and turned flat on its outer face. This is very useful for grinding the ends of tubes and stopcock keys.

A supply of carborundum powder, of the two grades known as 120 and 220, will be required. If a very fine finish is required in your stopcocks (for high-vacuum work, for instance) a very small stock of carborundum grade FFF (3F) is necessary. Some sheet iron about 22 S.W.G. thickness, or at a pinch, some thick tinplate, cut from old cans, will be required, together with a pair of metal shears with which to cut it, and some flat-nose pliers.

To drill holes in glass, special drills are required; we much prefer the kind sold under the name of " Novite ". These are fairly expensive, but can readily be sharpened on an ordinary grindstone. They are graded in size in millimetres, and the most useful sizes to purchase first are those of 2 and 3 mm. diameter; other sizes can be purchased as required. Tungsten carbide tipped drills are an extremely expensive luxury, and in addition they cannot be sharpened with an ordinary grindstone. They are, however, extremely useful when a large number of holes is required.

Do not be tempted to buy an expensive drilling-machine; the simplest and cheapest kind of drill sold for amateur mechanics is quite good enough. Inevitably the bearings get very badly worn due to the carborundum and glass dust generated in the grinding operations, and it is a complete waste to use an expensive machine. For this reason, do not use that nice machine in the workshop for this purpose!

Grinding the Barrel

When grinding stopcocks, the barrel and key are first ground separately, and then ground together using finer compound. The barrel is ground first, using the male taper mandrel Fig. 10-2(A), but in order not to wear the mandrel itself, a sheet of iron or tinplate is wrapped round it. This is best done by making a paper template, and cutting the sheet metal to this pattern; it is then wrapped round the mandrel (see Fig. 10-1), taking care that a smooth surface is maintained. Gentle hammering will help in this operation.

Half fill the tray (Fig. 10-1) with water, and in it stand a flat dish (a cheap pie-dish is admirable) directly under the mandrel.

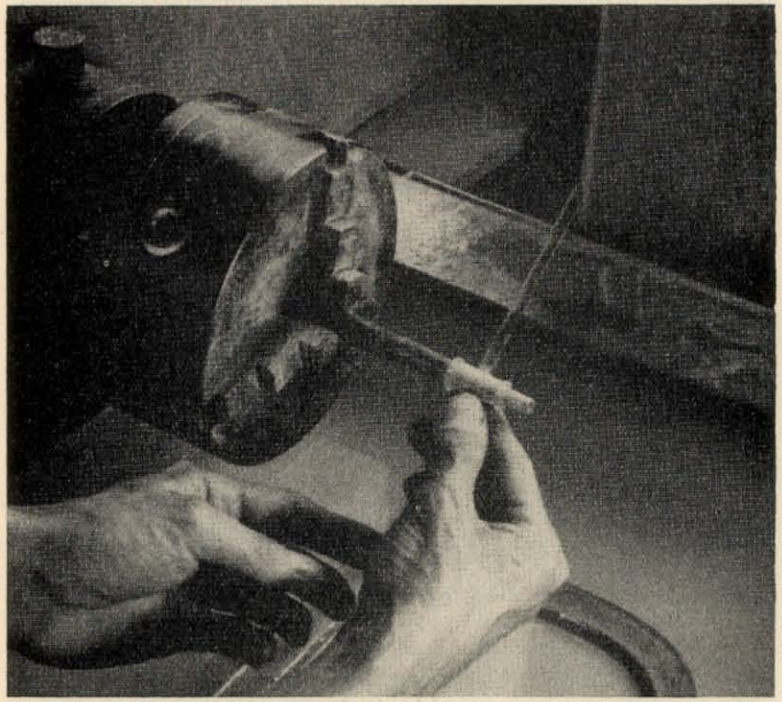


FIG. 10-4.—GRINDING A STOPCOCK BARREL

Place about a tablespoonful of 120 grit carborundum powder in this dish, and add water to make a paste. Start the head rotating, and with the fingers, smear the carborundum paste on the sheet covering on the mandrel; the gap left between the edges of the sheet will allow excess grinding paste to escape when in use.

Take the stopcock barrel in your right hand, dip in the water in the tray, and slide on the mandrel as illustrated in the photograph Fig. 10-4. Do not force the glass on to the taper; hold lightly in the fingers and, using an oscillating motion, keep it moving up and

down the taper mandrel. This continuous " backwards and forwards " motion is most important, and it is also very important to keep the surfaces wet at all times, by dripping water on to the mandrel. This can be done by scooping up water from the tray with the fingers.

From time to time, remove the barrel, rinse in water, and inspect the bore. At this stage, the grinding should be carried only far enough to eliminate all the low, unground spots. Do not forget to replenish the carborundum on the mandrel each time you remove the glass.

Above all, do not let the glass jam on to the barrel, otherwise the job may break and cause a serious cut. The grinding compound dries rapidly in use; light pressure and wet surfaces are the best safeguard.

Grinding the Key

The next job is to grind the key. For this purpose the female mandrel can be used if available. This is lined with a piece of iron

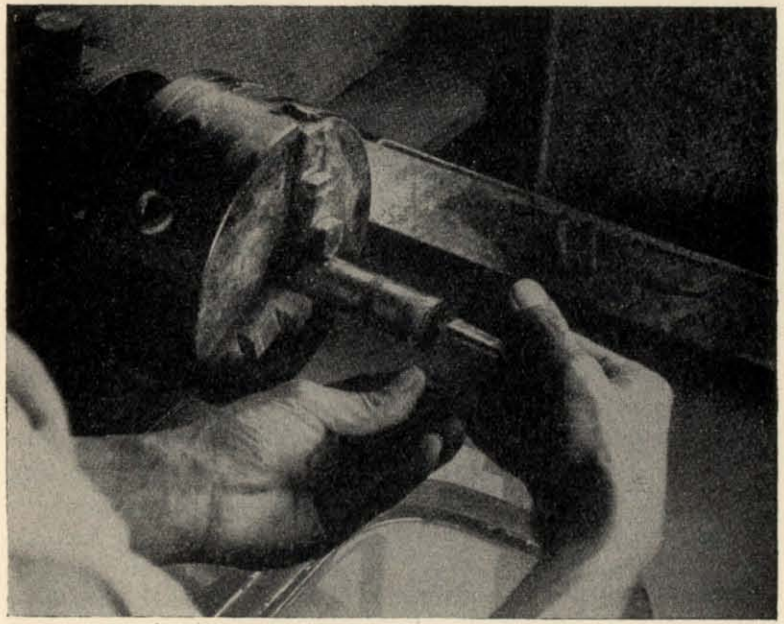


FIG. 10-5.—METHOD OF GRINDING THE KEY, USING SHEET-METAL " BUTTERFLY "

or tinplate, which is best formed on the male mandrel as already described.

