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SILHOUETTES OF CHEM-ISTRY

Science
for Everyone

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Занимательно о химии

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Silhouettes of Chemistry

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Mir
Publishers
Moscow

Instead of a Preface

Once upon a time there was a very wise and learned ruler in the East who wished to know all about the peoples that inhabited the Earth.

He summoned his viziers and commanded:

"Write me a history of all the nations in the world, and tell me how they lived before and how they live now, what they do, what wars they have fought and are waging now, and what trades and arts flourish in different countries."

And he gave them five years to do this.

The viziers bowed in silence. Then they called together the wisest of the wise men in the kingdom and announced their ruler's will to them. It is said this caused an unprecedented boom in the parchment industry.

Five years later the viziers reassembled at the palace.

"Your will is done, O great king! Look out of the window and you will see that which you have desired..."

The ruler rubbed his eyes in amazement. Before the palace stood a caravan of camels, so long that the end was lost beyond the horizon. Each camel carried two huge packs and in each pack were ten enormous volumes beautifully bound in Morocco.

"What is that?" asked the monarch.

"It is the history of the world," replied the viziers. "At your command the wisest of the wise have toiled at it incessantly for five years!"

"Would you make fun of me?" thundered the monarch. "I could not read a smallest part of what they have written by the end of my life! Let them write me a short history. But let it include all the important events."

And he gave them another year.

The year passed and again a caravan stood before the palace. It was now only ten camels long, each camel carrying two packs of ten volumes on its back.

The monarch was furious.

"Let them write only of the most important events that happened among all nations in all times. How long will that take?"

Then the wisest of all the wise men came forward and said:

"Tomorrow, my Lord, you will have what you desire!"

"Tomorrow?" echoed the ruler in surprise. "Very well. But if you are deceiving me you shall lose your head!"

...Hardly had the sun mounted the blue sky and the slumbering flowers opened in all their splendour, than the monarch had the wise man summoned.

The sage entered with a tiny sandal-wood box in his hands.

"You will find here, O great king, the most important events that ever happened in the history of all the peoples in all times," said the sage with a low bow.

The monarch opened the box. On a velvet cu-

shion lay a small slip of parchment with a single phrase written on it: "They were born, they lived, and they died."

So runs the old legend. And when we were asked to write an entertaining book about chemistry and were told that paper would be limited (meaning the size of the book, of course) we could not help remembering it. That meant we could only write about the most important things. But what are the most important things in chemistry?

"Chemistry is the science of substances and their transformations." (At the end of the book we shall return to this definition of chemistry.)

Can you blame us for recalling that scrap of parchment in the sandal-wood box?

We scratched our heads, and racked our brains and decided that everything in chemistry is important. One thing may seem more important to one person and less important to another. For instance, an inorganic chemist may consider inorganic chemistry the hub of the universe, but an organic chemist would be of quite the opposite opinion. There is no soothing uniformity of views on this point.

Civilization is the sum of numerous items, and one of the most important of them is chemistry.

Chemistry enables man to smelt metals from ores and minerals. Without chemistry modern metallurgy would be impossible.

Chemistry creates out of animal, vegetable and mineral materials some wonderful and surprising substances.

It does not simply copy nature or imitate it, but surpasses it in more and more dinerent ways

year by year. Thousands and thousands of substances have been produced that are not found in nature but possess very important and useful properties of great utility for the life and work of man.

The list of chemistry's good deeds is practically inexhaustible.

Every aspect of life involves an immense number of chemical processes. It is impossible to understand the fundamentals of vital activities without knowledge of the laws of chemistry.

Chemistry has had its say in the evolution of man.

Chemistry feeds us, clothes us, shoes us, and gives us the things without which modern civilized society cannot function.

The first rockets have been fired into outer space. Chemistry provided the fuel for their engines and strong heat-resistant materials for their design.

Should anyone try to write everything about chemistry in all its innumerable aspects and in all its splendour, the paper resources of even a highly developed state would be threatened with exhaustion. Fortunately, the idea has not yet occurred to anyone.

The second edition of this book in Russian was published almost two decades ago. The Russian edition of the book was entitled "Entertaining Chemistry". This title was not just a product of the authors' fantasy. In the 1960's Molodaya Gvardia Publishers was compiling a series of popular science books in different fields of science called "Entertaining...". So we were not able to take the initiative in this matter... However,

were it up to us, we would have chosen a different title.

Strictly speaking, "entertaining" means the same as "amusing": a kind of "amusing" reading on chemistry, a series of "intriguing" stories....

But chemistry in itself is such a fascinating sphere of human knowledge that it is simply impossible to write about it in a dull, impassionate manner. The language used should be simple and understandable, particularly when one is writing for laymen. But too much "amusement" is likely to be irritating....

The main thing is what to tell about? Chemistry does not have any definite bounds, its horizons are constantly expanding. The authors, however, are compelled to keep within the limits dictated by the size of the book. So, to use the language of publishers' annotations, "the authors have endeavoured to touch upon the most important and interesting problems of chemistry", namely:

—the Periodic System of Elements;

—various types of chemical reactions;

—some interesting and important chemical compounds;

—research methods applied to chemistry;

—some practical achievements of this science. Only minor additions and corrections were introduced into several subsequent editions of the book in foreign languages. Meanwhile, time has marched on. Many new chemical discoveries have been made which should be made known to the public.

We were fortunate enough to be given an oppor-

tunity to revise (with certain limits, of course) the present third edition in English.

In any case, we succeeded in having the book revised to a certain degree. Some of the old material was omitted and the necessary additions and corrections were made. Several new essays were added. Sometimes we even had to change the style of writing: in two decades the reader has become more sophisticated, more informed, more learned.

A much harder task was to give our book the appropriate title. We finally fixed our choice on "Silhouettes of Chemistry" to which there may be objections. But this, after all, is the right of the authors... .

Contents

Contents

The Inhabitants of the Big House

A Bird's-Eye View
of the Periodic System

A fleeting glance, a first impression, is usually of little value. Sometimes it leaves the observer indifferent, sometimes it surprises him. Once in a while it makes him exclaim, like the hero of the well known anecdote when he saw the giraffe at the Zoo: "It can't be true!"

But even a first acquaintance with a thing or a phenomenon, a bird's-eye view of it, if you like, is often useful.

Mendeleyev's Periodic System of Elements can hardly be called a thing or a phenomenon. It is rather a kind of mirror reflecting the essentials of one of the greatest laws of nature, the Periodic Law. This is a code of behaviour obeyed by the hundred odd elements found on Earth or produced artificially by man, a set of regulations, as it were, prevailing in the Big House of the chemical elements...

A first glance at this house reveals a great deal. The first feeling is one of surprise, as if in the midst of standard large-panel buildings we suddenly saw a house of whimsical but elegant architecture.

What is it that is surprising about Mendeleyev's Table? To begin with, the fact that its periods, its storeys, have different floor plans.

The first storey*, or first period of the Mende-
leyev Table, has only two rooms or boxes. The
second and third have eight each. The next two
storeys (the fourth and fifth) have eighteen rooms
each, like in a hotel. The sixth has even more
rooms, namely thirty-two. Have you ever seen
such a building?

Still that is the form of the Big House of chem-
ical elements known as the Periodic System.

Architect's whim? Not at all! Any building has
to be designed in accordance with the laws of
physics; otherwise the least breath of wind will
topple it over.

The physical laws that underlie the architec-
ture of the Periodic System are just as strict and
decree that each period of the Mendeleyev Table
contain a definite number of elements. For in-
stance, the first period has two elements, no
more and no less.

That is what the physicists affirm and the chem-
ists fully agree with them.

But they didn't always agree. There was a time
when the physicists said nothing, because the
Periodic Law had not yet begun to bother them.
But the chemists who were discovering new ele-
ments so often were finding it harder and harder
to know where to put the newcomers. And there
were annoying situations when there was a whole
queue of claimants for the same box in the table.

Not a few scientists were sceptical. They de-

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* Unlike ordinary houses, the "storeys" of Mendeleyev's
Big House (Periodic System) should be numbered from
top to bottom, because any new "storey" that might
have to be added to accommodate new elements would
have to be attached to the bottom of the table.

clared quite soberly that the edifice of Mende-
leyev's Table was built on sand. One of these
was the German chemist Bunsen, who developed
the method of spectroscopic analysis together with
his friend Kirchhoff. But when it came to the
Periodic Law Bunsen exhibited surprising scien-
tific shortsightedness. "One might just as well
seek regularities in the figures of stock exchange
bulletins!" he snapped out once in a fit of anger.

There had been attempts before Mendeleyev's
to put several dozen chemical elements then
known into some kind of order. But they were not
successful. The Englishman Newlands probably
came the closest to the truth. He suggested a
"Law of Octaves". On arranging the elements in
order of increasing atomic weight, Newlands
found that as in music where each eighth note
repeats the first at a higher level, the properties
of every eighth element resembled those of the
first. But the reaction Newlands' discovery evoked
was: "Why don't you try arranging the ele-
ments in alphabetical order? You might detect
some regularity that way too!"

What could Newlands reply to his sarcastic
opponent? Mendeleyev's Table was not particu-
larly lucky at first. Its "architecture" came under
furious attack. For much in it remained obscure
and required explanation. It was easier to
discover half-a-dozen new elements than to find
proper positions for them in the table. As time
passed things came to normal. Although even
now arguments on the point of rearrangement of
the Periodic System occur.

How the Astronomers
Sent the Chemists
on a Wild Goose Chase

"It never occurred to me that the Periodic System should begin precisely with hydrogen."

Whose words do you think these are? They would be most likely to come from one of the legion of investigators or amateurs who set themselves the task of drawing up a new periodic system all of their own or of rearranging it to suit themselves. As many "Periodic Systems" made their appearance as there were designs for perpetual motion machines.

Indeed, the number of different versions of the Periodic System of Elements is really great. And more are likely to appear in the future since the System possesses a unique attractiveness. It seems quite simple at first sight, but this is a deceptive simplicity. It creates the illusion that there can be nothing easier than drawing up a new "improved" version of the Periodic Table. And many find themselves in an awkward predicament because of this illusion.

A truly enormous work has been conducted in one of the Moscow research institutes which study the history of science: a thick "Atlas" was compiled of all the different forms of graphic representation of the Periodic System that have ever appeared on the pages of textbooks and scientific publications since 1869. The number of such forms exceeds 500. Some of them are of great educational value: it is a true "illustrated history" of the development of the teaching of period-

icity. Among the authors' names there are out-
standing chemists, physicists, geologists from all
countries of the world. And all of them did
their utmost to depict the regularity of periodic
changes of properties of chemical elements. There
were many architects but the number of "archi-
tectural indulgences" was no smaller. Quite a few
"annexes" could fit nicely into the "architectural
ensemble" of the Big House. The majority are of
historical interest only. Even greater number of
projects (no one knows how many in particular)
were rejected because of their one principal short-
coming: they all lacked common sense. Their
authors never bothered to study the fundamentals
of chemistry and physics.

The flow of "new" projects refused to dry up,
to the great discontent of the publishers... . One
such "inventor" showed one of the present authors
a table, which contained a thousand elements. To
the ironic question "Why not two thousand?" he
replied: "The sheet was not large enough..."

Well, the phrase in quotation marks at the
beginning of the chapter was written by none
other than D. Mendeleyev. It appeared in his
famous "Foundations of Chemistry", a textbook
used in its time by tens of thousands of students.

Now why was the author of the Periodic Law
mistaken?

In his time there were all grounds for such mis-
takes. The elements were then arranged in the
Table in order of increasing atomic weight. The
atomic weight of hydrogen is 1.008, of helium—
4.003. Hence, why not assume that there might
be elements with atomic weights of 1.5, 2, 3,
and so on? Or elements lighter than hydrogen,

with atomic weights smaller than unity?

Mendeleyev and many other chemists thought this to be quite possible. Amazing as it may seem, they based their conclusion on the facts established by the astronomers, representatives of a science very far removed from chemistry. But it was the astronomers that first proved new elements to be discoverable not only in the laboratory and not only by analysing terrestrial minerals.

In studying the total solar eclipse of 1868 the English astronomer Lockyer and the French astronomer Janssen passed the blinding light of the solar corona through a spectroscope prism. In the dense palisade of spectral lines they observed some that could belong to none of the elements known on Earth. Thus was discovered helium, the name coming from the Greek for "solar". Only twenty-seven years later did the English scientists William Ramsay and William Crookes discover helium on Earth. We shall dwell upon this a bit later.

The discovery proved contagious. Astronomers began to point their telescopes at distant stars and nebulae. Their findings were scrupulously published in astronomical yearbooks, and some even found their way into chemical journals. These were findings which treated of alleged discoveries of new elements in the boundless space of the universe. The elements were given pompous names such as coronium and nebulium, archonium and protofluorine. Apart from their names, chemists knew nothing about them. But bearing in mind the happy end of the helium story, they hurried to place these celestial strangers in the Periodic System. They put them before hydrogen

or in the space between hydrogen and helium. And they cherished the hope that at some time in the future new Ramsays and Crookeses would prove coronium and its no less mysterious fellows to exist on Earth.

But as soon as the physicists tackled the Periodic System these hopes were shattered. Atomic weights were found to be an unreliable footing for the Periodic Law. They were replaced in this function by the nuclear charge of the atom which is numerically equal to the atomic number of the element in the Periodic System.

In passing from element to element in the Periodic System this charge increases by one unit each time.

Time passed and more precise astronomic instruments scattered the myth of the mysterious nebuliums. They turned out to be atoms of long known elements, atoms that had lost some of their electrons and therefore gave unfamiliar spectra. The "business cards" of the celestial strangers proved false.

A Two-Faced Element

You may have heard a dialogue something like this during a chemistry lesson at school.

Teacher:

"What group of the Periodic System is hydrogen in?"

Pupil:

"In the first. This is so because like the other elements of the first group, the alkali metals lithium, sodium, potassium, rubidium, cesium, and

francium, the hydrogen atom has only one elec-
tron in its only electron shell. Like them, hydro-
gen displays a positive valence of 1 in chemical
compounds. Finally, hydrogen is capable of dis-
placing some metals from their salts."

Is this true? Yes, but only half true... .

Chemistry is a precise science and chemists do
not like half-truths. Hydrogen is a convincing
example.

What is there in common between hydrogen
and the alkali metals? Only their positive valence
of 1.   Only the similar arrangement of their
outer electron shells. As to the rest, they bear no
resemblance at all. Hydrogen is a gas and a non-
metal. Hydrogen forms a diatomic molecule. The
rest of the elements of the first group are classical
metals, and rather active ones as far as chemical
reactions go. Brandishing its only electron, hy-
drogen tries to don the toga of an alkali metal. But
actually it is a wolf in sheep's clothing.

The Big House is so arranged that kindred ele-
ments live one above the other off each stair well,
comprising the groups and subgroups of the Pe-
riodic System. This is the law for the inhabitants
of the Big House. By falling into Group I, hydro-
gen inevitably breaks this law.

But where is poor hydrogen to go? There are
several groups in the Periodic System, several
stair wells in the Big House. Helium, hydrogen's
first-floor neighbour, found its flat only in what is
now called the zero group. The places in the rest
of the groups are vacant. See how many possibili-
ties there are for replanning the first floor to find
hydrogen a real "place under the sun"!

Couldn't it be lodged in the second group,

with the alkaline-earth metals headed by beryllium? No, they feel absolutely no kinship towards hydrogen. The third, fourth, fifth and sixth groups also refuse to have anything to do with it. What about the seventh group? Wait! The halogens occupying this group, fluorine, chlorine, bromine, etc., are ready to extend a friendly hand to hydrogen.

"Are you a nonmetal?" fluorine asks hydrogen.

"Yes!"

"Are you a gas?"

"That's right."

"So are we," says fluorine, nodding at chlorine.

"My molecule consists of two atoms!" contributes hydrogen.

"Well, what do you know about that!" says fluorine in surprise. "Just like with us, halogens."

"And can you show negative valence, accept additional electrons? We are awfully fond of doing that!"

"Of course, I can. I form hydrogen compounds known as hydrides with the very alkali metals that dislike me so, and my valence in them is minus one."

"All right then, pitch right in with us and let's be friends!"

And hydrogen takes up its abode in the seventh group. But not for long. After getting to know its new relation a little better one of the halogens remarks disappointedly:

"See here, brother. You don's seem to have many electrons on your outer shell, do you? Only one, as a matter of fact... Like them blokes in group one. Hadn't you better get back to the alkali metals?"

See what difficult straits hydrogen is in: there are plenty of rooms but none it can occupy permanently, with full right.

But why? What is the reason for this surprising two-facedness of hydrogen? What makes hydrogen behave so eccentrically?

The specific properties of any chemical element become evident when it combines with other elements. It then donates or accepts electrons which either leave its outer shell or enter it. When an element loses all the electrons of its outer shell, the rest of its shells usually remain unchanged. Such is the case with all the elements except hydrogen. When hydrogen parts with its only electron, all that remains is its "naked" atomic nucleus. What is left is a proton, this being, as a matter of fact, all the hydrogen atom nucleus consists of (actually it does not always consist of only a proton, but we shall come to this important point later). Hence the chemistry of hydrogen is the only chemistry of its kind, as it were, the chemistry of an elementary particle, the proton. Thus, reactions involving hydrogen proceed under the influence of protons.

And that is why hydrogen behaves so inconsistently.