Hold the key by the handle, and having applied carborundum paste to it, thrust it gently, with a reciprocating motion as before, into the hollow mandrel (Fig. 10-2(B)). Again, inspect frequently, and grind only enough to get a uniformly ground surface; then check by putting the key in the roughly ground barrel—it should project not more than $\frac{1}{4}$ in. at the large end. If necessary, grinding should be continued until this condition is reached.

If you do not expect to do much stopcock grinding it is not worth while making these special female mandrels. Instead you can use a sheet-metal sleeve or " butterfly ", shown in Fig. 10-3(D). These are made by wrapping the sheet metal round the male mandrel, and then bending the wings back, so that the hollow taper can be closed by pressure of the fingers on the wings.

To use the " butterfly ", the key is held in the grip Fig. 10-2, and the butterfly, charged with grinding compound, is applied in the manner best illustrated in Fig. 10-5. Note the method of holding the wings of the grinding sleeve in the fingers of both hands, giving control of the amount of pressure which is applied to the key being ground.

Drilling the Key

At this stage the key should be drilled. To support it during this process you will require a block of hardwood about $2\frac{1}{2}$ in. square. A taper V-slot must be filed in one surface to accommodate the body of the key in such a position that its axis is horizontal and parallel with the table of the drilling-machine, so that the drilled hole will be produced quite square with the key. This is illustrated in Figs. 10-2(D) and 10-6. Taper slots of different sizes can be filed on four faces of the block to accommodate the various sizes of keys you wish to use.

If you wish to drill a double oblique stopcock, however, the base of the wood block must be filed or sawn until the line of the oblique hole is vertical; better still, the block can be mounted on a trunnion support fitted with clamping screws, so that the inclination of the block can be varied. This is shown in use in Fig. 10-7.

Before drilling, the position of the bore must be marked. Taking first the straight-bore stopcock, place the rough-ground key alongside the barrel, so that the large end of the key body

coincides with the large end of the barrel—*exactly coincides*, neither projecting nor receding beyond the end of the barrel. With a pencil, mark the position of the centre of the side arm on the key.

In the case of an oblique or double oblique stopcock the procedure is a little more complicated. Reference to Fig. 10-8 will make the method clear. Align the key to the barrel as described in the previous paragraph, and mark the centres of the tubes *X–X*. Turn the key through 180 degrees, re-align exactly as before, and mark the position of the middle tube, and the right-hand tube *Y–Y*. Note that if you have joined the side tubes on in the correct position the opposite ends of the two bores are on the same diameter, which coincides with the position of the single side arm.

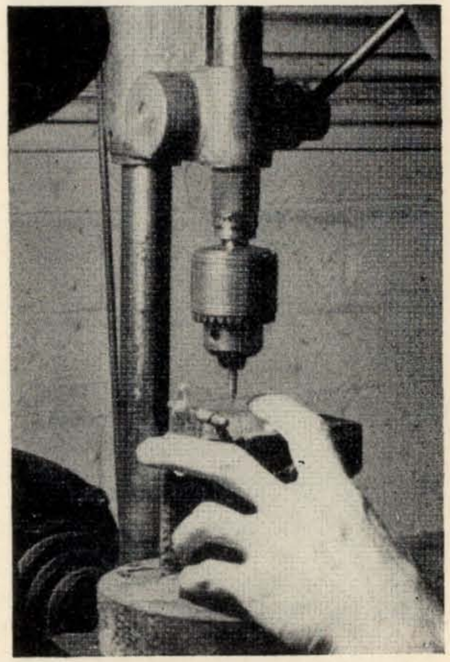


Fig. 10-6.—Drilling the Key

The actual drilling operation is shown in Fig. 10-6. First see that the correct drill is firmly held in the drill chuck, and runs true without wobble; the drill must run true, or the glass will be chipped, if it does not crack completely. Therefore make sure that your drills never get bent, and that when they are resharpened, all the facets are ground at the correct angle, and to the same degree as shown in Appendix B.

Turpentine is a good lubricant to use when drilling glass, so have a small pot of this handy, together with a pipe-cleaner with which to apply it.

Study the photograph, and note the method of holding the key and supporting block. The handle of the key is pressed against the side of the block with the middle finger of the left hand; the index finger holds the key body down in its groove; the thumb grips the other side of the block, while the second finger completes the grip. This method of holding not only secures the key in position, but also allows you to slide the block on the drilling-machine table, to align your pencil mark, indicating the position of the hole, directly under the drill.

Apply a little turpentine to the point of the drill with the pipe-cleaner, and bring the drill down to just lightly touch the key body. Raise the drill, and check that the drill is in fact on the mark. Drilling is effected by bringing the drill down in a series of light "jabs"; do not let the drill dwell too long in the hole, as the powdered glass will cause it to jam, and crack the key in two.

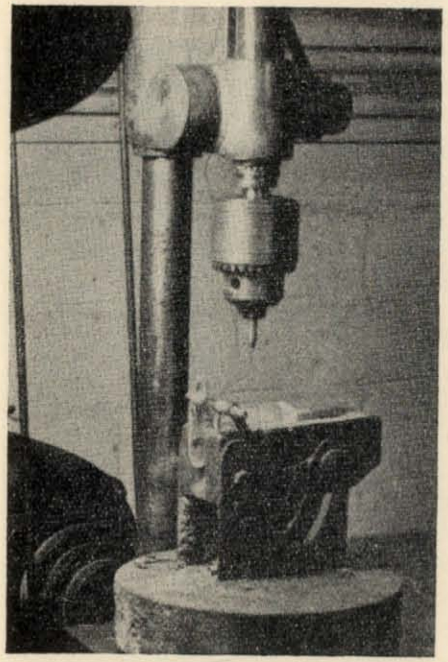


Fig. 10-7.—Drilling an Oblique-bore Key

When you have bored the key half-way through, turn it through 180 degrees, and drill from the opposite side to meet the first hole. If you try to go right through the key from one side, the glass will inevitably crack away on the side where the drill breaks through.