The First
and the Most Surprising

Hydrogen was discovered by the famous English physicist the Hon. Henry Cavendish. He was the richest of the learned and the most learned of the rich, as one of his contemporaries put it. We might add that he was the most punctilious of

scientists. It is said that whenever Cavendish borrowed a book from his own library he always signed his name on the book card. The most sedate of scientists, devoted entirely to scientific research, always engrossed in his science, he got the reputation of an eccentric recluse. But it was just these qualities that enabled him to discover the new gas hydrogen. And, believe us, it was no easy task! (However, there is some historical evidence indicating that the evolution of hydrogen was observed by Robert Boyle and Mikhail Vasilyevich Lomonosov prior to this event...)

Cavendish made his discovery in 1766, and by 1783 in France the first hydrogen-filled balloon was launched.

Hydrogen was a most valuable find to chemists, too. It helped in better understanding of the nature of acids and bases, these most important classes of chemical compounds. It became an indispensable laboratory reagent for precipitating metals from solutions of salts, and for reducing metallic oxides. And paradoxical though it seems, had hydrogen not been discovered in 1766, but, say, half a century later (such a thing could really have happened) the progress of chemistry, both in theory and practice, would have been retarded for a long time.

When the chemists had come to know hydrogen well enough, and practical workers had begun to utilize it for the production of important substances, this gas drew the attention of physicists. And they found out a great deal of information which enriched science many times over.

Do you need more evidence? For one thing, hydrogen solidifies at a lower temperature than

any other liquid or gas (except helium), at minus
259.1° Celsius. Secondly, the hydrogen atom
enabled the Danish physicist Niels Bohr to work
out a theory of the arrangement of electrons around
the atomic nucleus, without which the phys-
ical sense of the Periodic Law could not have
been understood. And these facts laid the founda-
tion for other very important discoveries.

Then the physicists passed the baton on to
their close relatives by profession, to the astro-
physicists who studied the composition and struc-
ture of the stars. The astrophysicists stated that
hydrogen is element Number One in the universe.
It is the main component of the Sun, the stars,
nebulae, and the basic "filler" of interstellar space.
There is more hydrogen in outer space than all the
other chemical elements taken together. Nothing
like on Earth, where its content amounts to less
than one per cent.

Scientists consider hydrogen the starting point
of the long train of "stellar" transformations of
atomic nuclei, the train which resulted in the
formation of all the chemical elements, of all
atoms without exception. Our Sun and all the
stars are luminous because of the thermonuclear
reactions occurring in them, involving the trans-
formation of hydrogen into helium with the re-
lease of enormous amounts of energy. A prominent
chemist on Earth, hydrogen is an outstanding
chemist in outer space.

Another remarkable property of hydrogen is
that its atom emits radiation having a wavelength
of 21 centimetres. This is called a universal con-
stant because it is the same throughout the uni-
verse. And scientists have taken up the problem

of organizing radio communications with other inhabited worlds on the "hydrogen" wave. If these worlds are inhabited by intelligent creatures, they should have an idea of what 21 centimetres is.

How Many Hydrogens Are There on Earth?

It was thought previously that there was only one hydrogen on Earth, that with an atomic weight of one. However, in 1932 scientists discovered a second hydrogen, twice as heavy. This was the hydrogen isotope having the atomic weight two. Isotopes are varieties of atoms with the same charge but different atomic weights. In other words, the nuclei of isotopic atoms contain an equal number of protons but different numbers of neutrons. Isotopes are known for all the chemical elements: some of them exist in nature, others have been obtained artificially by means of nuclear reactions.

The hydrogen isotope whose nucleus is a bare proton is called protium and its symbol is ^1H. This is the only atomic nucleus which contains no neutrons at all. (Another unique property of hydrogen!)

Add a neutron to this single proton and the result is the nucleus of the heavy hydrogen isotope called deuterium (^2H or ^2D). Protium is far more abundant in nature than deuterium, constituting over 99 per cent of all the hydrogen.

But there is a third variety of hydrogen, with two neutrons in its nucleus; this is tritium (^3H or ^3T). It forms continuously in the atmosphere

under the action of cosmic rays. It forms only to disappear again rather quickly. It is radioactive and decays into a helium isotope (helium-3). Tritium is a very rare element: its content in all the atmosphere of the Earth is only 6 grams. There is only one atom of tritium in every 10 cubic centimetres of air. Just recently still heavier isotopes of hydrogen ^4H and ^5H have been obtained artificially, but they are very unstable.

The mere fact of its having isotopes does not distinguish hydrogen among the chemical elements. What does distinguish it is that hydrogen isotopes differ noticeably in properties, primarily in physical properties. Isotopes of the other elements are almost indiscriminable.

Each variety of hydrogen has its own personality and behaves differently in chemical reactions. For example, protium is more active than deuterium. By studying the behaviour of hydrogen isotopes, scientists started an entirely new branch of science, known as isotope chemistry. The chemistry we know has to do with elements as a whole, with all the isotopes of each taken together. But isotope chemistry deals with separate isotopes. It enables investigators to look into the most intricate details of various chemical processes.

More Facts about the Architecture of the Periodic System

What would you say about a contractor who erected a building and after putting the roof on, asked the designers to calculate whether everything had been done right?

It sounds like an episode from "Through the Looking Glass", doesn't it?

Nevertheless that was just what happened to the Periodic System of Elements. The Big House was first built and the elements lodged, each in a flat of its own. Chemists made Mendeleyev's Table their tool. But why the properties of the elements repeat themselves periodically they could not tell for a long time.

The explanation was supplied by the physicists. They calculated the structure of the Periodic System building for strength, and their findings were remarkable. They found it to have been built absolutely right in accordance with all the laws of "chemical mechanics". And so we cannot but admire Mendeleyev's truly great intuition and profound knowledge of chemistry.

Physicists began by studying the structure of the atom in detail.

The heart of the atom is its nucleus. Around it revolve electrons, the number of which equals the number of positive charges of the nucleus. Hydrogen has one electron, potassium—twelve, uranium—ninety two... How do they revolve? Chaotically, like a swarm of moths fluttering around an electric light bulb, or in some definite order?

To answer this question the scientists had to resort to new physical theories and to develop new mathematical methods. And here is what they found: electrons revolve around the nucleus on definite orbits, like the planets around the Sun.

"How many electrons are there on each orbit? Any number at all or a limited number?" asked the chemists.

"A strictly limited number!" replied the phy-

sicists. "All electron shells possess a finite capacity."

Physicists have their own symbols for electron shells. They use letters K, L, M, N, O, P, and Q. These letters denote the shells in order of their remoteness from the nucleus.

In collaboration with mathematicians, the physicists drew up a detailed scheme indicating how many electrons each orbit contains.

The K-shell can have 2 electrons and no more. The first of them appears in the hydrogen atom, and the second in the helium atom. That is why the first period of the Mendeleyev Table consists of only two elements.

The L-shell can accommodate four times more, namely, 8 electrons. We find the first electron belonging to this shell in the lithium atom and the last in the neon atom. The elements from lithium to neon form the second period of Mendeleyev's System.

And how many electrons are there in the subsequent shells? The M-shell accommodates 18, the N-shell 32, the O-shell 50, the P-shell 72, etc. Though, the elements having O- and P-shells completed are not known as yet.

If the outermost electron shells of two elements are identically arranged, the properties of the elements are similar. For instance, lithium and sodium each contains a single electron in its outer shell. And this accounts for their being in the same group of the Periodic System, namely, in the first group. Note that the group number equals the number of valence electrons in the atoms of the elements in the group.

And now the conclusion: outer electron shells of

identical structure recur periodically. And that is why the properties of the elements also recur periodically.

But they do not just recur. The hotel rooms are not all alike. There are deluxe apartments, second class apartments, and finally there exist modest rooms furnished with only the most essential items. As to the "flats" of the Big House, they are all alike, since all the elements have equal rights to their own places in the Periodic System. Similar elements occupy the "rooms" whose "interiors" are similar and have only slight differences. Their principal characteristics recur periodically. For instance, all the alkali metals have one electron in the outermost shell, all of them are positively univalent, all are very active as far as chemical reactions go. But their reactivity is not uniform, it increases from lithium to francium.

The Triumph of Logic

There is logic in everything. Even the most unaccountable phenomenon has its logic. It may not be perceptible at first, and then inconsistencies appear. Inconsistencies are very unpleasant things for any theory or hypothesis. They either show that the theory is erroneous or make one think hard. And it often so happens that this hard thinking helps to penetrate deeper into the incomprehensible.

Here is an example of such an inconsistency. Equality reigns only in the first two periods of the Periodic Table. There are exactly as many

elements in each of these periods as the corres-
ponding outer shell can hold electrons. Thus, in
the atoms of the elements of the first period, hyd-
rogen and helium, the K-shell is filled. It cannot
contain more than two electrons, and therefore
there are only two elements in the first period.
An eight-electron (octet) L-shell fills up com-
pletely through the atoms of the elements of the
second period, from lithium to neon, and that is
why the second period contains eight elements.

After this things get more involved.

Count up the number of elements in the subse-
quent periods. There are 8 in the third, 18 in the
fourth, 18 in the fifth, 32 in the sixth, and there
should also be 32 in the seventh (which is incom-
plete as yet). But what about the corresponding
shells? Here the figures are different: 18, 32, 50,
and 72...

Now, were we not too hasty in concluding that
in undertaking to explain the structure of the
Periodic Table the physicists found no defects
in its construction? It would be a good thing if a
definite electron shell were filled regularly in the
inhabitants of each floor of the Big House, and if
each floor started with an alkali metal and ended
in an inert gas. The capacity of each period would
then be equal to the capacity of the electron
shell...

Alas, we are obliged to speak of this in the
subjunctive mood: if this, if that... . Actually
the balance does not tally. The third period of
Mendeleyev's Table accommodates less inhabi-
tants than there are electrons in the third shell,
the M-shell. And so on.

A sad incongruity... . But this incongruity

holds the clue to the essence of the Periodic System.

Now look: though the third period ends in argon, the third M-shell of the latter's atom is not completed. The completed shell should contain 18 electrons, but so far there are only 8 in it. Argon is followed by potassium which belongs to the fourth period, being the first inhabitant of the fourth floor. But instead of placing its latest electron in its third shell, the potassium atom prefers having it in its fourth, N-shell. This is no accident, but again a strict regularity established by the physicists. It is simply that no atom can have more than 8 electrons in its outside shell. The combination of 8 outer electrons is a very stable arrangement.

In calcium, potassium's next-door neighbour, the newest electron also finds it "more advantageous" to occupy the outermost shell, because then the energy supply of the calcium atom is smaller than with any other electron distribution. But in scandium, which follows calcium, the tendency to continue filling the outer shell of the atom vanishes. Its new electron "dives" into the incomplete second-last M-shell. And since this shell has ten vacancies (we already know that the maximum capacity of the M-shell is 18 electrons), the atoms of the next ten elements, from scandium to zinc, gradually fill up their M-shells. Finally, in zinc, all the electrons of the M-shell are in place. After this the N-shell again begins to accept electrons. As soon as it contains a total of 8 electrons we get the inert gas krypton. In rubidium the old story repeats itself: the fifth shell appears before the fourth is complete.

Such a step-by-step filling of electron shells is a "standard of behaviour" for the inhabitants of the Periodic Table from the fourth period on. This is the basic strict regulation of the Big House of Chemical Elements.

For this reason main and secondary subgroups are distinguished in it. The elements in which the outermost electron shells are being filled comprise the main subgroups. Those in which inner shells are being completed make up the secondary subgroups.

But the fourth, N-shell, does not fill up in one step. Its completion is drawn out into three whole storeys of the Big House. The first electron of this shell appears in potassium which occupies flat 19. But the 32nd electron appears in it only in ytterbium, a representative of the sixth period. Its atomic number is 70.

So you see, the incongruity has a silver lining. In trying to account for it we and the physicists got a better insight into the structure of the Periodic System.

How Chemists Came Across
the Unexpected

You have probably read the splendid science-fiction novel by Herbert Wells called "The War of the Worlds" about the invasion of Earth by emissaries from Mars.

You will recall that after the last Martian was killed and life on the Earth began to settle down again, the scientists, having recovered from the shock they had undergone, hurried to study the

little that was left of the unexpected visitors from the neighbouring planet. Among other things, they were interested in the mysterious black dust which the Martians used to destroy life on Earth.

After several unsuccessful experiments which ended in terrible explosions, they found the ill-starred substance to be a compound of the inert gas argon with some element not yet known on Earth.

However, at the time the great writer of science fiction was putting the finishing touches to his book, chemists were certain that argon could not combine with anything under any conditions. A large number of practical experiments had brought them to this conclusion.

Argon was called an inert gas. "Inert" comes from the Greek for "inactive". Argon is a member of a whole group of chemical sloths, which also includes helium, neon, krypton, xenon and radon.

In the Periodic System they were placed in what is known as the zero group, because the valence of these elements was considered to be equal to zero. The atoms of the inert gases seemed to be unable either to donate or to accept electrons.

What didn't chemists do to make them react! They heated them to temperatures at which the most refractory metals would turn into boiling hot liquids; they cooled them until they became solids; they passed enormous electric discharges through them, and they subjected them to attack by the most furious chemical agents. But all in vain!

Where other elements would long have surren-

dered and entered into chemical union, the inert
gases remained impassive. "You are wasting your
time," they seemed to say to the investigators.
"We have no desire to enter into any reaction.
We're above all that!" And their arrogance
earned them another title, that of "noble" gases.
But then this title has an ironic tinge to it.

Ramsay and Crookes who discovered helium in
terrestrial minerals, had reason to be proud: they
had presented the world with a new chemical ele-
ment which really existed. A chemical one! The
scientists would have paid dearly to make helium
behave like the other inhabitants of the Periodic
Table, namely, to combine with hydrogen, oxy-
gen, or sulphur, so that esteemed professors could
tell from their rostra about the oxides and salts
of helium.

But helium, the first in the group of inert
gases, failed them. At the end of the last century
Ramsay and Travers discovered neon and argon,
krypton and xenon. Later radon closed the last
of chemical "sloths". They were all elements with
atomic weights of their own. But honestly, one
could hardly bring oneself to prefix the word
"chemical", say, to the words "element argon".

And so scientists moved this arrogant family of
noble gases to the edge of the Mendeleyev Table,
adding a new section to it, which they called the
zero group. And they wrote in chemical textbooks
that there existed chemical elements which were
unable to form compounds under any conditions.

It was quite a blow to the scientists: quite
against their will, six elements fell out of the
sphere of activity of chemical science.

A Solution Which Brought
no Consolation

Even Mendeleyev was perplexed at first. He even ventured to suggest the "saving" idea that argon was no new element at all. It was, he said, a sort of compound of nitrogen with three atoms in its molecule: N_3, like the ozone molecule O_3 which exists alongside the oxygen molecule O_2.

But finally the facts convinced Mendeleyev of his error and he acknowledged Ramsay to be right. And now all the textbooks in the world name the English scientist as the discoverer of the group of noble gases, and nobody tries to challenge this fact.

...For twenty years N. Morozov, a member of the "Narodnaya Volya" group languished in the dungeons of the Schlusselburg Fort. Afterwards, under Soviet power, he became a world renowned scientist. The impenetrable walls of his stone prison were unable to break his will or to keep him away from scientific work. His persistent studies materialized in a number of daring and original ideas and hypotheses. In prison Morozov finished a study devoted to the Periodic System. In it he predicted the existence of elements which should be chemically inactive.

By the time Morozov was released the inert gases had already been discovered and had found their place in the table of elements.

It is said that Morozov visited Mendeleyev not long before the latter's death, and that the two great compatriots had a long talk about the Periodic Law. Unfortunately, the contents of this talk are unknown.

When the historians of chemistry studied the contents of chemical journals closely, they discovered a lot of interesting things. It turned out that many investigators of the past puzzled over the problem as to whether there were any still unknown elements between the alkali metals and halogens. And they concluded that there were. Some of them even ventured to predict the atomic weights of those elements. Others went even further in their assumptions, stating that their chemical activity would be the lowest. But nobody was sure about their state of aggregation: would they be solids, liquids or gases? Among those who predicted the existence of elements that followed halogens in the Periodic System were Paul Lecoq de Boisbaudran (the discoverer of "ekaaluminium"), and the prominent Danish thermochemist of the end of the last century, Julius Thomson. As you can see, Morozov was not the only forecaster. But as paradoxical as it may seem, all those forecasts had no impact at all on the course of history of helium and its analogues.

Mendeleyev died not long before the mystery of the inertness of the noble gases was solved. The secret was as follows.

The physicists who had so often, and still do, come to the aid of the chemists, established that an outer shell containing 8 electrons is very stable. It is a sort of ideal of stability of an electron shell. And hence, there is no reason for it to donate or accept electrons.

Thus the reason for the "nobility" of the inert gases is the 8 electrons in their outermost shell (or 2 in the case of the helium atom). The two-

electron shell of helium is no less stable than the octet ones of the other chemical "sloths".

And another thing became clear to the chemists: the addition of the zero group to the Periodic Table was not just a forced measure; without it the Periodic System would have looked like an unfinished edifice, because each of its periods ends in an inert gas after which the next electron shell begins to fill up and thus the next storey of the Big House begins to form.

As you see, it all turned out quite simple. Despite their aristocratic title, the noble gases exhibited some ability to do practical work: helium found usage for filling balloons and dirigibles and came to the aid of divers against caisson disease. Argon and neon lights decorate city streets at night.

But maybe "nevertheless it does move!"? Maybe there is something physicists have not thought out or calculated yet, or perhaps chemists have not yet exhausted all the means of making substances react with one another?

The Search for a "Crazy" Idea, or How the Inert Gases Stopped Being Inert

"Two parallel straight lines never intersect," asserted geometry through the lips of Euclid, the greatest mathematician of antiquity.

"Not so, they must intersect!" declared the Russian scientist Nikolai Lobachevsky in the middle of the last century.

And thus was born a new geometry, known as non-Euclidean geometry.

"Moonshine and gibberish!" was what many leading scientists said about it at first. But were it not for non-Euclidean geometry we would have neither the theory of relativity nor the daring ideas of the laws governing the structure of the universe.

Many of you have no doubt read A. Tolstoy's "Engineer Garin's Hyperboloid".

"Excellent science fiction," was the verdict of literary critics the world over.

"Fiction that can never become reality!" echoed the scientists.

Tolstoy died only fifteen years before the first ruby crystal emitted a light ray of unheard of brightness and power, and the word "laser" became known to by no means only specialists.

...Enthusiast-chemists continued to believe stubbornly in the possibility of conquering the unheard of obstinacy of the inert gases. If we took the trouble to thumb through the yellowish pages of scientific journals of the twenties, thirties and forties, we should come across quite a few curious articles and notes which show that chemists never relinquished the hope of drawing the inert gases into the sphere of their activities.

Unusual formulas stare out at us from these pages. They tell of strange substances, compounds of helium with mercury, palladium, platinum and other metals. Only one thing is wrong: these are not the chemical compounds we should like to obtain. In them helium's two-electron shell remains unchanged, and the compounds them-

selves exist only at a very low temperature, in the kingdom of absolute zero...

If we went on turning the pages of chemical journals we should come across another bit of news: the Soviet chemist Nikitin prepared much less fantastic compounds of xenon and radon with water, phenol and some other organic liquids: $Xe \cdot 6H_2O$, and $Rn \cdot 6H_2O$. They are stable under ordinary conditions, can be readily obtained but...

But as before, chemical bonding has nothing to do with these compounds. The xenon and radon atoms abide piously by the perfection of their outermost shell: 8 electrons there were and 8 electrons remained.

The twentieth century, the stormiest and most unforgettable of all the centuries of human history, will come to a close. And scientists will sum up the achievements of scientific thought during the past hundred years. The endless list of outstanding discoveries will include in a prominent place "the production of chemical compounds of the inert gases". And some enthusiastic commentator will add: one of most sensational discoveries. Sensational? Hardly! Rather a romantic story. Or even a story of how simple sometimes can be the solution of a problem which for dozens of years tormented the minds of numerous scientists with its insolvability...

In our days chemistry resembles a mighty tree with an immense ever-spreading crown. It is no longer possible for any one person to study even a whole branch in full. An investigator mostly has to spend years to become acquainted in detail with a small twig, a bud, or a hardly visible

shoot. Knowledge of the branch as a whole adds up from thousands of such investigations.

The "twig" studied by the Canadian chemist Neil Bartlett was a compound called platinum hexafluoride in the language of chemists, and having the formula PtF_6. It was not by accident that he devoted so much time and effort to this substance. Compounds of fluorine with the heavy metals are very interesting substances, of great importance to science and practice. One of their uses is in the separation of the uranium isotopes uranium-235 and uranium-238 for nuclear engineering. The separation of one isotope from another is a very complicated process, but it had been accomplished with the aid of uranium hexafluoride UF_6. Besides, heavy metal fluorides are very active chemical substances.

Bartlett reacted PtF_6 with oxygen and obtained a very curious compound. The oxygen is contained in it as the positively charged molecule O_2. A molecule which has lost one electron. Now what is so strange about that? The strange thing is that it is very difficult indeed to tear an electron away from the oxygen molecule, as this requires a great deal of energy. Platinum hexafluoride was found to be capable of removing an electron from the oxygen molecule.

Removal of an electron from the outer shells of inert gas atoms also requires a great deal of energy. There is a regularity here according to which the heavier the inert gas the smaller the amount of energy required. And it was found easier to make a xenon atom part with one of its electrons than to tear one away from the oxygen molecule.

And so... This is where the most interesting begins! Bartlett decided to make platinum hexafluoride steal an electron from the xenon atom. And he was successful—the world's first chemical compound of an inert gas was born in 1962. This is what it looks like: $XePtF_6$. And it is fairly stable. Nothing like the exotic compounds of helium with platinum or mercury.

This tiny grain immediately produced a sprout which began to grow like bamboo. Only yesterday many chemists were sceptical. The myth of the infallibility of the outer electron shell of inert gases had long been a serious obstacle for the scientists in their research in this sphere.

Today more than a hundred and fifty compounds of xenon, krypton and radon are known. Among them are fluorides, chlorides, oxides and all kinds of salts. Even the compound of xenon and nitrogen was obtained. More than a third of these compounds were obtained as a result of the efforts of Soviet chemists. Essentially, a new branch of inorganic chemistry was born, and it will surely have a great future. Many of the xenon and krypton compounds have already found practical applications.

Theorists have shattered former delusions by explaining the fine mechanism of the reactions of heavy noble gases with different substances. The peculiar thing is that no new ideas were required to do this, all could fit into the old theories of chemical interaction.

As often happens in the history of science, some of the old works of the twenties and thirties have been recalled, whose authors predicted, and not without reason, that noble gases (xenon, at least)

could be involved into chemical reactions. One
of those forecasters was the prominent American
scientist Lainus Pauling.

Alas, the grains of their thought fell onto bar-
ren soil... . Not even any special scientific daring
was needed, but only a slightly different approach
to the matter, unbiased and more cautious.

Neil Bartlett was the one to do this.

Zero or Eighth?

When reports about the synthesis of new com-
pounds of inert gases started appearing on the
pages of chemical journals one after another,
scientists were perplexed.

"A nightmare of xenon fluorides hangs over the
Mendeleyev Table!" exclaimed one of them, who,
by the way, had something to do with this night-
mare. It was high time to assess the situation.

"Since inert gases are no longer inert, what is
the point of keeping a special zero group for
them in the Periodic System?"

"Excuse me, but the chemistry of inert gases is
actually the chemistry of xenon only. Is there
any reason for building the whole Big House anew
on such a shaky foundation?"

Such dialogues were quite common in the mid
sixties.

The victory was finally scored by those who ad-
vocated the rearrangement of the Big House. The
zero group was abolished.

Now all the noble gases were included into the
main subgroup of the eighth group. And this
seemed to make even more sense, since the eighth

group had differed from the others for a long time by having only a secondary subgroup. It was considered a fault in the structure of Mendeleyev's Table.

The eighth group now became like "everybody else". The fact that the valence of eight is not typical of xenon is not really important. Every rule has some "annoying" exceptions. (For one's information: the number of the group is equal to the highest valency of elements that constitute the group.)

Now it's time to make an excursion into history again, into the "Atlas" of periodic systems mentioned at the beginning of the book, to be more exact. One can find in this atlas a number of tables presenting the inert gases as the members of the main subgroup of the eighth group. At that time such ideas did not find support among the scientists. Moreover, they were treated with hostility.

How changeable our world is... . Today they are part and parcel of the chemical theory and are quoted in every school textbook.

The popular wisdom says: haste makes waste. Weren't we too categorical in "expelling" the noble gases from their zero group?

Of about a dozen and a half presently known compounds of the inert gases, more than 80% are those of xenon. Krypton has much less and all of them are very unstable. Quite a few are known for radon. But this is by no means radon's "fault", but is more likely to be its "problem". Radon is very rare, and furthermore, it is highly radioactive. Although theoretically it is meant to be the most chemically active gas in the group

since the radius of its atom is the biggest, working with it is mere torture. Argon is of more interest to the theorists than to the practical researchers. And the prospects of the theorists are not optimistic. Quite a small number of argon compounds are likely to be obtained, and very unstable ones at that.

In recent years, some reports have come from researchers indicating that helium and neon have revealed their "chemical character" at last. Don't jump to conclusions: none of the compounds of those elements have scientists held in their hands. They just stated that under specific, extreme conditions, as it were, helium and neon reacted with some other elements, e.g. hydrogen. And they are hardly capable of anything else. Both abide in a kind of "chemical nirvana". Atoms of these elements possess one important peculiarity which distinguishes them from other noble gases, namely, the outer shells of helium and neon, K- and L-shells respectively, are unable to accept even a single electron. They are completely packed. Atoms of argon and further down of it have many vacancies on their outer shells, which accounts for their chemical activity.

Now let's consider this. Wouldn't there be more logic in leaving helium and neon in the zero group of the Periodic System, and transferring all the rest of the noble gases to the eighth group? Their chemistry is the objective reality, so to say. And this would not cause disharmony, but truly depict the real state of affairs. So, it should rather be "zero and eighth" instead of "zero or eighth". This would make a better title for this section.

The "Omnivorous"

That is what the prominent Soviet scientist A. E. Fersman called it. For the world knows no element more ferocious, nature has produced no substance chemically more active than the main character of this story. You will never find it in nature in the native state, but only in the form of compounds. And that is why it could not be obtained in the free state for so long.

Its English name is fluorine from the Latin *fluo* meaning "flow". But its Russian name *ftor* is derived from the Greek for "destructive". This is a second, no less forceful term characterizing the main feature of this representative of the main subgroup of the seventh group of the Mendeleyev Table.

It has been said that "the path to free fluorine led through human tragedy...". These are not just fine words. In the hunt for new simple substances researchers overcame a multitude of difficulties, knew many disappointments, became the victims of curious errors. The pursuit of traces of unknown elements has cost scientists a great deal of effort.

Fluorine, the element fluorine in its free form, has cost lives.

Long is the doleful list of casualties incurred in attempts to obtain free fluorine. Knox, a member of the Irish Academy of Sciences, the French chemist Niklesse, the Belgian researcher Layette, all fell victim to the "omnivorous". And many more scientists suffered severe injuries. Among them were the prominent French chemists Gay-Lussac and Thénard and the English chemist Humphry

Davy... There were no doubt also unknown investigators on whom fluorine took revenge for
insolent attempts to isolate it from its compounds.

The French scientist Henri Moissan was the
first to find out what the element fluorine was
like in the free state. And it must be owned that
many chemists were afraid to work with this
element.

Twentieth-century scientists have found methods of bridling the fury of fluorine, have hunted
out ways of making it serve mankind. The chemistry of this element has now become an independent field of inorganic chemistry.

The terrible "genius of the bottle" has been
subdued. And the efforts of the numerous fighters
for free fluorine have been well repaid.

Many types of modern refrigerators use freon as
their cooling agent. Chemists have a more complex name for this substance: difluorodichloromethane. Fluorine is an indispensible constituent of this compound.

Itself "destructive", fluorine can form compounds which practically nothing can destroy.
They will not burn nor rot and are insoluble in alkalies and acids; free fluorine does not attack them,
and they are almost wholly indifferent to arctic
cold and to sudden sharp temperature changes.
Some of them are liquids, others solids. Their
common name is fluorocarbons, compounds which
nature herself was unable to invent. They were produced by man. The union of carbon and fluorine
was found very useful. Fluorocarbons are employed as cooling fluids in motors, for impregnating special fabrics, as very long-lived lubricants,

insulators and structural materials for various kinds of equipment in the chemical industry.

When the scientists were searching for ways of harnessing nuclear energy, it became necessary to separate the uranium isotopes, uranium-235 and uranium-238. And as has already been said above, investigators succeeded in accomplishing this very complicated task with the aid of a very interesting compound called uranium hexafluoride.

It was fluorine which helped chemists to prove that the inert gases were not at all chemical "sloths" as had been thought for decades. The first compound of the inert gas xenon brought to life was its compound with fluorine.

Such is fluorine's work record.

Hennig Brand's "Philosopher's Stone"

There once lived in the Middle Ages in the German town of Hamburg a merchant by the name of Hennig Brand. We do not know how inventive he was in his trade operations, but can assert confidently that he had some idea of chemistry.

But even he could not resist the temptation to try and become a rich man all at once. This seemed easy: all he had to do was to find the notorious "philosopher's stone" which, the alchemists claimed, could change even a cobblestone to gold.

...Years passed. Brand's name was mentioned less and less frequently in conversations between merchants, and when it was, heads were wagged

sadly. Meanwhile he dissolved, mixed, sieved, and calcined various minerals and concoctions, and his hands were covered with unhealing acid, alkali and thermal burns.

One fine evening the former merchant had a streak of luck. A substance, white as snow, settled at the bottom of his retort. It burned quickly, forming thick asphyxiating fumes. And the strangest thing was that it glowed in the dark. The cold light it gave off was so bright that Brand could read his ancient alchemical treatises by it (for him these treatises had now taken the place of business letters and receipts).

...Thus was discovered by mere chance the chemical element phosphorus. Its name is from the Greek for "light-bearing" or "light-bearer".

Phosphorus is the main component of many luminous compounds. Do you remember the famous Hound of the Baskervilles that Sherlock Holmes hunted for so long? Its mouth was smeared with phosphorus. Though, to be honest, it is hard to believe.

No other representative of the Periodic Table possesses such a unique property.

The valuable and important properties of phosphorus are legion.

A certain scientist once said: "Without phosphorus there is no thought." This is true, because cerebral tissues contain many complex phosphorus compounds.

But neither is there life without phosphorus. Without it respiratory processes would be impossible and muscles could store no energy. Finally, phosphorus is one of the most important "bricks" of any living organism. As a matter of fact, the

principal component of bone tissue is calcium phosphate.

Now is this not just as good as the "philosopher's stone", seeing that it animates the inanimate?

And lastly, why does phosphorus glow?

There is always a cloud of phosphorus vapours over white phosphorus. These vapours become oxidized, evolving a large amount of energy. The latter excites the phosphorus atoms and this causes the glow.

The Odour of Freshness, or the Transition of Quantity into Quality Exemplified

Your breath comes easier after a thunderstorm. The air is clear and charged with freshness.

This is not just poetical image. Thunderclaps result in the formation of ozone gas in the atmosphere, and it is this gas that makes the air seem cleaner.

Ozone is essentially oxygen. The difference is that the oxygen molecule contains two atoms of oxygen while the ozone molecule contains three. O_2 and O_3—one atom more or one atom less of oxygen, should that make a big difference?

It does make a very big difference: ozone and oxygen are entirely different substances.

Without oxygen there is no life. On the other hand, ozone in large concentrations kills all living things. It is a most powerful oxidizing agent, second only to fluorine. On combining with organic substances ozone immediately destroys them.

When attacked by ozone all the metals, except for gold and platinum, change rapidly into their oxides.

It is two-faced! A murderer of all living things, ozone also promotes life on the Earth in many ways.

This paradox is easy to explain. Solar radiation is not uniform. It contains what are known as ultraviolet rays. If all these reached the Earth's surface, life on Earth would be impossible because these rays carry an immense amount of energy and are fatal to living organisms.

Fortunately, only a very small fraction of the Sun's ultraviolet rays reach the Earth's surface. Most of them lose their force in the atmosphere at an altitude of 20-30 kilometres. At this level of the air blanket enveloping our planet, there is a great deal of ozone. And it absorbs the ultraviolet rays.

By the way, one of the present-day theories of the origin of life on Earth relates the appearance of the first organisms to the time of formation of the ozone layer in the atmosphere.

But people need ozone on the Earth too, and in large quantities.

They, and primarily chemists, need thousands and thousands of tons of ozone very badly.

The chemical industry made use of the astounding oxidizing power of ozone.

Oil industry workers are also grateful to it. The petroleum of many oil fields contains sulphur. Sour oils, as they are called, cause a great deal of trouble, for one thing, by rapidly corroding equipment, for instance, boiler stokers at power stations. With ozone such oils could easily be freed

from sulphur, and the sulphur removed could be utilized to double or even treble the present production of sulphuric acid.

We drink chlorinated water. It is harmless, but its taste is inferior to that of spring water. Drinking water treated with ozone is absolutely free from pathogenic bacteria and has no unpleasant taste.

Ozone can renew old automobile tyres and bleach fabrics, cellulose, and yarn. There are many other things it can do. And that is why scientists and engineers are working on the design of high-capacity industrial ozonizers.

That is what ozone is! Philosophy has long ago formulated the dialectical principle of the transition of quantity into quality. The example of oxygen and ozone is one of the most vivid manifestations of dialectics in chemistry.

So Simple and Yet So Wonderful

Before the last war there was a comedy on at the movies. In it a blithe water carrier sings as he ·whips up his lazy horses:

"For water's needed everywhere:
Without't you're neither here nor there..."

The song was a great success and has now even become proverbial.

But this simple ditty holds profound implications.

For water, H_2O, really is substance No. 1 in life. One atom of oxygen plus two atoms of hydrogen. Probably one of the first chemical formulas you ever learn. Now try to imagine what would

become of our planet if the water suddenly disappeared from it.

...Dismal yawning "cavities" of sea and ocean hollows covered with a thick layer of the salt once dissolved in the water. Dry river channels, springs which will never bubble again. Rocks disintegrated to ash: water was one of their main constituents

Neither bush nor flower, not a living thing on the dead planet. And above it a cloudless sky of a horrifying unusual colour.

So simple a compound, and yet where there is no water, no life, intelligent or unintelligent, is possible.

Why? First of all because water is the most remarkable chemical compound in the world.

When Celsius invented his thermometer, he based his device on two values, or two constants: the boiling point and the freezing point of water. He took the former as equal to 100°, and the second to zero. Then he divided the interval between them into 100 divisions. Thus appeared the instrument indispensible in measuring temperatures.

But what would Celsius have thought if he knew that in theory water should not freeze at all at zero nor boil at 100 degrees?