Hollow-bore keys, of course, are not drilled; do not be tempted to try to drill out a distorted hollow key—it will surely break.

Before drilling an oblique-bore key, the pivoted block Fig. 10-7 must be adjusted to the right position. This is best done by trial-and-error adjustment, using the stationary drill in the machine as a guide. Align the key directly under the drill, and slide the block sideways until the drill can be brought down to the surface of the block; align the drill with the pencil marks on both

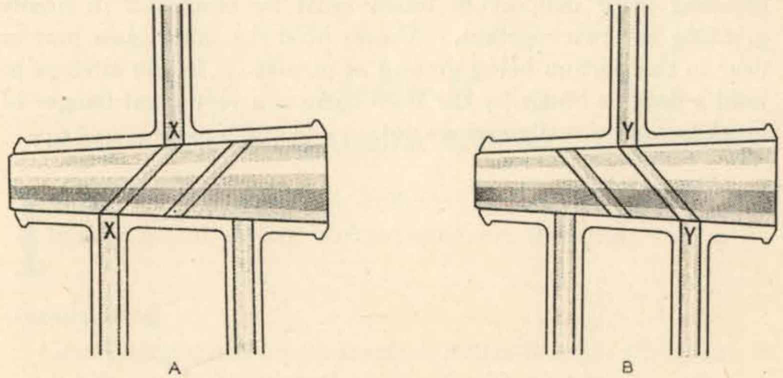


Fig. 10-8.—Method of Marking and Checking the Drilling of an Oblique-bore Key

sides of the key body, adjusting the supporting block until it is at the correct inclination.

Final Grinding

Before commencing final grinding, be most careful to remove all traces of the coarser carborundum powder from the vicinity of the grinding head. Only one grain of coarse carborundum will produce a deep score on the finished stopcock, and ruin all your work.

Hold the tap key in one of the holders shown in Fig. 10-2 or Fig. 10-5, and make sure that it is running true. Use carborundum of 220 grade, and grind the stopcock barrel to the key in just the same manner as you did with the barrel on the mandrel, but use a very delicate touch and wash and inspect frequently. The grinding should be continued until the clean key fits the barrel with the key bore just coinciding with the bore of the side arms.

As usual, none of these operations can be performed as easily as they are described. Nevertheless, care and patience will enable you to make a good job. You will soon find that you can accurately judge the allowances to be made for grinding when you are making the stopcock.

It is not necessary to describe the method of grinding stoppers to flasks, tubes, or bottles, further than to say that after rough grinding great delicacy of touch must be employed in finally grinding the two together. Always hold the outer glass part as near to the portion being ground as possible. If you attempt to hold a flask or bottle by the bulb there is a very great danger of breakage and a really serious cut.

CHAPTER 11

GRADUATING AND OTHER SPECIAL TECHNIQUES

In this short chapter are collected a few operations which, though useful, do not warrant extensive treatment.

Graduating

Graduating articles such as gas burettes is a job which can be undertaken only by experts equipped with expensive machinery. However, there are occasions when a piece of apparatus requires graduation at only one or two capacity marks, and this can be done without much difficulty, particularly if great accuracy is not required.

Before any graduating can be attempted the glassware must be cleaned very thoroughly with sulphuric acid–dichromate mixture (see Appendix B), washed out with distilled water, and dried.

The capacity of a glass vessel is based ultimately on the weight of water it contains, but the calibration and adjustment required for really accurate results are beyond the scope of this book. Useful details about calibration by weighing will be found in the National Physical Laboratory Publication *Notes on Applied Science No. 6—Volumetric Glassware* and British Standard 1797 : 1952, which gives tables for use in calibrating volumetric glassware.

We will confine our directions to calibration using an ordinary laboratory burette. You will require some ordinary beeswax, and a small tin to melt it in; a stout bristle mounted in a short wooden handle; some hydrofluoric acid; a pair of rubber gloves; and two small flat paint-brushes. A little stencil ink will also be required.

First try your hand at graduating a 20 mm. by 150 mm. test-tube every 5 ml. Melt the beeswax in a small receptacle (a tin lid will do), and slightly warm the test-tube. With a brush paint a strip of beeswax about 1 cm. wide down the length of the tube, as shown in Fig. 11-1. Allow the wax to cool, and clamp the tube vertically beneath a burette filled with distilled water. Run exactly 5 ml. of water into the test-tube; the liquid meniscus will be visible through the thin layer of wax on the glass. Dip the bristle in the stencil ink, and holding it perfectly horizontally as depicted in the figure, draw it across the wax, level with the lower edge of the water meniscus. Run another 5 ml. of water into the tube, and mark the new level; repeat every 5 ml. as required.

Empty the tube, and with a darning-needle scratch through the wax, right down to the glass, along your marks or " points "; also scratch the calibration figures at the proper places.

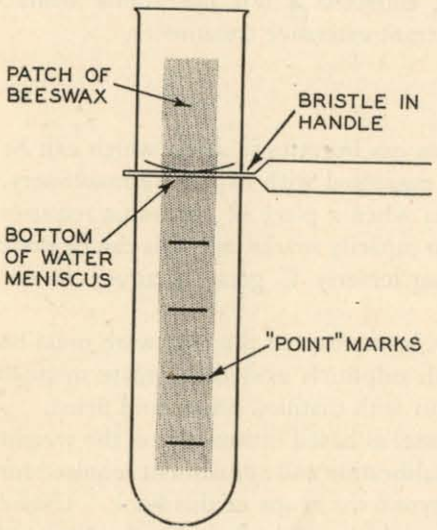


FIG. 11-1.—METHOD OF GRADUATING A TEST-TUBE

To etch the glass, we use hydrofluoric acid. This is a very dangerous material to handle; if spilled on the flesh it causes serious burns which take a very long time to heal; rubber surgical gloves should always be worn when using it. Suitable ones can be purchased very cheaply from a well-known multiple stores. The vapour of the acid must not be inhaled, and the bottle (which incidentally is of wax or polythene) must be kept stoppered, otherwise the vapour will etch any glass in the vicinity.

The acid is best applied to the glass by means of either a small brush or a pinch of cotton-wool held on the end of a slip of wood. Paint the acid on the scratched wax patch on the glass, rubbing it well in so that it flows into the scratch marks, and allow to act for some ten minutes. Wash off with lots of water, and view the marks through the opposite side of the glass. If the marks do not appear to be etched deeply enough the acid treatment can be repeated.

The wax can be removed from the surface of the glass either by using petrol or other solvent, or by warming and wiping off with a clean rag.

To make the graduations easily visible, they should be filled in

with black or white wax, or the black liquid sold by laboratory suppliers for renovating thermometer graduations. If none of these is available, suitable filling can be effected by applying ordinary paint, which is wiped off with a rag, leaving the etched lines filled with paint.

A useful set-up for calibrating the volume of pipettes, separating funnels, and similar articles is shown in Fig. 11-2. A good-quality burette is connected by means of a thick-wall rubber tube (pressure tube) to the (waxed) article to be calibrated. Do not use thin-wall rubber tube for this purpose, as it may either expand under the weight of water or flatten when being flexed. After both vessels have been thoroughly cleaned, they are fitted to a retort stand and adjusted to be truly vertical. Fill the assembly with distilled water, to just below the required zero on the job to be graduated; close the burette tap and fill the burette to just below the top graduation. Gradually open the tap, and adjust the liquid to the zero on the job being calibrated; close the burette tap, and " point " the zero. Again open the tap, and run into the article an amount of water equal to the required capacity. It may be necessary to raise the burette to enable this to be done. Close the burette tap and mark the new " point ". The process may be repeated as often as necessary to give the requisite number of calibration points; if the burette has to be refilled do not forget, first, to close the tap, and secondly, to make a note of the amount of liquid added to the burette.

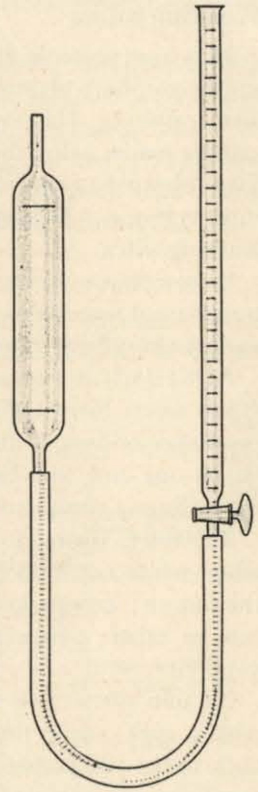


FIG. 11-2.—SET-UP FOR CALIBRATING THE VOLUME OF PIPETTES AND SEPARATING FUNNELS

For a temporary job, for which it is not worth the trouble to etch the glass with acid, a very useful glass-marking ink is made. This is obtainable in a variety of colours, and can be applied either with a brush or a steel pen. After drying on the glass for about two days the ink is fully waterproof. In case of urgency the ink can be rendered reasonably waterproof by heating for some minutes.

Working Silica

It is not possible to work large or complicated silica articles unless you have elaborate oxygen–hydrogen blowpipes and extensive training. However, repairs can often be effected, or small articles made, using the special blowpipe described in Chapter 2. This blowpipe requires a good oxygen supply, and gives a very intense flame. Efficient dark goggles must be worn when flame-working silica.

Semi-opaque or translucent silica is easier to handle than the transparent material, and is very much cheaper. The transparent variety should therefore be avoided wherever possible.

Particularly in two aspects, silica differs considerably from glass. It has a very low coefficient of expansion and is an extremely poor conductor of heat, so that it is possible to heat a piece of tube white hot at one end, and hold it comfortably only a few inches away. Annealing is completely unnecessary.

Secondly, owing to the high viscosity of this material, even when white hot, it is not easily possible to blow molten silica by the mouth; compressed air must be used for this purpose. This can be taken, properly controlled by a tap, from your blower supply.

To join silica tubes of equal size, the end of one piece is closed with a cork, while the other piece is connected through a stopcock to the compressed-air supply. The ends of the tube, which must previously have been ground square, are heated in the blowpipe, and when white hot to incandescence, are pressed firmly together. The joint is reheated, blown (not too strongly), and pulled out in the usual way to make a nice smooth joint.

A T-piece is also made in the usual manner, but you will find that the side tube can be attached much more easily than in the case of borosilicate, for instance. The end of a tube is closed by pulling down—the point can be quite short; pull the blob off with forceps to remove excess material. You will certainly need the help of compressed air to blow the end to a nice round shape.

When working silica, and particularly transparent silica, cleanliness is essential. Near, and at the melting point, silica forms

compounds with many metals and other materials, causing devitrification and stains, which extend rapidly. All silica must therefore be cleaned very thoroughly before heating in the flame, and care must be taken not to handle with the bare fingers the parts to be heated subsequently.

To remove ordinary dust a thorough washing and drying both inside and out with a really clean rag will suffice. To remove grease and other contamination, however, the silica must be washed in 20% hydrofluoric acid—taking all the precautions necessary when handling this dangerous material, and being particularly careful to wash thoroughly and dry afterwards.

Joining Glass *In Situ*

For certain very precise chemical work and for vacuum circuits it is necessary to have an all-glass construction in place of rubber joints; the various parts of the system are therefore made in such a manner that they can be fused together *in situ*. The components must be designed and made so that only tubes of the same diameter have to be joined. These tubes must be left long, so that they overlap when *in situ*; they are then cut exactly to length, so that the edges of the tubes butt accurately together (see Fig. 11-3).