Nowadays scientists have established that in this respect water is a great fraud. It is the most anomalous compound on the globe.

Here is what scientists claim: water should boil at a temperature 180° lower, i.e. at minus 80 degrees. At any rate, the regulations current in the Periodic System would have it boil at such an antarctic temperature,

The properties of the elements of any one sub-group of the Periodic System gradate quite regularly from the light elements to the heavy ones. Take, for instance, the boiling point. The properties of compounds do not vary just in any old way, but depend on the location of the elements, comprising the molecule, in the Mendeleyev Table. This refers, in particular, to hydrogen compounds, to hydrides of elements of the same group.

Water may be called oxygen hydride. Oxygen is a member of the sixth group, which also includes sulphur, selenium, tellurium, and polonium. The hydrides of all these elements have the same molecular pattern as the water molecule: H_2S, H_2Se, H_2Te, and H_2Po. The boiling points of these compounds are known to gradate regularly from sulphur to its heavier brothers. And unexpectedly we find that the boiling point of water falls out of this series, being much higher than it should be. Water refuses to acknowledge the rules of behaviour established for the Periodic Table, as it were, and postpones its transition to the vapour state for 180 degrees. This is only the first amazing anomaly of water.

Its second anomaly has to do with its freezing point. The laws of the Periodic System specify that water shall solidify at a temperature of 100 degrees below zero. Water violates this requirement harshly and turns to ice at zero.

This wilfulness of water suggests that its liquid and solid states are abnormal on Earth.

According to the rules water should exist here only in the vapour form. Now imagine a world where the properties of water obey the strict re-

gularities of the Periodic System. For fiction writers such a unique picture would be an excellent basis for thinking up amusing novels and stories. But for us, and for scientists, it is further evidence that the Periodic Table is a much more complex structure than it seems at first glance and that the characters of its inhabitants very greatly resemble those of live people in that they cannot be confined to definite bounds. Water is of a wilful character...

But why?

Because the molecules of water have a specific arrangement and for this reason possess a pronounced ability to attract one another. In vain would we look for single molecules in a glass of water. The molecules form groups which scientists call associations. And it would be more correct to write the formula of water as $(H_2O)_n$, the subscript n indicating the number of molecules in the association. These associative bonds between the water molecules are very difficult to break. And that is why water freezes and boils at much higher temperatures than would be expected.

"Ice, Not Yet Firm, on the Cold Little River

In 1913 news of a grave tragedy spread all over the world. The huge ocean liner "Titanic" ran into an iceberg and sank. Experts gave various reasons for the catastrophe. It was said that owing to a fog the captain could not see the immense floating mountain of ice in time, and the ship collided with it and so perished.

If we consider this tragic event from the standpoint of a chemist, we come to a quite unexpected conclusion: the "Titanic" fell victim to another anomaly of water.

Frightful mountains of ice—icebergs—float like cork on the surface of water, though these mountains weigh tens of thousands of tons.

This is possible only because ice is lighter than water.

Try melting any metal and throwing a piece of the solid metal into the melt: it will sink immediately. The density of any substance in the solid state is higher than in the liquid. Ice and water are an astonishing exception to this rule. But were it not for this exception, all the water bodies in the middle latitudes would soon freeze in winter right down to the bottom and all living things in them would perish.

Remember Nekrasov's poem:

"Ice, not yet firm, on the cold little river
Like melting sugar, in patches is spread."*

When the frosts come the ice hardens. A winter road can be laid on the river. But under the thick layer of ice water continues to flow as before. The river never freezes to the bottom.

Ice, the solid state of water, is a very peculiar substance. There are several kinds of ice. The one found in nature is that which melts at zero (of the Celsius scale). By using high pressures scientists have obtained six more varieties of ice in the laboratory. The most fantastic of them (ice VII), occurring at pressures over 21.700 at-

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* Translation by Juliet M. Soskice.

mospheres, might be called red-hot ice. It melts at 192 °C above zero when the pressure is 32000 atmospheres.

It would seem that there could hardly be anything more familiar than the picture of ice melting. But what surprising things it involves!

After melting any solid begins to expand. But the water that forms when ice melts behaves quite differently: it contracts and only afterwards, if the temperature continues to rise, does it begin to expand. This is again due to the ability of water molecules to attract one another. At four degrees above zero this ability becomes especially pronounced, and therefore at this temperature the density of water is at its highest; that is why our rivers, ponds and lakes do not freeze to the bottom even in the coldest weather. The coming of spring makes everyone glad; we have all taken pleasure in the golden days of autumn. The joyous spring thaw and the crimson attire of the woods...

Again the result of an anomalous property of water!

A great deal of heat is required to melt ice, much more than to melt the same quantity of any other substance.

When water freezes this heat is evolved, and in returning it, ice and snow warm the Earth and the air. They soften the sharp transition to severe winter and enable autumn to reign for several weeks. In the spring, on the contrary, the melting of the ice holds back the sultry weather for a time,

How Many Waters are There on Earth?

Three isotopes of hydrogen have been found by scientists in nature, and each of them can combine with oxygen. Hence, one may speak of three kinds of water: protium, deuterium, and tritium waters: H_2O, D_2O, and T_2O, respectively.

There may also be "mixed" waters containing, say, an atom of protium and an atom of deuterium, or an atom of deuterium and one of tritium in their molecules. This increases the list of waters: HDO, HTO, and DTO.

But the oxygen contained in the water is also a mixture of three isotopes that exist in nature: oxygen-16, oxygen-17, and oxygen-18, the first being by far the most common.

Taking into account these varieties of oxygen, another 12 possible waters can be added to the list. When you draw a cup of water from a lake or river, you probably never suspect that you have in your cup eighteen different kinds of water.

And so water, no matter where it comes from, is a mixture of different molecules, the lightest being $H_2^{16}O$ and heaviest, $T_2^{18}O$. Chemists can now prepare each of these eighteen kinds of water in the pure form.

Hydrogen isotopes differ perceptibly in their properties. And what about the different kinds of water? They differ in some ways, too. For example, they have different densities, and different freezing and boiling points.

And still the relative content of the different kinds of water in nature is always and everywhere different,

For example, tap water contains 150 grams of heavy deuterium water, D_2O, per tonne. But its content in the water of the Pacific Ocean is noticeably higher: about 165 grams. A tonne of ice from the Caucasian glaciers contains 7 grams of heavy water more than a cubic metre of river water. In a word, the isotopic composition of water is different everywhere. The reason for this is that there is a mighty process of isotope exchange occurring continuously in nature. The different hydrogen and oxygen isotopes keep replacing one another under various conditions.

Is there any other natural compound with as large a number of varieties? There is not.

Of course, we have to do mainly with protium water. But the other kinds of water cannot be disregarded. Some of them are widely used in practice, especially heavy water D_2O. It is used in nuclear reactors for moderating neutrons which cause uranium fission. Besides, scientists use various kinds of water for investigations in the field of isotope chemistry.

Eighteen kinds, and no more? Actually, the varieties of water may be much more numerous. Besides the natural isotopes, there are also man-made radioactive isotopes of oxygen: oxygen-14, oxygen-15, oxygen-19, and oxygen-20. And the number of hydrogen isotopes has also increased: we can now speak of ^4H and ^5H.

Now if we take into account the man-made isotopes of hydrogen and oxygen, the list of possible waters increases to over 100. You can easily count up the exact number yourself...

"Water of Life", Life-Giving, Omnipresent Water

Multitudes of folk tales of various peoples are based on the legend of the "water of life". It healed wounds and revived the dead. It made the coward brave and increased the strength of the brave hundredfold.

It is not by chance that man attributed such magic properties to water. The very fact that we are alive on Earth, that we are surrounded by green woods and flowering fields, that we can go boat riding or run through puddles under the rain in summer and go skiing or skating in winter—is all due to water. To be more exact, all this is due to the ability of water molecules to attract each other and form associations. This is one of the conditions for the origin and development of life on our planet.

The history of the Earth is primarily the history of water. It has continuously changed and still goes on changing the face of our planet.

Water is the greatest chemist in the world. No natural process takes place without it—be it the formation of a new rock, a new mineral, or a highly complicated biochemical reaction taking place in the organism of a plant or an animal.

Chemists could hardly do anything in their laboratories without water. In studying the properties of substances, their transformations, in producing new compounds they can get along without water only in rare cases. Water is one of the best solvents known. And many substances must be dissolved before they can enter into reactions.

What happens to a substance when it dissolves? The forces acting between the molecules and atoms at its surface are weakened many hundredfold in water, as a result of which they break away from the surface and pass into the water. In a glass of tea a piece of sugar breaks down into separate molecules. Table salt decomposes into charged particles known as sodium and chloride ions. Owing to its peculiar structure the water molecule possesses a great ability to attract the atoms and molecules of a substance being dissolved. Many other solvents are inferior to water in this respect.

There is not a rock on the Earth that can resist the destructive action of water. Even granites yield slowly but surely. Water carries the substances it dissolves off to the seas and oceans. That is what makes these tremendous bodies of water salty, though hundreds of millions of years ago the water in them was fresh...

The Icicle's Secrets

Little children adore playing with icicles. They are such pretty, glistening things. But before you know it the child has got the icicle in its mouth. Is it so tasty? Try to take it from him and you'll see.

An amusing childish whim? No, it is far more serious than that.

The following experiment was performed on little chicks. One group was given ordinary water to drink, while the other was allowed to drink

only snow melt water with pieces of ice floating in it.

The test could hardly have been simpler. But the results were surprising. The chicks drinking the ordinary water would do so serenely and without fuss. But the basin of melt water was always a virtual battlefield. The chicks swallowed the water as greedily as if it were something unusually tasty.

A month and a half later the experimental birds were weighed. Those brought up on melt water were much heavier, had gained more weight than the chicks which had been drinking ordinary water

In a word, snow melt water possesses certain wonderful properties. It is very beneficial to live organisms. Why is this so?

At first it was thought to be due to the higher deuterium content in the melt water. In small concentrations heavy water stimulates the development of living organisms. But this was only partly true...

Now it is believed that the true reason lies elsewhere, in the very process of melting.

Ice has a crystalline structure. But, generally speaking, water is also a liquid crystal. Its molecules are not in complete disorder, but form a strict openwork skeleton. Of course, the structure of the latter differs from that of ice.

When ice melts its structure persists for a fairly long time. Outwardly melt water is a liquid, but the molecules in it remain in "ice formation". For this reason the chemical activity of melt water appears higher than that of ordinary water. It participates readily in a multitude of

biochemical processes. When taken up by an organism it combines with various substances more easily than ordinary water.

Scientists believe that the structure of water in an organism greatly resembles the structure of ice. When ordinary water is assimilated by an organism, its structure has to be rearranged. Melt water already has the "right" structure and so the organism does not have to spend any extra energy on rearranging its molecules.

Evidently, the role of melt water in life is very great.

A Bit of Linguistics,
or Two Very Different Things

Without words there can be no speech, without letters, no words. We begin to study a language by learning the alphabet. Each alphabet contains two kinds of letters, vowels and consonants. Without either of these human speech would just go to pieces... . There is a science-fiction novel in which the inhabitants of an unknown planet speak to each other by means of sounds consisting only of consonants. But that is pure science fiction!

Nature speaks to us in the language of chemical compounds. And each of these is a sort of combination of chemical "letters", or elements occurring on Earth. The number of such "words" exceeds three million. But there are only just over a hundred "letters" in the chemical "alphabet".

This "alphabet" also contains "vowels" and

"consonants". The chemical elements have for ages been divided into two groups: nonmetals and metals.

Nonmetals are much less numerous than metals, four times less, in fact. Quite like in human speech, which has much fewer vowel than consonant sounds.

A combination of only vowel sounds in human speech rarely expresses anything articulate. It is most often something like a senseless howl.

In the chemical language combinations of only "vowels" (nonmetals) are rather common. All life on Earth owes its existence to compounds of the nonmetals with each other.

Not in vain do scientists call the four main nonmetals—carbon, nitrogen, oxygen, and hydrogen—organogens, meaning substances which give rise to organic life. If we add phosphorus and sulphur, these six "bricks" just about exhaust the list of materials used by nature to build proteins and carbohydrates, fats and vitamins—in a word, all vital chemical compounds.

Two nonmetals, namely, oxygen and silicon (two "vowels" of the chemical "alphabet") combine to form a substance written SiO_2 and read silicon dioxide in the language of chemistry. This substance is the ultimate foundation of the Earth's firmament, a kind of cement which keeps all the rocks and minerals from falling apart.

It doesn't take much more to complete the list of "vowels" of the chemical "alphabet". All we have to add are the halogens, the noble gases of the zero group (helium, and its brothers) and three not very well known elements, boron, selenium and tellurium.

However, it would be wrong to say that all living things on Earth are made up only of nonmetals.

Scientists have detected more than seventy different chemical elements in the human organism: all the nonmetals and a great number of metals, from iron to the radioactive elements, including uranium.

The reason why there are more consonants than vowels in the human language has long been a point of controversy among linguists.

Chemists are interested in why there are two such different groups as nonmetals and metals in the Periodic System. Each of these groups includes elements which differ greatly from one another, but there is nevertheless some resemblance between them.

Why "Two Very Different Things"?

A jester once remarked that two basic qualities distinguish humans from animals: their sense of humour and their sense of historical experience. A human being is capable of laughing over his own misfortune, and will not be caught a second time where he has stumbled once. We might add another quality, that of asking "why" and trying to find the answer.

And now let us use this little word "why".

For instance, why are the nonmetals not distributed uniformly over the storeys and sections of the Big House, but grouped in definite parts of it. Metals are metals and nonmetals are nonmetals, but what is the difference between them?

Now that is a good question to start with.

When two elements (no matter which) react, the outermost electron shells of their atoms are rearranged. The atoms of one of the elements give away electrons, and those of the other accept them.

Now the difference between metals and nonmetals lies in this most important chemical law.

Nonmetals are capable of two opposite actions: as a rule, they acquire electrons, but they are also capable of giving them away. Their behaviour is pliable and they can change their aspect depending on the circumstances. If they find it more profitable to accept electrons, nonmetals appear as negative ions. If not, they form positive ions. Only fluorine and oxygen know no compromise: they only accept electrons and never give them away.

Metals are much less "diplomatic" and more consistent in their habits. Their motto is invariably "give electrons away and never accept them". They form positively charged ions. The gain of extra electrons is not in their line. Such is the rigid rule of behaviour of the metal elements.

This is the basic difference between metals and nonmetals.

However, meticulous chemists have found exceptions even to this very strict rule. There are inconsistent characters even among the metals. Only two metals have displayed "unmetallic" features. Astatine and rhenium (the inhabitants of the 85th and 75th boxes of the Mendeleyev Table) are known to form negative univalent ions. This fact is like a black mark for the surprisingly purposeful family of metals...

Now, generally speaking, which atoms part with their electrons more easily and which accept them more readily? Atoms which have few electrons on their outermost shell find it more convenient to give them away, and those which have many of them find it more profitable to complete their electron octets by acquiring them. The alkali metals have only a single electron on their outsides. These metals think nothing of parting with it. Once they have done so they find the stable electron shell of the nearest inert gas on their outside. That is why the alkali metals are chemically the most active of all known metals. And the "very most active" among them is francium (box 87). The heavier an element is in its group, the larger its atom and the weaker the hold the nucleus has on its only outside electron.

The most furious in the kingdom of nonmetals is fluorine. It has seven electrons in its "outer sphere". All it needs for complete bliss is an eighth electron. And it grabs it greedily from almost any other element of the Periodic System; nothing can resist fluorine's mad onslaught.

The other nonmetals also accept electrons, some of them more, others less easily. And now we can understand why they are grouped mainly in the upper right-hand corner of the table: they have plenty of electrons on their outsides, and this is possible only in atoms near the ends of the periods.

Two More "Whys"

Why are there so many metals and so few nonmetals on Earth? And why do metals resemble each other much more than nonmetals? Indeed, one is not likely to confuse, say, sulphur and phosphorus or iodine and carbon by their appearance. But even the expert eye cannot always distinguish between niobium and tantalum, potassium and sodium, or molybdenum and tungsten.

Transposition of terms does not change the sum. This is probably one of the most "rigid" principles of arithmetic. But in chemistry, relative to the structure of atomic electron shells, this principle applies far from always...

All is good and well as long as we have to do with the elements of the second and third periods of the Periodic Table.

In each element of these periods the new electron goes into the outermost shell of the atom. An electron is added, and the properties of the new element are entirely different from those of its predecessor. Silicon does not resemble aluminium, sulphur has nothing in common with phosphorus. Metallic properties soon give way to nonmetallic, because the more electrons the atom has in its outer shell, the less readily it parts with them.

But now we come to the fourth period. Potassium and calcium are "first-rate" metals. We expect them to be followed soon by nonmetals.

Not so fast! We are in for a disappointment, because beginning with scandium each added electron prefers the second-last shell to the outer one. "Transposition of terms..." But this transposition

changes the "sum"—the sum of the properties of the elements.

The second-last shell is more conservative than the outer one, and it affects the chemical properties of the elements much less. Therefore, the difference between the elements is less pronounced.

Scandium "recalls", as it were, that its third electron shell is incomplete. It should contain 18 electrons but has only 10 so far. Potassium and calcium must have "forgotten" about this, and arranged their newly-added electrons in their fourth shells. In scandium, justice is restored.