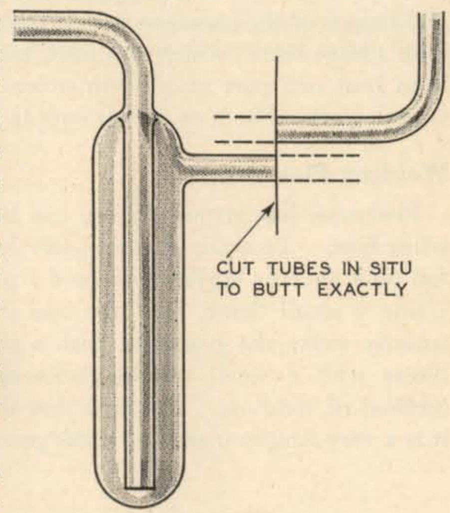


FIG. 11-3.—JOINING GLASS TUBES IN SITU

To make the joint, the adjacent parts must be only loosely held in position. Excepting, of course, the open ends of the tubes you wish to join, all openings in the system but the one most convenient for blowing must be closed by corks or other suitable means. The joint will be blown through a rubber tube connected to the chosen point, which should be as near to the new joint as possible; to protect the system from moisture it is advisable to include a calcium chloride filter in the blowing tube.

Using a hand blowpipe, such as the *Flamemaster*, first warm the ends of the tubes to be joined; be careful to do this all round, not from one side only. Then heat the tubes to the proper temperature and quickly press the ends of the tubes together. Immediately reduce the blowpipe flame to a very small point, and work and blow the joint in the usual manner. If something goes wrong and you get a large gap in some part of the joint, draw a piece of glass tube or rod down to about 2 mm. diameter, and melt this on to one side of the gap; then " sew " the small rod backwards and forwards across the gap until it is filled up. With a little manipulation, the " darn " can be melted down and blown to fill the gap; any excess glass can be removed by touching with a cool (but not cold) glass tube, and drawing off.

Do not forget the importance of keeping the whole of the joint warm all round while you are completing the joint, and keep the joint quite warm enough to yield while you tighten up the clamps and fixings of the components. Finally, heat the whole joint area with a large flame, which you must keep moving without allowing it to heat one part unduly, in order to relieve all strain on the various parts. Reduce the air supply gradually to anneal the job.

Welding Platinum

Platinum, like wrought iron, can be welded when at a bright white heat. To make platinum-foil electrodes, place a piece of the foil on a flat iron surface and hold a piece of platinum wire on it. Using a small flame, heat the two pieces to a white heat, and smartly strike the platinum with a small hammer. A series of blows with a small watchmaker's hammer is a very effective method of welding. Provided that the platinum is hot enough, it is a very simple matter to make good welds.

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British Standards

The various British Standard Specifications mentioned in the text of this book are published by The British Standards Institute, 2 Park Street, London, W.1.

APPENDIX A

WEIGHT OF GLASS—STANDARD JOINT SIZES—STANDARD TAP KEYS

Size and Weight of Tubes

The following table gives the range of glass tube generally available, and the approximate number of feet per pound for the various sizes.

The Table is constructed for soda–lime glass; for borosilicate glasses, which have a slightly lower density, add 10% more feet per pound, and for lead glasses, deduct 20% feet per pound.

APPROXIMATE NUMBER OF FEET PER POUND OF VARIOUS SIZES AND WALL THICKNESSES OF SODA–LIME TUBE

Ext. Diam. mm.	Tubing. Wall 0·25 mm.	Wall 0·50 mm.	Wall 0·75 mm.	Wall 1·0 mm.	Wall 1·25 mm.	Wall 1·50 mm.	Wall 2·0 mm.	Wall 2·5 mm.	Wall 3·0 mm.	Rod.
2	436	254	203	—	—	—	—	—	—	189
3	277	152	113	95·3	87·3	—	—	—	—	84
4	203	109	78·2	63·5	55·5	50·8	—	—	—	47
5	160	85	59·8	47·7	40·7	38·0	31·8	—	—	30
6	132	69	48·3	38·1	32·1	28·3	23·9	21·7	—	21
7	113	58·7	40·7	31·8	26·5	23·1	19·0	16·9	15·7	15·5
8	98	51	35·1	27·2	22·6	19·6	15·9	13·8	12·6	12
9	87	45	30·8	23·8	19·7	17·0	13·6	11·7	10·5	9·5
10	78·2	40	27·5	21·2	17·4	15·0	11·9	10·1	9·0	7·5
11	71·0	36·3	24·8	19·1	15·6	13·4	10·6	8·9	7·9	6·2
12	64·8	33·1	22·6	17·3	14·2	12·1	9·5	8·0	7·0	5·2
13	59·8	30·5	20·8	15·9	13·0	11·0	8·7	7·2	6·3	4·5
14	55·5	28·3	19·2	14·6	12·0	10·1	7·9	6·6	5·7	3·9
15	51·7	26·3	17·8	13·6	11·1	9·4	7·3	6·0	5·2	3·4
16	48·3	24·6	16·7	12·7	10·3	8·8	6·8	5·6	4·8	3·0
17	45·5	23·1	15·6	11·9	9·7	8·2	6·3	5·2	4·5	2·6
18	43·0	21·8	14·7	11·2	9·1	7·7	5·9	4·9	4·2	2·3
19	40·7	20·6	13·9	10·6	8·6	7·2	5·6	4·6	3·9	2·1
20	38·5	19·6	13·2	10·0	8·1	6·9	5·3	4·3	3·7	1·9
21	36·7	18·6	12·5	9·5	7·7	6·5	5·0	4·1	3·4	1·7
22	—	17·7	12·0	9·1	7·3	6·2	4·7	3·9	3·2	1·5
23	—	17·0	11·4	8·7	7·0	5·8	4·5	3·7	3·1	1·4
24	—	16·2	10·9	8·3	6·7	5·6	4·3	3·5	2·9	1·3
25	—	15·6	10·5	7·9	6·4	5·3	4·1	3·3	2·7	1·2
26	—	15·0	10·1	7·6	6·1	5·1	4·0	3·2	2·6	1·1
27	—	14·4	9·7	7·3	5·9	4·9	3·8	3·1	2·5	1·0
28	—	13·9	9·3	7·0	5·7	4·7	3·6	2·9	2·4	1·0
29	—	13·4	9·0	6·8	5·5	4·6	3·5	2·8	2·3	0·9
30	—	12·9	8·7	6·6	5·3	4·5	3·4	2·7	2·3	0·8

Ext. Diam., mm.	Wall 0·50 mm.	Wall 0·75 mm.	Wall 1·0 mm.	Wall 1·25 mm.	Wall 1·50 mm.	Wall 2·0 mm.	Wall 2·5 mm.	Wall 3·0 mm.
31	12·5	8·4	6·3	5·1	4·3	3·3	2·6	2·2
32	12·1	8·1	6·1	4·9	4·1	3·2	2·5	2·1
33	—	7·9	5·9	4·8	4·0	3·1	2·5	2·1
34	—	7·6	5·7	4·7	3·9	3·0	2·4	2·0
35	—	7·4	5·6	4·5	3·8	2·9	2·3	2·0
36	—	7·2	5·4	4·4	3·6	2·8	2·2	1·9
37	—	7·0	5·3	4·3	3·5	2·7	2·2	1·9
38	—	6·8	5·1	4·1	3·4	2·6	2·1	1·8
39	—	6·6	5·0	4·0	3·3	2·5	2·1	1·7
40	—	6·5	4·9	3·9	3·3	2·5	2·0	1·7
41	—	6·3	4·7	3·8	3·2	2·4	2·0	1·6
42	—	6·1	4·6	3·7	3·1	2·4	1·9	1·6
43	—	5·9	4·5	3·6	3·0	2·3	1·9	1·6
44	—	5·8	4·4	3·5	3·0	2·3	1·8	1·5
45	—	5·7	4·3	3·4	2·9	2·2	1·8	1·5
46	—	5·6	4·2	3·3	2·8	2·2	1·7	1·4
47	—	5·5	4·1	3·2	2·8	2·1	1·7	1·4
48	—	5·4	4·0	3·2	2·7	2·1	1·7	1·3
49	—	5·3	3·9	3·1	2·6	2·0	1·6	1·3
50	—	5·2	3·9	3·1	2·6	2·0	1·6	1·3
51	—	—	3·8	3·0	2·5	1·9	1·5	1·2
52	—	—	3·7	3·0	2·5	1·9	1·5	1·2
53	—	—	3·6	2·9	2·4	1·9	1·5	1·2
54	—	—	3·5	2·9	2·4	1·8	1·5	1·2
55	—	—	3·4	2·8	2·3	1·8	1·4	1·2
56	—	—	3·3	2·8	2·3	1·8	1·4	1·1
57	—	—	3·2	2·7	2·2	1·7	1·4	1·1
58	—	—	3·2	2·7	2·2	1·7	1·4	1·1
59	—	—	3·1	2·6	2·1	1·6	1·3	1·1
60	—	—	3·1	2·6	2·1	1·6	1·3	1·1

GAUGING TOLERANCES ON DIAMETER are normally: 1 mm. overall up to 25 mm.; 2 mm. from 25 to 30 mm.; and 3 mm. over 30 mm. Special selection can, however, be undertaken if required.

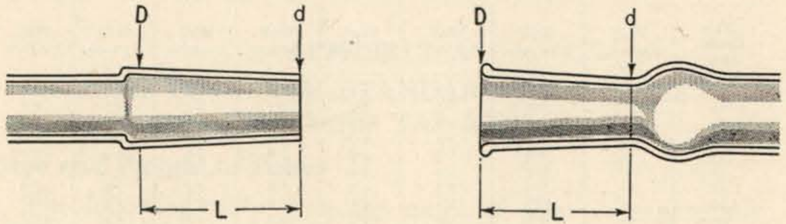
STANDARD BUNDLES of machine-drawn tubing and rod are: up to 25 mm., 14 lb.; over 25 mm., 10 lb. Hand-drawn tubing and rod can be supplied in any quantities.

(*By Courtesy of Osram–G.E.C. Ltd.*)

Standard Joints

The standard interchangeable ground joint is a most useful means of connecting glass parts. The production of these items is, however, beyond the reach of any but the professional glass-blower; the whole range can be purchased either from the larger glass firms or from laboratory suppliers, in either soda–lime or borosilicate glass. The joints are supplied fused on the end of a length of the nominal-diameter tube. They should not be cut shorter than absolutely necessary for joining to apparatus, as the ground part will be seriously distorted and rendered useless if it is overheated.

Sizes of the most useful " B " joints are given below for reference; complete tables of all sizes of these interchangeable joints are given in B.S. 572.



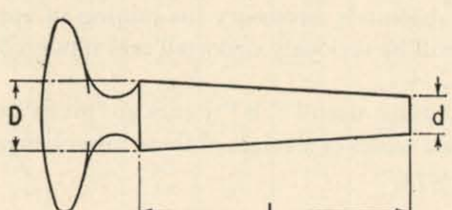
Size No.	Diam. (D), mm.	Length Ground (L), mm.	Diam. (d), mm.
B5	5·0	15	3·5
B7	7·5	18	5·7
B10	10·0	22	7·8
B12	12·5	24	10·1
B14	14·5	25	12·0
B16	16·0	26	13·4
B19	18·8	28	16·0
B24	24·0	30	21·0
B29	29·2	32	26·0
B34	34·5	34	31·1
B40	40·0	36	36·4
B45	45·0	38	41·2
B50	50·0	40	46·0
B55	55·0	42	50·8
B60	60·0	44	55·6

Standard Pressed Key Blanks

The following table shows the range of pressed key blanks which is generally available. The most useful sizes are numbers 2 and 3.

The "A" sizes are rather larger than standard, and are used when double oblique keys are required.

These pressed keys can be obtained from Messrs. Davey and Moore Ltd., 33 Blundell Street, London, N.7.



Size No.	Length (L), mm.	Diam. (D), mm.	Diam. (d), mm.	Size No.	Length (L), mm.	Diam. (D), mm.	Diam. (d), mm.
00	22	8	5·8	4	35	16	12·5
0	22	10	7·8	4A	50	16	11
1	30	11	8	5	41	18·8	14·7
1A	30	11·5	8·5	5A	70	18·8	11·8
2	32·5	12·5	9·25	5B	43	21·2	16·9
2A	42·5	12·5	8·25	6	43	24	19·7
3	35	14·5	11·0	7A	73	27	19·7
3A	45	14·5	10·0				

APPENDIX B

MATERIALS AND SUPPLIERS

Bellows, Foot

Obtainable from any of the laboratory supply firms.