The second-last shell is gradually completed over a series of ten elements. The outer shell remains unchanged, with only two electrons in it. Such a small number of electrons in the outer shell of an atom is peculiar to metals. And that is why there are only metals in the scandium-zinc "span". Why should they accept electrons in their outer shell when forming compounds if they have only two electrons in it? It is much easier for them to give away these two electrons to the elements they react with. Besides, they do not object to borrowing additional electrons from their incomplete second-last shell. As a result, they can display various positive valences. For instance, manganese may be positively di-, tri-, tetra-, hexa-, and even heptavalent.

The same is observed in the subsequent periods of the Periodic Table.

That is why there are so many metals and why they are more like one another than the nonmetals.

Originality in Architecture

Have you ever seen a house with all its bays or
sections planned identically according to a type
design, except for one which differs entirely from
the rest, as if a different architect had made it?

It is not very likely that you have.

Well, the Big House is just such a curious
structure. Mendeleyev fashioned one of its sec-
tions quite uniquely. It may be added that he
had to.

The section in question is the eighth group of
the Periodic System. The elements in it are
arranged in threes. Furthermore, they are not on
each floor, but only in the long periods of the
table. Iron, cobalt, and nickel are in one of them
and the platinum metals, in the other two.

Mendeleyev tried hard to find more suitable
places for them. But he was finally obliged to
add an eighth group to the Periodic Table.

Why an eighth? Simply because the last group
before that was the seventh, the one with the
halogens.

But that makes the group number purely formal.

A valence of plus eight in the eighth group is a
rare exception rather than the rule. Only ruthe-
nium and osmium try to conform, though they
find it far from easy; their oxides, RuO_4 and OsO_4,
are unstable.

None of the other metals has ever reached
such "heights" despite all the scientists' efforts
to help them.

Let us try to solve this riddle together.

Note the platinum metals participate in
chemical reactions very reluctantly. That is

why chemists often use platinum laboratory ware for their experiments. Platinum and its companions are the "noble gases", as it were, among the metals. It is therefore not without reason that they have been called "noble" for ages. Note also that they often occur in nature in the native, uncombined state.

Now take iron, for instance. Ordinary iron behaves chemically like a moderately active element. Pure iron is very stable.

By the way, here is something to think about. Maybe many of the elements, not only metals, are highly resistant to chemical influences when extra pure.

It is not the outermost, but the second-last electron shell in the atoms of the platinum metals that is responsible for their "nobility".

This shell lacks but a very few electrons to make a complete set of eighteen*, an eighteen-electron shell being also a fairly stable structure. That is why the platinum metals are not inclined to give away electrons from this shell. Nor can they accept electrons, because they are metals, after all.

This "irresoluteness" of the platinum metals accounts for their peculiar behaviour.

Fourteen Twins

They are called lanthanides. Such is their name because all of them—fourteen in all—are "lanthanum-like", that is, resemble lanthanum and

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* The element palladium actually has a complete set of eighteen electrons in its second-last (N) shell, and no electrons in its outer (O) shell.—Tr.

one another very much. Because of this astonishing chemical similarity they are all situated in a single box, the box of lanthanum whose number in the Table is 57.

Isn't this some terrible misunderstanding? Mendeleyev himself and many other scientists reasoned that each element had a single quite definite place in the Periodic Table.

But here fourteen inhabitants of the system have crowded into the same box, all of them being elements of the third group and of the sixth period.

Why not try sorting them out among the other groups?

Many chemists have tried, among them Mendeleyev. They placed cerium in the fourth group, praseodymium in the fifth, neodymium in the sixth, and so on. But this distribution defied all logic. The main and secondary subgroups of the Mendeleyev Table contain similar elements. But cerium had very little in common with zirconium, praseodymium and neodymium were strangers to niobium and molybdenum. Nor could the other rare-earth elements (such is the general name for lanthanum and the lanthanides) find relatives in the corresponding groups. On the other hand, they resembled each other like twin brothers. Especially when showing the valence of three.

When chemists were asked what boxes of the Table to place the lanthanides in, they shrugged their shoulders in bewilderment. Indeed, what could they say when they did not know the reason for the astonishing similarity of the lanthanides?

But the explanation proved quite simple.

The Periodic System has curious groups of elements whose atoms have quite a peculiar constitution. The last electron added to form these atoms does not settle in their outermost, or even in their second-last shells, but penetrates, in conformance with strict physical laws, right through to the third-last shell.

They feel quite cosy there and have no inclination to abandon their places under any circumstances. They participate in chemical reactions only in very rare cases.

Nor is it accidental that the number of lanthanides is fourteen, neither more nor less. This is because there are exactly fourteen vacancies in the third-last shell of their atoms, the one that is being filled.

That is why chemists found it possible to place all the lanthanides in one single box together with lanthanum.

The World of Metals and Its Paradoxes

Over eighty of the elements in the Periodic System are metals. On the whole, they resemble one another more than the nonmetals. And yet there is no end of surprises in the metal kingdom.

For instance, what colour are the different metals?

Metallurgists divide all metals into ferrous and non-ferrous. The ferrous metals include iron and its alloys. All the rest are nonferrous metals, except for the noble ones, their "Majesties" Silver, Gold and Platinum and its companions.

This is a very crude division and even the metals themselves object strongly to such lack of discrimination.

Each metal actually has its own particular hue. Its dark, dull, or silvery base always has a definite tint. Scientists have become convinced of this by studying metals in the very pure state. Many of them when left in the air, become coated sooner or later with a very thin film of oxide which masks their true colour. But the pure metals give a very wide range of colours. The observant eye can discern metals with bluish, greenish-blue and greenish shades, with a reddish or yellowish play of colours, dark-grey like sea water on a cloudy autumn day, and shiny silvery ones which reflect solar rays like a mirror.

The colour of a metal depends on many factors. Among others, it depends upon the method of its production. A metal obtained by sintering has a different appearance from the same metal poured into an ingot.

If we compare metals by weight, we can distinguish light, medium and heavy ones.

These "weight classes" have their record-holders.

Lithium, sodium, and potassium do not sink in water, because they are lighter than water. For example, the density of lithium is almost half that of water. Were lithium not so active an element, it would be an excellent material for a great variety of purposes. Imagine a ship or an automobile made entirely of lithium. Unfortunately, chemistry bans this attractive idea.

The "heavy-weight champion" among the metals is osmium. One cubic centimetre of this

noble metal weighs 22.6 grams. To balance one
cube of osmium we would have to put on the
other pan, say, three cubes of copper, two cubes
of lead or four cubes of yttrium. The "perfor-
mance" of osmium's closest neighbours, namely,
platinum and iridium, is almost as high. The
noble metals are also the heaviest metals.

The hardness of metals has become proverbial.
If a man is always composed and cool-headed,
we say he has "iron nerves". But in the world of
metals the situation is different.

Here iron is hardly a model of hardness. The
hardness champion is chromium which is just
slightly inferior to diamond. By the way, para-
doxical though it sounds, the hardest chemical
elements are not metals at all. At the top of the
conventional hardness scale stand diamond
(a form of carbon) and crystalline boron. Iron
should rather be classed as a soft metal; it is
only half as hard as chromium. And as to the
lightweights, the alkali metals, they are as
soft as wax.

Liquid Metals
and a Gaseous (?) Metal

All the metals are solids, harder or softer. Such
is the general rule. But there are exceptions.

Some metals are more like liquids. A chip of
gallium or cesium melts on your palm, because
the melting point of these metals is just below
thirty degrees Celsius (86 °F). Francium, which
will never be prepared as the pure metal would
melt at room temperature. Mercury is a clas-

sical example of a liquid metal which everybody knows. It freezes at minus 39 °C (—38.2 °F), which makes it eligible for various kinds of thermometers.

An important rival to mercury in this respect is gallium, and here is why. Mercury boils at the comparatively low temperature of about 300 °C (572 °F). This makes mercury thermometers useless for measuring high temperatures. But it takes a temperature of 2000 °C (3670 °F) to turn gallium into a vapour. Not a single metal can remain in the liquid state for so long, i.e. has such a large interval between its melting and boiling points, as gallium. This makes gallium an excellent material for high-temperature thermometers.

One more thing, and this is quite remarkable. Scientists have proved theoretically that if there existed a heavy analogue of mercury (an element with a very large atomic number, an inhabitant of the imaginary seventh floor— eighth period—of the Big House, unknown on Earth), its natural state at ordinary conditions would be gaseous. A gas possessing the chemical properties of a metal! Will scientists ever have such a unique element to study?

A lead wire can be melted in a match flame. Tin foil immediately changes into a drop of liquid tin if thrown into a fire. But to liquefy tungsten, tantalum or rhenium, the temperature has to be raised above 3000 °C (about 5500 °F). These metals are harder to melt than any of the others. That is why the filaments of incandescent electric light bulbs are made of tungsten and rhenium. The boiling points of some metals are

really tremendous. For instance, hafnium begins
to boil at 5400° (almost 9800 °F) (!), almost the
temperature of the Sun's surface.

Unusual Compounds

What was the first chemical compound deliber-
ately produced by man?

The history of science can give no definite ans-
wer to this question.

Let us take the liberty to make our own assump-
tions on this point. The first substance which
man prepared, knowing beforehand what he
wanted to obtain, was a compound of two metals,
copper and tin. We have deliberately avoided
using the word "chemical", because the compound
of copper and tin (commonly known as bronze)
is an unusual one. It is called an alloy.

The ancients first learned to smelt metals from
their ores and only afterwards to fuse them with
each other.

Thus, at the dawn of civilization appeared the
first seeds of a branch of the future science of
chemistry, now called metal chemistry. The
structure of compounds of metals and nonmetals
usually depends on the valence of the elements
contained in them. For example, the molecule
of common salt contains positively univalent
sodium and negatively univalent chlorine. In
the ammonia molecule NH_3 negatively trivalent
nitrogen is linked with three positively univa-
lent hydrogen atoms. The chemical compounds
of metals with one another (called intermetallic
compounds) usually do not obey the laws of

valence, and their composition bears no relation
to the valence of the reacting elements. For
this reason the formulas of intermetallic com-
pounds look rather strange, for instance, $MgZn_5$,
KCd_7, $NaZn_{12}$, etc. The same pair of metals can
often give several intermetallic compounds; for
instance, sodium and tin form nine different
combinations.

Metals interact with one another in the molten
state, as a rule. But metals do not always form
chemical compounds with each other when fused.
Sometimes one metal simply dissolves in the
other. The result is a homogeneous mixture of
indefinite composition which cannot be ex-
pressed by any distinct chemical formula. Such
a mixture is called a solid solution.

Alloys are legion; nobody has ever taken the
trouble to count up even approximately how
many of them are known already and how many
can be obtained, in general.

There are some alloys which consist of no less
than a dozen metals, and each new addition has
a specific effect on their properties. There are
many alloys which contain only two metals,
these being called bimetallic, but their proper-
ties depend on the proportion of their components.
Some metals fuse very readily and in any pro-
portion. Such are bronze and brass (an alloy of
copper and zinc). Others, such as copper and
tungsten, are reluctant to mix under any condi-
tions. Still, scientists have succeeded in making
an alloy of them, though in an unusual manner,
by what is known as powder metallurgy, that is,
by sintering copper and tungsten powders under
pressure. And finally, experiments on board of

spaceships were carried out to obtain the unusual alloys under the conditions of weightlessness.

Some alloys are liquids at room temperature; others are very resistant to high temperatures. The latter are used in large quantities in space engineering. Finally, there are alloys which do not yield even when attacked by the strongest chemical agents, and alloys which are almost as hard as diamond.

The First "Electronic Computer" in Chemistry

Electronic computers can do many things. They have been taught to play chess, to forecast the weather, to find out what is happening in the depths of distant stars, to carry out calculations involving unthinkable difficulties. All one has to know is how to assign their programme of operations. Great automatic plants are controlled by these machines. With their aid, investigators learn everything about numerous chemical processes before putting them into practice.

But chemists have at their disposal a rather unusual "electronic computer". It was invented more than a hundred years ago before the term electronic computer ever appeared in the languages of the world.

This remarkable machine is the Periodic System of Elements.

It enables scientists to do what even the most daring investigators would not risk doing before. The Periodic System made it possible to predict

the existence of elements yet unknown, undiscovered even in the laboratory. And not only to predict them, but even to describe their properties. It could tell whether they would be metals or nonmetals, heavy like lead, or light like sodium, and in what terrestrial ores and minerals the unknown elements were to be sought. The answers to all these questions were supplied by the "electronic computer" invented by Mendeleyev.

In 1875 the French scientist Paul Emile Lecoq de Boisbaudran made an important report to his colleagues. He had succeeded in detecting an admixture of a new element in a zinc ore, a tiny grain weighing not more than a gram. Being an experienced investigator, he studied the properties of gallium (such was the name of the "newborn" element) in detail, and wrote a paper about it.

Some time passed and the post brought de Boisbaudran an envelope bearing a St. Petersburg postmark. In the brief letter the French chemist read that his correspondent agreed in full with his results, except for one detail: the specific gravity of gallium should be 5.9 instead of 4.7.

The letter was signed: D. Mendeleyev.

Lecoq de Boisbaudran was worried. Had the Russian chemist anticipated him in the discovery of the new element?

No, Mendeleyev had not had gallium in his hands. He had simply made efficient use of the Periodic System. Mendeleyev had long since known that sooner or later an unknown element would be found to take the place in the table, which was now occupied by gallium. He had

given it the preliminary name of eka-aluminium and had predicted its chemical nature very accurately, knowing the properties of its neighbours in the Periodic Table.

So Mendeleyev became the first "programmer" in chemistry. He predicted almost a dozen other then unknown elements, and described their properties more or less completely.

Today the example of how the properties of Mendeleyev's "eka-boron" and "eka-silicon" so fully coincided with those of scandium and germanium is quoted in almost every school textbook. The former was discovered by the Swedish scientist Lars Nilson in 1879, the latter—by a German, Clemens Winkler in 1886, and those discoveries forced the whole world to aknowledge Mendeleyev's Periodic System.

Other elements, whose existence and properties were "programmed" by Mendeleyev, were discovered only in the twentieth century. Technetium, No. 43 (Mendeleyev's "eka-manganese") was synthesized artificially in 1937; No. 85, astatine ("eka-iodine"), and No. 87, francium ("eka-cesium") were synthesized as far back as the forties. At the turn of the 19th century the radioactive elements polonium ("dvitellurium")— No. 84, radium ("eka-barium")—No. 88, actinium—No. 89, and later protactinium ("eka-tantalum")—No. 91 came into existence.

It had been stressed by Mendeleyev many times that the Periodic System eliminated the element of chance in the discovery of new chemical elements. But the system had no profound physical footing so far. The "remarkable computer" refused to work at times. The elements lighter than hy-

drogen and heavier than uranium still remained a point of controversy. It was no easy task to bring some order into the chaos of rare-earth elements. The Periodic System could not tell for sure exactly how many such elements existed and could not account for their being so much alike.

But there is nothing absolutely perfect in the world.... Anyway, the advantages of Mendeleyev's "computer" far exceeded its shortcomings.

A Hitch in the "Electronic Computer"

Physics and chemistry had made tremendous progress by the twenties of our century. In a matter of two decades these sciences had scored no less achievements than throughout the preceding history of mankind.

But the discovery of new elements suddenly came to a standstill.

Which particular boxes of Mendeleyev's Table were still vacant became clear when physicists revealed the essence of the theory of periodicity and introduced the new concept of atomic number.

So, boxes No. 72 and No. 75 were empty. The first of them was filled by the element discovered by the Hungarian and Danish scientists George Hevesy and Dirc Coster as far back as 1923. They discovered a very rare element, hafnium, in the mineral zircone. This appeared to be the analogue of zirconium. The chemical separation of these elements is a difficult task even today. Hence, hafnium was to take its place in the

secondary subgroup of the fourth group, having left the family of rare-earth elements to which it had been assigned by some scientists. Thus the exact number of lanthanides was established. And this provided a good experimental confirmation of the correctness of the young theory of periodicity.

Box No. 75 was occupied by rhenium in 1927 once and for all. It was placed there by the German chemists Ida and Walter Noddak. This was one of those rare cases when a woman discovered a new chemical element. In 1898 Marie Curie, together with her husband Pierre, discovered radium, and in 1939 a French woman, Marguerite Perey, found francium.

Rhenium was the last stable chemical element to be found on Earth. There remained several "blank" spaces in the Periodic Table which had to be filled. These were the boxes corresponding to the atomic numbers 43, 61, 85, and 87.

What strange elements were these which refused flatly to settle in the Periodic Table?

The first stranger. An element of Group Seven with the atomic number 43, situated between manganese and rhenium, and probably similar in properties to these elements. It was decided to look for it in manganese ores.

The second stranger. A companion of the rare-earth elements resembling them in all aspects. Atomic number 61.

The third stranger. The heaviest halogen, iodine's elder brother. It could be a great surprise to chemists, for it was not impossible that its properties would be weakly metallic. Halogen and metal—what a splendid example of a two-

faced element! Flat 85 of the Big House was kept in readiness for it.

The fourth stranger. Now this is an interesting element. The most furious, the most active metal, and it would melt if just held on the palm of your hand. The heaviest of the alkali metals. Its atomic number is 87.

Scientists compiled very detailed files on the mysterious strangers. Sherlock Holmes could detect a criminal by the ashes of a cigar he had smoked, by specks of clay adhering to his shoe leather. But his methods were nil compared to the delicate methods of chemists who had learned to identify the minutest amounts of unknown substances.

The clever detective was always lucky. The chemists were not. All their efforts to find the mysterious strangers and install their flats ended in failure.

The strangers were sought everywhere: in cigar ashes and in plant remains; in the rarest and most exotic minerals, the pride of mineralogical museums; in the waters of the seas and oceans. All in vain!

On the shelf of unsolved problems there appeared a new brief entitled "The Case of the Mysterious Disappearance of the Chemical Elements 43, 61, 85, and 87" A "disheartening case", some crime investigators might have called it.

Could nature have been up to the unsuspected trick of eliminating these elements from the list of elementary substances existing on our planet? Could it be another of her strange whims?

Indeed, it looked like magic. They say that miracles don't happen, but for reasons unknown

the four flats of the Big House remained vacant.
They were filled only after the scientists
learned to make chemical elements artificially.

How to Change One Element
into Another

Innumerable chemical reactions occur in the
world around us. They all obey the authority of
electron-shell configurations. An atom may gain
electrons or may lose them becoming a negatively
or a positively charged ion. An atom can com-
bine with hundreds and thousands of others to
form a giant molecule. But it always remains the
carrier of the properties of the same element. Car-
bon forms over six million compounds, but in
each of them, be it carbon dioxide CO_2 or the
most complicated protein, carbon remains carbon.

Changing an element into another involves
rearranging its atomic nuclei to alter their
charge.

To bring about chemical processes chemists
make use of high temperatures and pressures and
of catalysts, substances which accelerate reac-
tions when added in small amounts.

Temperatures of thousands of degrees and
pressures of hundreds of thousands of atmo-
spheres fail to rearrange the atomic nucleus. One
element cannot be changed into another in this
way.

But it can be done by the methods applied by
another branch of science called nuclear chemistry.
The "temperatures and pressures" of nuclear
chemistry are protons and neutrons, nuclei of

heavy hydrogen isotopes (deuterons) and nuclei of helium atoms (alpha-particles), and finally, ions of various elements of the Mendeleyev Table, boron and oxygen, neon and argon, calcium, iron, chrome. Its chemical equipment includes nuclear reactors in which certain bombarding particles are formed, and accelerators, complex apparatus for speeding up the particles to immense velocities. To penetrate the atomic nucleus, the missile particle must possess an extremely high energy (especially if it is positively charged); this makes it easier to overcome the repulsive action of the nuclear charge. Nuclear chemistry has its own system of symbols, but the equations of its reactions resemble "conventional" chemical equations.

It was due to nuclear chemistry that the blank spaces in the Mendeleyev Table were finally filled.

The Greek word "technetos" meaning "artificial" went into the name of the first element prepared artificially by man. In late 1936 a beam of fast deuterons accelerated in a cyclotron crashed down on a molybdenum plate. The swift deuterons cut through the electron shells like a knife through butter and reached the nucleus. On hitting the nucleus each deuteron, consisting of a proton and a neutron decomposed, the neutron glancing off at an angle and the proton being captured by the nucleus. This increased the nuclear charge by one unit, and molybdenum, which occupies Box No. 42 changed into its right-hand neighbour, element No. 43.

Like in ordinary chemistry, where the same compound can be obtained by various routes, so

in nuclear chemistry the same elements can be prepared artificially by means of different reactions.

People learned to make technetium in hundreds of kilograms at the most wonderful factory in the world. This factory is the nuclear reactor, where energy is produced by slow neutrons splitting uranium nuclei.

The uranium nuclei break up into different fragments, each nucleus producing two fragments. These are atomic nuclei of elements situated in the centre of the Mendeleyev Table. On fission uranium gives birth to elements which occupy more than 30 boxes of the Periodic Table, ranging from No. 30 to No. 64, and including technetium, and another of the strange elements, which had been sought in vain for decades in the Earth's crust. This was promethium, the inhabitant of Box No. 61.

Similarly, as a result of different nuclear reactions, elements No. 85 and No. 87, astatine and francium, were obtained.

Now there were no vacant boxes between hydrogen and uranium. As we know there can be no other elements before hydrogen. And after uranium?

Seventeen Steps Beyond Uranium

Today we can claim to know of seventeen transuranium elements: from No. 93—neptunium, up to No. 109 which doesn't have a name yet. But the extent of our "knowledge" about each of these elements differs. What we know for sure is

that none of them occur in nature. The insignificant traces of the lightest of them, neptunium and plutonium, were found in some of the uranium minerals. They are constantly formed as a result of nuclear reactions taking place in nature. But, generally speaking, it is too minor a thing to be considered.

All the transuranium elements are radioactive, of course, and rather highly at that. As the atomic number increases the element's lifetime decreases considerably.

What else do we know? We know, and we can assert that we know rather well, the properties of neptunium, plutonium, americium, curium which appeared as far back as the 1940's. The chemistry of plutonium, the remarkable nuclear fuel, which is far more efficient than uranium, was studied extensively. Today large quantities of this element are synthesized in nuclear reactors.

With respect to berkelium (No. 97), californium (No. 98), einsteinium (No. 99), fermium (No. 100), mendelevium (No. 101), our "knowledge" is less certain. And this certainty decreases with the increase of the atomic number. This quintet of elements is far more difficult to work with: their synthesis is harder to carry out, it is anything but easy to obtain sufficient quantities of them for experimental work. With respect to berkelium and californium, things seem to be satisfactory: scientists managed to obtain both in the form of metals. For einsteinium and fermium it is a matter of fractions of a gram, and the quantity of mendelevium when synthesized for the first time amounted to... a few hundred atoms. It is hardly ever possible to weigh the metal

mendelevium, since it cannot be accumulated in sufficient quantities because its lifetime does not exceed two months. However, scientists speak of the "chemistry of mendelevium". By the way, this element has somewhat unexpected chemistry. Mendelevium and its fellow fermium are so unstable that their "resources" must constantly be restored in the laboratories.

The next "cohort" of the transuranium elements starts with No. 102. The history of its discovery is full of mistakes. For one thing, an absolutely new method was applied for its synthesis, for another, its half-life is measured by minutes. Naturally, the amount of it that can be synthesized is a matter of several hundred atoms. Such peculiarities of this element led to lots of delusions and mistrust. Today students dedicate their graduation works to element No. 102.

Element No. 102 started the list of the real "chemical ghosts". Every time anybody wants to get to know them better, one has to call them into being first, i.e., carry out a nuclear synthesis from scratch.

A strange, mysterious world of elements that disappear almost immediately after their birth! There is so much that is vague and uncertain in it. It is more likely that we do not know it than we know it. No one can be quite sure of which group of scientists was the first to synthesize this or that element. And this uncertainty often causes long and pointless discussions. That is why the investigators are not too fast in giving names to the new elements.

To study chemical properties of an element, having just a few atoms of it at your disposal,

is a very difficult task. The ingenuity and art-
fulness of the scientists seemed to have reached
their peak. And they did it. Precise and compli-
cated experiments made it possible to establish
that elements No. 102 and No. 103 belong to the
family of actinides. This was a very important
find that added to the knowledge of the structure
of the Periodic System. Later the chemical nature
of kurchatovium and nielsbohrium was deter-
mined. As to the other transuranium elements,
chemists haven't turned their attention to them
yet.

Mortality and Immortality
in the World of Elements

There came a time when chemists became archeol-
ogists in a way. They learned to measure the
age of various minerals in the Earth's crust,
much like an archeologist determines how many
centuries ago a bronze adornment or an earthen-
ware vessel was made.

Some minerals were found to be more than
four and a half billion years old. They are as
old as the planet Earth itself. But minerals are
chemical compounds. They consist of elements.
Therefore the elements are practically immortal.

Isn't it absurd to ask whether an element can
die? Death is the sad fate of living creatures.

No, this question is not so pointless as it
seems at first glance.

There is a physical phenomenon called radio-
activity. It consists in elements (rather, atomic
nuclei) decaying spontaneously. Some nuclei

emit electrons from their depths. Others throw up
what are known as alpha-particles (helium nuclei).
Still others break up into two approximately
equal halves, this process being known as spon-
taneous fission.

Are all the elements radioactive? No, not all,
but mainly those at the end of the Periodic
System, starting from polonium.

In decaying, a radioactive element does not
vanish altogether. It changes into another. The
chain of radioactive transformations may be
very long.

For example, thorium and uranium finally
change into stable lead. But along their route a
good dozen of radioactive elements are born and
perish.

Radioactive elements possess different vitali-
ties. Some of them may exist tens of billions of
years before vanishing entirely. The lifetime of
others is a matter of minutes, or even fractions of
seconds. Scientists assess the vitality of radioac-
tive elements by means of a special quantity called
the half-life period or just half-life. During this
period any quantity of the radioactive element
taken decays to exactly half of its initial weight.

The half-lives of uranium and thorium are
several billion years each.

It is entirely different with the elements that
come before them in the Periodic Table, pro-
tactinium, actinium, radium and francium, ra-
don, astatine, and polonium. Their lifetime is
much shorter, not more than a hundred thousand
years in any case. And this brings up an unex-
pected puzzle.

How is it that these short-lived elements still

exist on Earth seeing that our planet is something like 5 billion years old? This almost unimaginable time period should have been long enough for radium, actinium, and the other elements of their group to vanish a hundred times over.

Still, they do exist and have been concealed in terrestrial minerals for ages. It is as if nature has some elixir at its disposal which keeps them from perishing.

No, this is not the case. It is simply that they keep reappearing, because they are fed by an inexhaustible source, the terrestrial reserves of uranium and thorium. As long as these radioactive "patriarchs" keep travelling down their long and complex path of transformations, ultimately to form stable lead, they must continue changing into the intermediate elements. Thus, among the chemical elements we can distinguish two large groups, namely, the primary and the secondary elements.

The primary elements are all the nonradioactive elements and uranium and thorium whose half-life periods are greater than the Earth's age. They witnessed the formation of the solar system.

All the rest are secondary elements.

Still, there will come a time when the Periodic System will find itself lacking several elements. These will be uranium and thorium, the eternal source of secondary elements which are, however, eternal only relatively. At some future time they will also disappear from the face of the Earth in a matter of a few hundred billion years. And together with them will vanish the products of radioactive transformations, if the Earth itself persists in such an unimaginably distant future.

One, Two, Three, Many...

That was about what the counting abilities of
primeval man amounted to. His mathematical
apparatus included only two quantitative magni-
tudes, namely, "much" and "little".

People used much the same criterion less than
hundred and fifty years ago when they tried to
estimate the amounts of separate elements our
planet had stored away in its "granaries".

For example, lead, zinc, and silver had found
wide usage in practice; there was much of them.
Hence, these elements were considered abundant.
But the rare earths (lanthanides) were rare be-
cause they were hardly ever encountered on Earth.
There was little of them. See how easy it was to
reason then.

The first inspectors of the chemical elements
storehouses had an easy job to do. Our contempo-
raries laugh to think of their "activities"

And how can they help laughing since they can
now state exactly how much there is of every-
thing! If they can even tell how many atoms of
each element there are in the Earth's crust.
They know for certain that the notorious rare
earths are just slightly less abundant in the
minerals of our planet than lead, zinc, and
silver all taken together.

The formation of the science of geochemistry
is closely connected with the name of the Ameri-
can scientist Francis Clark.

He was the first to introduce a strict order into
the chaos of the atomic weights of the chemical
elements. Until then, different scientists had
established different values for one and the same

element. How was the right one to be chosen? After a critical analysis of more than 5000 samples, Clark fixed his choice on the most realistic ones. It was none other than he, Francis Clark, who took a scientific approach to the problem of the abundance of elements in nature.

It was on his initiative that the International Commission on Atomic Weights was founded. Each year it issued bulletins reflecting the atomic weight changes. This tradition is still alive.

Clark's findings introduced a great deal of certainty into the problem of abundance of chemical elements on Earth. Now scientists could tell which elements were abundant and which were scarce, and how much of every element there was on Earth. And the quantitative magnitude used to denote the distribution of elements on Earth was called clark after the founder of modern geochemistry.

So was born the science of geochemistry. It told wonderful stories such that had never before been known to man.

It appeared that the first 26 representatives of the Mendeleyev Table, from hydrogen to iron, form practically the entire crust of the Earth. They constitute 99.7 per cent of its weight, leaving only a "miserly" three tenths of per cent for all the other 67 elements occurring in nature.

Now what is there the most of on Earth?

Neither iron, nor copper, nor tin, though man has been using them for thousands of years and the supply of these metals seemed immense, even inexhaustible. The most abundant element is oxygen. If we place all the Earth's resources of oxygen on one pan of an imaginary pair of

scales and all the rest of the elements on the other, the scales will strike an almost perfect balance. Almost half of the Earth's crust is oxygen. It is everywhere: in water, in the atmosphere, in an enormous number of rocks, in any animal and plant, and everywhere it plays a very important part.

One quarter of the Earth's crust is silicon. It is the ultimate foundation of inorganic nature, the Earth's "firmament", so to say.

Further, the elements of the Earth arrange themselves in the following order of abundance: aluminium, 7.4 per cent; iron, 4.2 per cent; calcium, 3.3 per cent; sodium, 2.4 per cent; potassium and magnesium, 2.35 per cent each; hydrogen, 1.0 per cent; and titanium, 0.6 per cent.

Such are the ten most abundant chemical elements on our planet.

But what is there the least of on Earth?

There is very little gold, platinum and platinum metals. That is why they are valued so highly.

But it is a curious paradox that gold was the first of the metals to become known to man. Platinum was discovered before oxygen, silicon or aluminium had ever been heard of.

The noble metals possess a unique feature. They do not occur in nature as compounds but in the native state. No effort is required to smelt them from their ores, that is why they were found on Earth, precisely found, so very long ago.

However, these metals do not "take the cake" for rarity. This lamentable prize goes rather to the secondary radioactive elements.

They are very scarce indeed.

The geochemists tell us that the amount of

polonium on Earth totals only 9600 tons, the amount of radon is still smaller, 260 tons; there is 26 thousand tons of actinium. Radium and protactinium are veritable "giants": they total about 100 million tons, but compared to gold and platinum this is a very small quantity. As to astatine and francium, they can hardly be classed even as ghosts, because they are still less material. The terrestrial reserves of astatine and francium are measured, ridiculous though it sounds, in milligrams.

The name of the rarest element on Earth is astatine (69 milligrams in all of the Earth's crust). No further comments are necessary.

The first transuranium elements, neptunium and plutonium, have also been found to exist on Earth. They are born in nature as a result of very rare nuclear reactions between uranium and free neutrons. These ghosts can "boast" of hundreds and thousands of tons. But as to promethium and technetium, which are also due to uranium (the latter is capable of spontaneous fission, with its nuclei breaking up into two approximately equal fragments), there is nothing that can be said of them. Scientists have found hardly perceptible traces of technetium, and promethium. The balance has yet to be invented on which the Earth's "reserves" of those elements could be weighed.

Has Nature Been Just?

Today scientists say that all the chemical elements known to nature can be detected in any mineral sample. All without exception. Of course

their proportion varies immensely. But why is there so much of some and so little of others?

In the Periodic System all the elements have equal rights. Each occupies its own definite place. But when it comes to the terrestrial reserves of the elements, these equal rights vanish into thin air.

The light elements of the Mendeleyev Table, its first thirty or so representatives, at any rate, constitute the bulk of the Earth's crust. But there is no equality among them either. Some are more abundant, others less. For instance, boron, beryllium and scandium are among the very rare elements.

Since the Earth has been in existence there has been something of a "revision" of the supplies of its elements. A considerable amount of uranium and thorium has disappeared owing to their radioactivity. A large amount of the noble gases and hydrogen has been lost to outer space. But the general picture has not changed.

The scientists of our days write that the abundance of the chemical elements in the Earth's crust decreases regularly from the light elements to the medium-weight ones and then to the heavy ones. This isn't always the case. For example, there is much more heavy lead on Earth than many of the light representatives of the Mendeleyev Table. Why so? Why not equal amounts of all? Has not nature been unjust in "accumulating" some of the elements and not attending to the supplies of others?

No, there are laws according to which there is bound to be a great deal of some of the elements and little of the others. To be quite honest about

it, we do not know these laws as yet, and content ourselves with assumptions.

You see, the chemical elements have not always existed. The universe is so constituted that there is always a gigantic process of formation or synthesis of elements going on in various parts of it, a process so great that there is nothing it can be compared to. The cosmic nuclear reactors, the cosmic accelerators are the stars. Chemical elements are always being "cooked" in the depths of some of them.

Unheard-of temperatures, unimaginable pressures reign there. The basic laws are those of nuclear chemistry, the rulers—nuclear chemical reactions transforming one element into another, the light elements into heavy ones. And such are these laws that some elements form more easily and in greater quantities while others form with greater difficulty and therefore in smaller proportions.

It all depends on the stability of the different atomic nuclei. In respect to this nuclear chemistry has a quite definite opinion. The nuclei of light-element isotopes contain almost equal numbers of protons and neutrons. Here these elementary particles form very stable structures. That is why the light nuclei are easier to synthesize. In general, nature tends to create systems of the highest possible stability. They are easier to synthesize but participate less readily in nuclear reactions resulting in nuclei with larger charges. Nuclei of the latter kind contain considerably more neutrons than protons, and therefore nuclei of medium and heavy mass have no very great stability to boast of. They are more

subject to the rule of chance, more inclined to
change, and are therefore incapable of accumulat-
ing in very large quantities.

According to the laws of nuclear chemistry the
higher the charge on the nuclei, the more difficult
such nuclei are to synthesize, and therefore the
less of them is formed.