Blowers or Compressors

The air compressor required to feed the blowpipe may be obtained either from one of the laboratory suppliers or direct from Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

If compressed air is available in the laboratory this may be utilised, provided that its use does not seriously deplete supplies to other parts of the laboratory.

Blowpipes

These can be purchased from any of the usual laboratory suppliers, whose names are listed below.

The *Bornkessel* and *Flamemaster* blowpipes are made by Messrs. Stone-Chance Ltd., Lighthouse Works, Smethwick, Birmingham 40.

The special torch used for working silica is made by the British Oxygen Co., and is their Ref. 44379. If the makers are told the purpose for which it is required they will fit the proper nozzle.

Carborundum

This material is obtained direct from the makers, Carborundum Ltd., Trafford Park, Manchester 17. One pound each of grade 120 and grade 220 will be a sufficient stock.

Cleaning Solutions

Ordinary dust may be removed from glass articles by using warm water and soap or detergent; but if the glass is greasy or contaminated by chemical residues, more vigorous cleaning will be necessary.

The usual cleaning solution employed for this purpose is a mixture of sodium or potassium dichromate and sulphuric acid.

It is made by first making a saturated solution of sodium or potassium dichromate in water, and diluting this with an equal

volume of water. To this solution, an equal volume of concentrated sulphuric acid is added. As this operation is one of considerable danger, the following instructions must be strictly observed.

Place 1 litre of the diluted water solution in a 2- or 3-litre flask, which can be immersed in a sink full of water. Put a small funnel in the mouth of the flask; this is to prevent the contents of the flask from spurting out. Pour about 20 ml. of the concentrated sulphuric acid—not more—through the funnel into the solution, and shake the flask thoroughly. Add two further 20-ml. portions of the acid, shaking the solution between each addition. The liquid in the flask will get very hot, and should be cooled by immersing the flask in cold water. Continue the addition of acid in similar small portions, with shaking and cooling of the flask, until a total of 1 litre of acid has been added; then set aside to cool, and keep in a stoppered bottle. Never, never, add water to the strong acid, or a violent eruption will take place, and the liquid will be thrown out of the flask.

To clean glass with this solution, the glass apparatus is either filled with or immersed in the solution (or both) and left overnight. The glass is then washed with water and dried. The solution may be used many times until it turns green, when it should be diluted with a very large quantity of water and thrown down the sink.

An even more useful cleaning solution is composed as follows:

Hydrofluoric acid	5%
Nitric acid	33%
Teepol	2%
Water	60%

This solution is very potent, and will cause serious burns if spilled on the skin. Unless you have experience in handling these acids, we strongly advise you not to use this solution.

When handling both these cleaning materials, use rubber gloves, and avoid splashing. Also keep the liquids in a safe place, where they will not be accessible to unauthorised persons.

Glass

The firms who supply laboratory apparatus generally hold a small stock of soda–lime and borosilicate glasses, but if serious glassblowing is contemplated, it is best to obtain supplies direct from the makers.

The *Wembley*, *Osram–G.E.C.* and *Lemington* series are made by the Osram–G.E.C. Co. and are obtainable through Messrs. Grainger and Threlfall Ltd., 20 Elden Square, Newcastle upon Tyne 1.

Phœnix borosilicate glass, made by the British Heat Resisting Glass Co. Ltd., is distributed by Messrs. Plowden & Thompson Ltd., Dial Glass Works, Stourbridge, Worcs.

Firmasil blown glassware is made by Wood Bros. Glass Co. Ltd., Barnsley, Yorks.

Hysil glass, made by Chance Bros. Ltd., is not now in production, but is occasionally obtainable from laboratory suppliers; it will seal to *Pyrex*.

Pyrex glass, the oldest of the borosilicate series, is obtained from the makers, James A. Jobling Ltd., Wear Glass Works, Sunderland.

Monax glasses are manufactured by John Moncrieff Ltd., Perth, Scotland.

The *B.T.H.* Series of glasses are obtainable only direct from The British Thomson-Houston Co. Ltd., Rugby.

Glass tube with precision bore is made by Messrs. J. A. Jobling in *Pyrex* glass, and as *Veridia*. Tubing in *Hysil* glass by Messrs. Chance Brothers Ltd., Glass Works, Smethwick, Birmingham 40. The bores of these tubes are accurate to 1/100 mm., but the outside diameters are only held to a tolerance of ½ mm. Tubes are at present made in a range of bores from 0·04 to 34·5 mm.; the larger sizes can be produced in lengths up to 4 ft., but the smaller-bore tubes can be made only in 12-in. lengths.

These precision-bore tubes are extremely useful when uniformity of bore is essential, as in special manometers or calibrated apparatus, but the cost, unfortunately, limits the use of this material.

Goggles

Dark goggles for use when blowing borosilicate, and particularly silica, must be really effective. Do not use ordinary sun glasses purchased from the optician, but get the special types made specifically to cut out highly actinic rays. We particularly recommend the *Bocal* goggles, *Type F G* 2(*B*) complete with light and

dark glasses (which can be used together), made by The British Oxygen Co. Ltd., whose address is given elsewhere in this appendix.

Laboratory Apparatus Suppliers

Most of the equipment described in this book can be obtained from any of the numerous firms who supply laboratory apparatus. It is not possible to give a list of all the firms specialising in this field, but the following have either branches or agents in many of the larger provincial cities:

- Baird & Tatlock Ltd., Cross Street, Hatton Garden, London, E.C.1.
- A. Gallenkamp & Co. Ltd., 17 Sun Street, London, E.C.2.
- Griffin & George Ltd., "Nivoc House", Ealing Road, Alperton, Wembley, Middlesex.
- C. A. Hendley & Co., Victoria Road, Buckhurst Hill, Essex.
- Townson & Mercer Ltd., 101 Beddington Lane, Croydon, Surrey.

"Liquid Metal"

The *Liquid Silver* and *Liquid Platinum* solutions mentioned in Chapter 8 are extremely useful in the laboratory, though very expensive. They can be obtained from either Messrs. Johnson Matthey Ltd., 73–83 Hatton Garden, London, E.C.1, or the Melton Metallurgical Laboratories, Slough, Middlesex.

Marking Materials

Special grease pencils for writing on glass are made by Arthur Johnson Ltd., and are called *Chinagraph* pencils. They are obtainable from any laboratory supply firms. Black or white wax, for filling graduations, and special liquid black graduation filler are obtainable from the same source.

The *Rampart* glass-writing fluid mentioned in Chapter 8 is made in a variety of colours by Rampart Inks Ltd., 109 Great Russell Street, London, W.C.1.

Oxygen and Cylinder Fittings

Oxygen can be obtained either from the British Oxygen Co. Ltd., East Lane, North Wembley, Middlesex, or British Industrial Gases, 32 Victoria Street, London, S.W.1. It is best to ask for 200-cu. ft. cylinders, which are generally hired for a small sum, the gas being charged per cubic foot.

The cylinder valve, reducing valve and gauge, non-return valves (hose protectors), and gas-main non-return valves must be purchased, and can be obtained from the same source.

Silica Tube

This is manufactured either as the opaque (or translucent) variety or as pure transparent fused silica. The makers are The Thermal Syndicate Ltd., 12–14 Old Pye Street, Westminster, London, S.W.1. The clear material is extremely expensive, and should be used only when transparency is necessary.

Stopcock Greases

For all ordinary purposes, Stevens rubber grease is most satisfactory. For use in high-vacuum systems *Apiezon L* grease, or silicone grease must be used. All these materials are obtainable from the usual suppliers.

In the average laboratory it is the exception rather than the rule to see a tap properly greased. The correct method described below not only ensures proper and sufficient lubrication, but also saves material. First see that both the bore of the stopcock and the key are clean and thoroughly dry. With a matchstick, apply two thin longitudinal streaks of lubricant to the key, on opposite diameters 90 degrees away from the bore. Insert the key into the barrel, and press home; this will spread the lubricant evenly over the whole bore, producing a transparent layer, free from streaks.

A "streaky" tap is certain to leak, and is an indication of improper lubrication. If the first application is not successful it is best to clean off all the lubricant and start again. In the case of high-vacuum greases, which are very viscous, it is advisable to slightly warm the stopcock key before applying the material.

When lubricating burette taps it is usual to interrupt the longitudinal streaks in the region of the bore, so that there is no danger of the lubricant coming into contact with the liquid in the burette.

It should be noted that silicone grease is very difficult to remove completely, and unless all traces are removed before working in the flame, silicones combine with the glass, and may cause devitrification.

Strain Viewers

A strain viewer is an extremely useful apparatus with which glass can be examined to check if annealing has been properly carried out. It utilises polarised light, and consists essentially of two sheets of special material, Polaroid, which respectively polarise and analyse the light passing through them.

The polarising sheet is illuminated from behind by an ordinary electric lamp, and the glass to be examined is inserted between the polariser and analyser, and viewed through the analyser. A pattern of coloured bands is observed in the glass under examination, and the colour and direction of these bands is a measure of the strain in the glass.

It is not possible here to give details of how to make and use such a strain-viewer—particulars will be found in any good book on applied optics.

Complete apparatus, or the polarised sheets only, with information as to their use can be obtained from H. S. B. Meakin Ltd. 36 Victoria Street, London, S.W.1.

Tools for Glassblowing

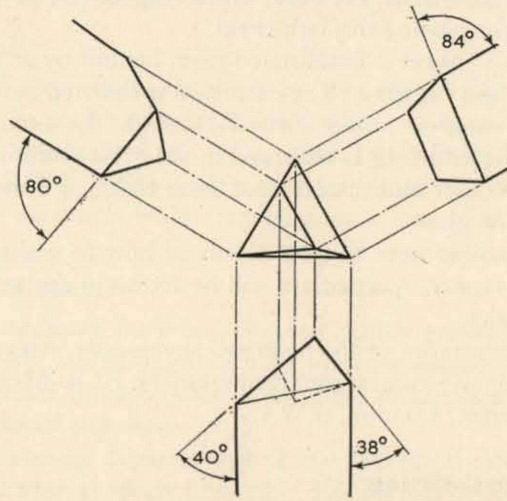
As described in the text, many of the small tools used by glassblowers can be made with very little trouble from odds and ends of material. Not only is there a saving in money by doing this, but also the advantage that the craftsman can make the exact shape he finds most useful.

However, a wide range of tools will be found listed in the catalogues of the various firms who supply laboratory apparatus. Do not, however, be tempted to purchase complete sets of tools, as many of those included will not be of much use.

We should specially mention the glass-cutting knife. Although a sharp triangular file can be used, the purchase of one of the modern carbide knives is well worth while; although expensive, they will last a very long time with reasonable care. We would specially recommend that sold by Griffin & George Ltd., their Catalogue No. B32-697.

Carbon plates and reamers are supplied by The Morgan Crucible Co. Ltd., Church Road, Battersea, London, S.W.1. The reamers are made in various sizes, and it is only necessary to purchase the size to suit the stopcock keys you will use. Carbon plates also are made in various sizes; one about 4 in. by 3 in., and $\frac{1}{4}$ in. thick, will meet most requirements.

Glass drills are sold in millimetre sizes. Those made by G. Jonas & Colver (Novo) Ltd., The Novo Steel Works, Sheffield, under the name *Novite*, are very good, and will last a considerable



time with care. They can be resharpened with an ordinary grindstone. Before grinding, however, carefully examine the point of a new drill; the point is not symmetrical, and is in fact as shown in the accompanying illustration. You must be careful to reproduce this shape when sharpening the drill.

This firm will also supply tungsten carbide tips, which must be welded on to a steel shank for use. However, these tips are intended primarily for production drilling of glass, and their cost is not warranted where only occasional use is required.

Wires

TUNGSTEN AND MOLYBDENUM WIRE. These materials should be ordered as ground rod, specifying the diameter and length required. Suppliers are either The Vactite Wire Company Ltd., 31 Spencer Street, Westminster, London, S.W.1, or the Tungsten Manufacturing Co. Ltd., 68 Victoria Street, London, S.W.1.

PLATINUM. This is obtainable from Johnson Matthey Ltd., 73–83 Hatton Garden, London, E.C.1, or Baker Platinum Ltd., 52 High Holborn, London, W.C.1.

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LABORATORY GLASSBLOWING L.M. PARR & C.A. HENDLEY