The chemical composition of our Earth is like
a silent replica, a voiceless reflection of the
dynamics of the laws governing the process of
origination of the elements. When scientists have
learned these laws in full, we shall understand
why the different chemical elements differ so
widely in abundance.

In the meantime, theoretical physicists came
to a conclusion that strikes one's imagination.
It appears that atomic nuclei vary in stability
and the most stable among them is likely to be
the nucleus of iron-56. Sooner or later all the
other nuclei must be transformed into it.

A giant "iron clot" instead of our varied Uni-
verse.... It sounds more like an episode from
a science-fiction story.

On the Track of False Suns

The history of science knows of two lists of chem-
ical elements. One of them includes those which
took their places in Mendeleyev's Table once and
for all. Their discovery is unquestionable, no
matter whether they were found in nature or
synthesized artificially. And together with this
list there is another one which cannot be found
in the textbooks. It remains unnoticed by the

majority of scientists but it is known to quite
a few specialists studying the history of chemi-
cal elements. It is a ponderous register of errors,
i.e. the discoveries of elements that proved to be
false. And there were at least twice as many
such discoveries as true discoveries of chemical
elements. No science can avoid delusions, errors,
misinterpretations in its development. There is
no progress without mistakes.

The discovery of a new chemical element is
a matter of prestige for the scientist. Having
discovered a new element, the investigator com-
memorates his name, makes it a part of history.
Such discovery is an absolute discovery, as
it were, it can neither be improved, nor disproved,
nor expanded upon. This discovery is once and
for all.

In the times when chemistry was not a true
exact science yet, and had rather imperfect meth-
ods of investigation, when physics gave no
explanation of the essence of the chemical ele-
ments themselves and the system of their classi-
fication, i.e. Periodic System, false discoveries
were hard to avoid. This lack of knowledge
led to all kinds of errors and speculations.
Among the errors there were indeliberate ones,
when, say, the results of chemical analyses were
given a wrong interpretation, and there were deli-
berate errors, if you like, whose authors tried
to make the desirable pass for reality in order to
"get into history" by hook or by crook...

Lots of peculiar things did happen: either the
"discoverers" themselves admitted their errors,
or their colleagues proved their "discoveries"
to be false. Once in a while trivial mystification

took place, something like an April Fool's joke... And "stillborn" elements were given such pompous names as demonium, damarium, carolinium, denebium, glaucodimium, incognitium, kosmium, neokosmium... .

One cannot help recalling the Englishman Freehand who organized a special expedition to Palestine to "fish" for traces of elements No. 85 and No. 87 in the lifeless waters of the Dead Sea. Or the American Allison who, while scientists puzzled over the question why no heavy analogues of iodine and cesium could be found on Earth, suddenly began discovering them everywhere. He detected them in all solutions and minerals checked by a new method he had worked out. The method turned out to be faulty. The analysis greatly fatigued the operator's eyes and caused illusions.

Even great men have not escaped errors on the track of false suns. The Italian Fermi thought that several transuranium elements at once appeared in uranium on bombardment with neutrons. Actually these were the fission fragments of uranium nuclei, elements of the middle of the Periodic System.

This notorious track persists even in our days. In 1957 a group of scientists in Stockholm synthesized a new element with the atomic number 102. It was named nobelium in honour of the inventor of dynamite. Soviet and American researchers disproved these results. And now the scientists say jestingly that all that is left of nobelium is its symbol "No". However, isotopes of the 102nd element have now been obtained quite authentically by other methods in the USSR and the USA.

"False suns" on the sky of the history of science... . Most of them, having flashed brightly, died out, either shortly or after some time. But some, that seemed to have been extinguished forever, after decades began shining again but with a new light.

In the eighties of the last century, the well known to us William Crookes claimed to have isolated from yttrium a host of yet unknown simple substances. He never took the trouble to think up names for them, but just denoted them by different letters of the Greek alphabet. As all the elements were very much alike in terms of their properties, Crookes gave them the general name of "meta-elements". Scientists soon disproved his results and Crookes himself had to admit his errors. But the most peculiar thing is that Crookes never considered his "meta-elements" independent chemical individuals, but varieties of some particular element. And this was nothing but the anticipation of the phenomenon of isotopy of chemical elements, which was discovered at the end of the first decade of our century.

In the 1920's in Germany, Richard Swinne (a Lett by nationality, by the way) sought transuranium elements in samples of what was thought to be cosmic dust collected among the boundless glaciers of Greenland. And this was not a blind search. Swinne was guided by the scientific hypothesis that the transuranium elements of large atomic weights should possess elevated stability, that is, their radioactivity level enabled them to exist until the present time. Swinne even reported to have observed the X-ray spectrum of one of those elements, namely, of No. 108.

Nobody took this seriously then. But fourty years later Swinne's idea was revived, but in a new aspect, of course. It materialized in the so-called hypothesis of the "relative stability islands" which shall be dealt with a bit later. This hypothesis played a great part in the determination of the limit of existence of the chemical elements.

In 1877 the Russian chemist Sergei Kern announced his discovery of a new element, davium, which he named after the outstanding English chemist Humphry Davy. This discovery was not confirmed. Many years later the historians came to the conclusion that he was likely to be the first to find traces of rhenium in natural minerals. Rhenium was authentically discovered in 1927.

So, not all of the "false suns" turned out to be really false.

All we have told you here suggests that the history of science cannot be ignored. There is no less of the unexpected in it than in chemistry itself. Sometimes even old, long forgotten things can sparkle and shine like new ones....

The Fate of One of the Hundred and Nine

This is a little story about the fate of a chemical element.

It occupies the box No. 92 and its name is uranium.

The name speaks for itself. Two of the greatest scientific discoveries of all times and all peoples are connected with uranium. These are the

discovery of radioactivity and the discovery of the fission of heavy nuclei. Uranium gave people the key to the mastery of nuclear energy. Uranium helped them to produce elements unknown in nature: the transuranium elements, technetium and promethium.

Historical documents witness that the biography of uranium began on September 24, 1789.

All kinds of things have happened in the history of the discovery of the chemical elements. In some cases nobody knows who the discoverer was. On the other hand there are elements that have a rather bulky list of "discoverers" But uranium's "godfather" has been established quite definitely. This was the Berlin chemist Martin Klaproth, one of the founders of analytical chemistry. However, history has played a prank on him: Martin Heinrich Klaproth proved to be only one of the "godfathers" of our hero.

Pitchblende has been known to man for ages, and was considered an ore of zinc and iron. The sharp eye of the analyst Klaproth suspected an admixture of an unknown metal in it, and soon this suspicion became fact. The new element appeared as a black powder with a metallic lustre. It was named in honour of the planet Uranus, discovered not long before by the English astronomer Herschel.

After that for half a century nobody doubted the truth of Klaproth's discovery. Nobody even dared to question the work of Europe's foremost analytical chemist. The element uranium marched through the pages of chemical textbooks.

In 1843 this triumphant march was slowed down somewhat by the French chemist Eugene

Peligot. He proved that what Klaproth had held in his hands was not the element uranium but only uranium oxide. Later unbiased historians wrote that Peligot could be considered the second "godfather" of the element.

But this did not exhaust the list of "godfathers" of uranium. The third was D. Mendeleyev.

At first uranium just would not fit into the Table. It was given a place in the third group between cadmium and tin, where indium is now situated. This place was allotted to uranium in accordance with its atomic weight, but not its properties. With respect to properties uranium looked like a casual stranger in the box allotted to it.

Mendeleyev concluded that the atomic weight of uranium had been determined incorrectly and he increased it twice. This put uranium in Group VI of the table and made it the last in the series of elements. Such was the third "birth" of uranium.

Soon experimenters showed that Mendeleyev was right.

Where is Thy Place, Uranium?

There are no elements in Mendeleyev's System which have no place at all. There are elements with no definite place. Such, for instance, is the very first of them, hydrogen. Investigators are still at odds as to whether element No. 1 should be in the first, or in the seventh group of the Periodic Table...

Uranium is in much the same predicament.

But had not Mendeleyev determined its position once and for all?!

For decades no one questioned uranium's being in the sixth group of the Periodic Table as the heaviest member of the family including also chromium, molybdenum and tungsten, and its position seemed quite infallible.

But times changed, and uranium was no longer the last in the series of elements. A whole "cohort" of man-made transuranium elements ranged out at its right, and they all had to be placed in the Mendeleyev Table. What groups and what boxes were to be assigned to the transuranium elements? After much controversy a large number of scientists came to the conclusion that they should all be placed together in a single group and in a single box.

This decision did not fall from the Moon, something of the sort had happened once before in the Periodic Table. The lanthanides, a total of 14 elements of the sixth period were all placed together with lanthanum in a single box of Group III.

The physicists had long since predicted that a similar phenomenon would recur in the next period. They stated that a family of elements resembling the lanthanides should exist in the seventh period. The name of this family would be actinides, because it would begin right after actinium which is situated just below lanthanum in the table.

Hence, all the transuranium elements are members of this family. And not only they, but also uranium and its nearest left-hand neighbours, namely, protactinium and thorium. They all had

to leave their old, familiar places in the sixth, fifth and fourth groups, and move into the third.

A long time ago Mendeleyev had moved uranium out of this group. Now it was back in it, but this time with "fuller rights" See what curious things may happen in the life of the Periodic System.

The physicists agreed to such a state of affairs, but not all the chemists, and not without reserve, because as regards properties uranium is just as much a stranger to Group III as it was in Mendeleyev's time. Nor is the third group quite suitable for thorium and protactinium.

Where is thy place, uranium? We shall seek for the answer to this question a bit later.

Little Stories from Archeology

When did man first begin to use iron? The answer seems self-evident: when he learned to smelt iron from its ore. Historians have even established the approximate date of this great event, the date of the beginning of the "Iron Age" on Earth.

But actually the Iron Age started before the primeval metallurgists produced the first kilogram of iron in the primitive furnace. Such was the conclusion drawn by the chemists armed with mighty methods of analysis.

The first pieces of iron used by our antecedents literally fell from the sky. What we call iron meteorites always contain nickel and cobalt besides iron. Now when analysing some of the

most ancient iron tools chemists found them to contain iron's neighbours in the Mendeleyev Table, namely, cobalt and nickel.

These metals are by no means always present in the iron ores on Earth.

Is this conclusion quite unquestionable? Not a hundred per cent, anyway... . The study of antiquity is a very difficult matter. But here one is very likely to come up against the unexpected.

Archeologists once sprang the following surprise on the historians of chemistry.

In 1912, while carrying on excavations among ancient Roman ruins near Naples, Professor Günther of Oxford University found some glass mosaics of surprising beauty. The colour of the glass did not seem to have faded in two thousand years.

To establish the composition of the colouring matter used by the ancient Romans Günther sent two samples of pale green glass to England where they fell into the hands of the chemist Maclay.

The analysis showed nothing unexpected, not to mention some impurity amounting to about one and a half per cent. But what this impurity was, Maclay could not say.

Chance saved the situation. It occurred to someone to see whether the impurity was radioactive. This was very fortunate, for the impurity actually displayed radioactivity. But what element could have caused it?

The chemists reported the unknown impurity to be uranium oxide.

Was this a discovery? Hardly. Uranium salts had rather long since been used for colouring glass. It was one of the first practical uses of

uranium. But in the Roman glasses uranium was evidently a chance admixture.

That put an end to the story for the time being. But some decades later this forgotten fact came to the knowledge of the American archeologist and chemist Kelly.

After extensive investigations, repeated analyses and comparison of various data, Kelly came to the conclusion that the presence of uranium in the ancient Roman glasses was the rule rather than the exception. The Romans knew about uranium minerals and used them for practical purposes, particularly, for colouring glass.

Perhaps this is where uranium's biography starts?

"Mirrors" of the Periodic Law

The Mendeleyev Periodic Law has one peculiar feature and cannot be expressed quantitatively, i.e. in the form of some mathematical formula, not even a cumbersome one. It just proclaims an unquestionable fact that chemical properties of elements recur periodically in order of the growth of their atomic charge, which is numerically equal to the atomic number of the element in the Periodic System.

The Periodic Law finds its graphic expression in the Periodic System of Elements. That is what distinguishes it from the other fundamental laws of nature. Strictly speaking, the Periodic System is unique, because the concept of the period, the main constituent of its "architecture", is defined well enough. The number of graphic forms of the

Periodic System that had been suggested (and are still being suggested) is tremendous. We would like to refer you to page 18 of this book in connection with this. All these forms are kind of "mirrors" of the law discovered by Mendeleyev. To analyze the "reflective abilities" of each of these "mirrors" is the lot of historians of chemistry.

Practice demands certainty. It needs such a form of the Periodic System, which would satisfy the needs of a scientist, a teacher and even a schoolboy, give all of them the key to understand the essentials of modern chemistry and the most important properties of chemical element.

One such version is the so-called classical form of the Periodic System, shown on pages 112, 113.

The Periodic System is something like a live, constantly changing, developing organism. Its task is not only to reflect the long since established facts, but to absorb everything new which results from the joint efforts of chemistry and physics in investigating new properties of the known elements and chemical nature of heavy transuranium elements obtained during nuclear synthesis. As it has been already said, great discoveries have been made within the past few decades. No doubt, all of them must be taken up by the Periodic System. Therefore we found it appropriate to present to the reader another version of the Periodic System (p. 114). It has not found wide aknowledgement yet. However, it reflects the most recent facts about the chemical properties of some elements. Thus, actinides are no longer situated under lanthanides at the bottom of of the Table, but stand next to them. It turned out

MENDELEYEV'S PERIODIC

Periods	Rows	Groups of				
		I	**II**	**III**	**IV**	**V**
1	I	(H)				
2	II	Li 3 6.94, $2s^1$ Lithium	Be 4 9.01218 $2s^2$ Beryllium	B 5 10.81 $2p^1$ Boron	C 6 12.011 $2p^2$ Carbon	N 7 14.0067 $2p^3$ Nitrogen
3	III	Na 11 22.98977 $3s^1$ Sodium	Mg 12 24.305 $3s^2$ Magnesium	Al 13 26.98154 $3p^1$ Aluminium	Si 14 28.085, $3p^2$ Silicon	P 15 30.97376 $3p^3$ Phosphorus
4	IV	K 19 39.098, $4s^1$ Potassium	Ca 20 40.08 Calcium	Sc 21 44.9559 $3d^14s^2$ Scandium	Ti 22 47.90 $3d^24s^2$ Titanium	V 23 50.9415 $3d^34s^2$ Vanadium
	V	29 Cu 63.54, $3d^{10}4s^1$ Copper	30 Zn 65.38 $4s^2$ Zinc	31 Ga 69.72 $4p^1$ Gallium	32 Ge 72.59 $4p^2$ Germanium	33 As 74.9216 $4p^3$ Arsenic
5	VI	Rb 37 85.467, $5s^1$ Rubidium	Sr 38 87.62 $5s^2$ Strontium	Y 39 88.9059 $4d^15s^2$ Yttrium	Zr 40 91.22 $4d^25s^2$ Zirconium	Nb 41 92.9064 $4d^45s^1$ Niobium
	VII	47 Ag 107.868 $5s^1$ Silver	48 Cd 112.41 $5s^2$ Cadmium	49 In 114.82 $5p^1$ Indium	50 Sn 118.69 $5p^2$ Tin	51 Sb 121.7, $5p^3$ Antimony
6	VIII	Cs 55 132.9054 $6s^1$ Cesium	Ba 56 137.33 $6s^2$ Barium	La * 57 138.905, $5d^16s^2$ Lanthanum	Hf 72 178.4, $5d^26s^2$ Hafnium	Ta 73 180.947, $5d^36s^2$ Tantalum
	IX	79 Au 196.9665 $5d^{10}6s^1$ Gold	80 Hg 200.5, $6s^2$ Mercury	81 Tl 204.3, $6p^1$ Thallium	82 Pb 207.2 $6p^2$ Lead	83 Bi 208.9804 $6p^3$ Bismuth
7	X	Fr 87 [223] Francium	Ra 88 226.0254 $7s^2$ Radium	Ac ** 89 [227] $6d^17s^2$ Actinium	Ku 104 [261] $6d^27s^2$ Kurchatovium	105 $6d^37s^2$

* LANTHANIDES

Ce 58 140.12 $4f^16s^2$ Cerium	Pr 59 140.9077 $4f^36s^2$ Praseodymium	Nd 60 144.24 $4f^46s^2$ Neodymium	Pm 61 [145] $4f^56s^2$ Promethium	Sm 62 150.4 $4f^66s^2$ Samarium	Eu 63 151.96, $4f^76s^2$ Europium	Gd 64 157.2, $4f^75d^16s^2$ Gadolinium

** ACTINIDES

Th 90 232.0381 $6d^27s^2$ Thorium	Pa 91 231.0359 $5f^26d^17s^2$ Protactinium	U 92 238.02, $5f^36d^17s^2$ Uranium	Np 93 237.0482 $5f^46d^17s^2$ Neptunium	Pu 94 [244] $5f^67s^2$ Plutonium	Am 95 [243] $5f^77s^2$ Americium	Cm 96 [247] $5f^76d^17s^2$ Curium

SYSTEM OF ELEMENTS

elements

VI	VII	VIII		
	1 H 1.0079 1s¹ Hydrogen			**2** He 4.00260 1s² Helium
8 O 15.999₄ 2p⁴ Oxygen	**9** F 18.998403 2p⁵ Fluorine			**10** Ne 20.17₉ 2p⁶ Neon
16 S 32.06 3p⁴ Sulphur	**17** Cl 35.453 3p⁵ Chlorine			**18** Ar 39.94₈ 3p⁶ Argon
Cr **24** 51.996 3d⁵4s¹ Chromium	Mn **25** 54.9380 3d⁵4s² Manganese	Fe **26** 55.84₇ 3d⁶4s² Iron	Co **27** 58.9332 3d⁷4s² Cobalt	Ni **28** 58.70 3d⁸4s² Nickel
34 Se 78.9₆ 4p⁴ Selenium	**35** Br 79.904 4p⁵ Bromine			**36** Kr 83.80 4p⁶ Krypton
Mo **42** 95.94 4d⁵5s¹ Molybdenum	Tc **43** 98.9062 4d⁵5s² Technetium	Ru **44** 101.0₇ 4d⁷5s¹ Ruthenium	Rh **45** 102.9055 4d⁸5s¹ Rhodium	Pd **46** 106.4 4d¹⁰5s⁰ Palladium
52 Te 127.6₀ 5p⁴ Tellurium	**53** I 126.9045 5p⁵ Iodine			**54** Xe 131.30 5p⁶ Xenon
W **74** 183.8₅ 5d⁴6s² Tungsten	Re **75** 186.207 5d⁵6s² Rhenium	Os **76** 190.2 5d⁶6s² Osmium	Ir **77** 192.2₂ 5d⁷6s² Iridium	Pt **78** 195.0₉ 5d⁹6s¹ Platinum
84 Po 209 6p⁴ Polonium	**85** At [210] 6p⁵ Astatine			**86** Rn [222] 6p⁶ Radon

Atomic mass — U **92** — Atomic number
Distribution of electrons and following completed sublevels
238.02₉ 5f³6d¹7s² Uranium
Distribution of electrons by levels

Atomic masses conform with the International Table of 1977. The accuracy of the last significant digit is ±1 or ±3 if it is set in small type. The numbers in brackets on the mass numbers of the most stable isotopes. The names and symbols of elements in parentheses are not generally adopted.

Tb **65** 158.9254 4f⁹6s² Terbium	Dy **66** 162.5₀ 4f¹⁰6s² Dysprosium	Ho **67** 164.930₄ 4f¹¹6s² Holmium	Er **68** 167.2₆ 4f¹²6s² Erbium	Tm **69** 168.9343 4f¹³6s² Thulium	Yb **70** 173.0₄ 4f¹⁴6s² Ytterbium	Lu **71** 174.96₇ 5d¹6s² Lutetium
Bk **97** [247] 5f⁸6d¹7s² Berkelium	Cf **98** [251] 5f¹⁰7s² Californium	Es **99** [254] 5f¹¹7s² Einsteinium	Fm **100** [257] 5f¹²7s² Fermium	Md **101** [258] 5f¹³7s² Mendelevium	No **102** [255] 5f¹⁴7s² (Nobelium)	Lr **103** [256] 6d¹7s² (Lawrencium)

ONE OF THE MODERN VERSIONS OF THE PERIODIC SYSTEM

Period \ Groups	I a	I b	II a	II b	III a	III b	IV a	IV b	V a	V b	VI a	VI b	VII a	VII b	VIII b	VIII a	0
1								1 H									2 He
2	3 Li		4 Be		5 B		6 C		7 N		8 O		9 F				10 Ne
3	11 Na		12 Mg		13 Al		14 Si		15 P		16 S		17 Cl				18 Ar
4	19 K	29 Cu	20 Ca	30 Zn	21 Sc / 31 Ga		22 Ti / 32 Ge		23 V / 33 As		24 Cr / 34 Se		25 Mn / 35 Br		26 Fe 27 Co 28 Ni		36 Kr
5	37 Rb	47 Ag	38 Sr	48 Cd	39 Y / 49 In		40 Zr / 50 Sn		41 Nb / 51 Sb		42 Mo / 52 Te		43 Tc / 53 I		44 Ru 45 Rh 46 Pd		54 Xe
6	55 Cs	79 Au	56 Ba	80 Hg	ΣLn 81 Tl 57-71		72 Hf / 82 Pb		73 Ta / 83 Bi		74 W / 84 Po		75 Re / 85 At		76 Os 77 Ir 78 Pt		86 Rn
7	87 Fr		88 Ra		ΣAn 89-103		(90 Th) / 104 Ku		(91 Pa) / 105 Ns		(92 U) / 106		107				

		57 La							
ΣLn	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64		

ΣAn	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	(No) 102	(Lr) 103

that the chemistry of actinides is characterized by extreme specificity and they do not have as much in common with lanthanides as had been previously considered.

The zero group was left for the noble gases helium and neon. It is hardly likely that any more or less stable compounds of these elements would ever be obtained. An attempt was also made to express graphically the unique properties of hydrogen, the element which cannot be assigned to any particular group of the Periodic System.

With the development of chemistry, "internal rearrangements" of the Big House are likely to occur, but the framework built by the great Mendeleyev will remain unchanged.

Where Is the Limit?

We would like to repeat once again the prophetic words of Dmitri Ivanovich Mendeleyev: "The future is not likely to damage the Periodic Law, but it promises extensions and development..."

Which "extensions" and which "development" did the twentieth century bring to the Mendeleyev's teaching have been discussed in literature many times. The discovery of new chemical elements in particular "extended" it.

In 1934 the whole world celebrated the 100th anniversary of Mendeleyev's birth. The exact number of elements situated between hydrogen and uranium was known by the time. Just a few had not yet been discovered.

Uranium seemed to be the immovable upper

limit. No one expected that elements heavier than uranium would be discovered.

Six years later this delusion was dispelled. The successful synthesis of transuranium elements started and the bounds of the world of chemical elements began to widen.

That's when the sacramental question arose: where is the limit? Which will be the last atomic number of the element prepared by the nuclear synthesis?

However, we haven't been quite precise. To be honest, this question about the last element in the Table stirred the minds of chemists and physicists as far back as the twenties of our century. And the search for the answer to this question was rather unusual.

The number 137 began to appear on the pages of serious papers in theoretical physics. And one prominent scientist even ventured to write a booklet with a rather unusual title "The Magic Number 137"

As a matter of fact, magic has always fascinated human minds. Extraordinary things attract people. But in most cases, if not always, magic is accompanied by mystery.

In theoretical physics there is no room for mysticism. The "magic" number 137 was actually the product of physical theories and mathematical calculations.

The K-shell is the closest to the atomic nucleus. There are only two electrons in it. The radius of the shell becomes smaller as the nuclear charge increases. Therefore in the uranium atom this shell is much closer to the nucleus than, say, in

potassium. Uranium's nuclear charge is 92. What if it were larger? Having conducted not very complicated calculations, the theorists came to the conclusion that at a certain value of the nucleus charge, the diameter of the K-shell will become the same as that of the nucleus. The result is likely to be as follows: the electron would "fall" on the nucleus and be "swallowed up" by it. This would reduce the total positive charge of the nucleus by one unit. And this event would happen, claimed the theorists, when the charge of the nucleus were equal to 137. This theory obviously suggests that elements with atomic numbers larger than 137 cannot exist.

If this were in fact true, what bright prospects would open before chemistry! It would mean that Mendeleyev's Table was still missing over fourty new elements...

It seemed rather strange, however, that none of those elements had been discovered yet. That is because the number 137 was more mystical than magical. Theorists carried out their calculations not taking into consideration one "minor thing"—the radioactivity of the heavy elements, which makes it impossible for elements heavier than uranium to exist in nature.

This became apparent after the successful synthesis of more than a dozen transuranium elements. The half-life of the first of them neptunium, is too short for it to be found on Earth. With the growth of the nuclear charge of transuranium elements, their half-life decreases swiftly.

And this poses another question: at what value of the nuclear charge would the synthesis of a new

element be impossible, i.e. the synthesized nucleus would fall apart precisely at the very moment of its formation?

The "Relative Stability Islands" (RSI) Hypothesis

RSI stand for "islands of relative stability". But what does it mean? By the fifties the amount of elements known to scientists exceed 100, the atomic numbers became three-digit. The scientists were quite happy. However, the calculations suggested that there would soon be a limit. The list of elements was likely to be cut short somewhere between the 108th and 110th.

The greatest "enemy" of the heavy atomic nuclei is spontaneous fission. It seems as if they feel an "urge", as it were, to split into two fragments. The greater the charge on the nucleus, the more pronounced is this "urge". Thus, the lifetime of No. 104, kurchatovium, is only 3/10 of a second. Therefore, it seemed that the question "where is the limit?" would soon be removed from the agenda.

History took its own course. One can find a lot of examples of how some unusual idea changed the entire course of events, the common mode of thinking.

The RSI hypothesis was one such "crazy" idea. It was born in 1965. The essence of it is as follows: certain heavy transuranium elements can turn out to be resistant to spontaneous fission, "relatively stable", as it were. They may be stable to such a degree, that one can even venture

to synthesize them or even try to find traces of such "superelements" in nature.

Theory gave the precise "coordinates" of such "islands": they were to be situated next to elements No. 110 and No. 114, 126 and 164 (!), and represent "pieces of firm land" in the "ocean of instability".

All this meant that the upper limit of the Periodic System was again uncertain.

The RSI hypothesis made physicists optimistic. The investigators applied themselves to the work enthusiastically. It seemed that the first confirmation of the correctness of the theory was about to occur, the flag with the name and the symbol of the new element on it would be hoisted on the first "island". But nothing of the kind ever happened, although two decades passed since the birth of the hypothesis.

The nuclear synthesis of the lightest among the "islanders", No. 110 and No. 114, encountered some technical difficulties which were hard to overcome. A series of experiments were conducted, but nobody could tell what particular nuclei had been obtained. More hopes were set on finding such elements in nature. From time to time scientists reported to have found traces of some unknown heavy elements in the samples of minerals. The tests for radioactivity usually confirmed their finds. But no one was lucky enough to see even a tiny speck of such elements. Consequently it turned out that these finds were false. This is where the "track of false suns" had led scientists...

The attitude toward the RSI hypothesis became cooler and cooler.

The recent syntheses of elements No. 108 and No. 109 proved that their lifetime is a matter of thousandths of a second. Maybe it was wrong to send the theories of the fifties to the archives? Maybe the notorious limit is quite near?

Maybe. It might just be that the RSI hypothesis will remain in the history of nuclear physics as a beautiful legend of a theoretical mistake. But it would be premature to reject it altogether. It has happened more than once that a theory began to work many years after being proposed. Even a negative result is a result.

"Computer" Chemistry

If the seekers of "superelements" finally succeeded in synthesizing them, the quantity would be a matter of several atoms. At the beginning, anyway. And that would present another problem.

The physicists would be satisfied with some information about the radioactive properties of the newborn nuclei and of their mass. But what about the chemists? They are interested primarily in the chemical properties of elements. This requires some knowledge of how the electrons arrange themselves in the outer shells of atoms.

One or two dozen atoms is too little for chemical experiments. However, history knows of some examples when chemists succeeded in accounting for the main chemical properties of an element having just a few atoms of it at their disposal. This applies to kurchatovium and nielsbohrium. But in this case, the investigators, being guided

by the Periodic System, could foresee that the 104th element would be like hafnium and the 105th like tantalum. In accordance with this they worked out the strategy of an experiment involving only several dozen atoms.

What would the 114th, 110th, and say, 126th be like? Would the Periodic System be of any help in this matter?

As we know, its seventh period is unfinished. Like the previous one, the sixth, it should comprise 32 elements. Obviously, the 110th element would be like platinum, and the 114th—like lead.

"Obviously" does not mean "definitely".

Let's look at the examples again. When chemists studied the properties of actinides in detail, they became convinced that this group of elements from the seventh period and the lanthanides from the sixth were representatives of two noticeably different chemical worlds. Their chemical characteristics are completely different. The present position of actinides below lanthanides, which is common for most modern variants of the Periodic System, is only a tribute to the past. The expected analogy is not there.

This fact puts one on the alert. Maybe the unknown elements of the seventh period might also behave in a whimsical way? This question cannot be answered offhand. It requires lots of calculations involving physical and mathematical methods. Those calculations are extremely labour-consuming. It is not possible to carry them out "by hand".

In such cases, the computer comes to the rescue. Sometimes it produces the result in matter of seconds, sometimes it has to do some "hard

thinking" which takes many hours. But those periods of time are nil compared to years and years it would take to calculate on paper.

All the necessary data, such as the parameters of the atomic structure, the main properties of the known chemical elements and regularities of their changes, were fed into the computer. All the computer had to do was to work out the electron configurations for a large number of hypothetical elements and to evaluate the most important chemical properties of some of them. It was a big job for the computer to do, since the investigators' interests were very broad. They intended to penetrate into such distant areas of the Periodic System, that it took one's breath. For instance, several works were dedicated to the element with the atomic number... 184.

But this sounds unreal. Let us stick to the business. What forecasts were made with respect to element No. 114? It will look like lead, but will possess some properties not quite common to lead. The same applies to the other hypothetical elements of the seventh period: every one of them apparently had a surprise of its own in store for the researchers. In a word, it appears that the further the element is from the beginning of the Periodic Table, the more extraordinary its properties are. Therefore, one should be very careful in drawing analogies.

When the computer produced the results of the calculations regarding the elements of the eighth period, it was the physicists turn to get surprised: this period should consist of 50 elements and end with the "superheavy" noble gas ("noble liquid", to be more exact) with the atomic

number 168. This, at least, could be expected
following the regularities of the Periodic System
and the structure of atoms. The computer was of
a different opinion: it was inclined to consider
element No. 164 to be the upper limit of the
eighth period. Previously the theorists tried more
than once to draw a sequence of formation of the
electron configurations of the atoms of the eighth
period. And there was not too much controversy
among them. But the sequence suggested by the
computer was quite unexpected. It was more
chaotic than regular. It was not actually chaotic
in the full sense of this word: simply some other,
yet unknown, laws started working in this dis-
tant area of the world of elements, laws of a
mysterious nature.

Here is the conclusion drawn by the chemists.
Had those fantastic elements really come into
existence chemists would have had to think hard
before choosing the proper place for them in the
Periodic System in conformance with the archi-
tectural principles of the Big House: "in the
opinion of the computer" their properties were
specific in the sense that they should not change
with the growth of the atomic number in the old
way. Had those elements become real, the pre-
sent concept of the phenomenon of periodicity
would have been amended.

A scientist once "christened" this sphere of
theoretical chemistry as "computer chemistry".
So far, these theoretical calculations serve to
demonstrate the abilities of computer technology
and tease the investigators' imagination. But
what a great thing it would be if these elements
materialized! A new fascinating world of unusual

chemical elements, of extraordinary chemistry, would open up to hundreds and thousands of impatient researchers.

All that is necessary is to find the ways to synthesize such elements. The sceptic might say, however, that those ways shall never be found, because wise nature knows the exact amount of elements necessary for it. All those "transuranium" and "superelements" are nothing but "manufactural wastes" discarded a long time ago. So, is it worth trying to revive them by putting so much money and effort into it? Every atom of a heavy transuranium element is worth a pretty sum of money.

The sceptic is fundamentally wrong. The penetration into the sphere of the yet unknown elements is likely to deepen and widen our knowledge of the material world. Every scientific achievement is worth a great deal of effort.

Now it is high time to finish our series of stories about the inhabitants of the Big House. Though, wait! We have something else to tell you.

Element Register

There was once a rum fellow who when told about the stars, about their structure and why they emit light, exclaimed: "I can understand all that! But what I want to know is how the astronomers discovered the names of the different stars."

Stellar catalogues contain hundreds of thousands of "christened" heavenly bodies. But don't think that such pretty names as "Betelgeuse" or

"Syrius" have been thought up for all the stars. Astronomers prefer to denote stars by a sort of code, a combination of letters and figures. If they did not, there would be much confusion. But from the code the expert can easily locate the star and determine its spectral class.

The number of chemical elements is incomparably smaller than that of the stars. But here also their names often conceal thrilling stories of their discovery. And chemists who had discovered a new element were not infrequently at a loss to find a name for the "newborn".

It was important to think up a name which would be at least partly indicative of the element's properties. Such were business names, if you like. They could hardly be called romantic. Examples are hydrogen (the Greek for "producing water"), oxygen ("producing acid"), and phosphorus ("light-bringing"). These names record important properties of the elements.

Some elements were named after the planets of the solar system; such are selenium, and tellurium (from the Greek for Moon and Earth, respectively), uranium, neptunium and plutonium.

Other names are derived from mythology.

One of these is tantalum. Tantalus, the favourite son of Zeus, was cruelly punished for an offence against the gods. He had to stand up to his neck in water and above him hung branches with juicy aromatic fruit. But whenever he wanted to quench his thirst the water would flow away from him, and whenever he wanted to appease his hunger and stretched his hand out to pick a fruit, the branches would swing away from him. The sufferings experienced by chemists before

their efforts to isolate the element tantalum from
its ores were successful could be compared only
to those of Zeus's son...

The names titanium and vanadium also stem
from Greek mythology.

There are elements which were named in honour
of various countries or continents, such as ger-
manium, gallium (from Gaul, the ancient name
of France), polonium (Poland), scandium (Scan-
dinavia), francium, ruthenium (Ruthenia is the
Latin for Russia), europium and americium.
Other elements were named after cities. These
are: hafnium (Copenhagen), lutetium (from Lute-
tia, the Latin name for Paris), berkelium (in
honour of the town of Berkely, USA), yttrium,
terbium, erbium, and ytterbium (after Ytterby,
a small town in Sweden where the mineral
containing these elements was first discovered).

Finally, some elements were named to immorta-
lize the names of great scientists: curium, fermi-
um, einsteinium, mendelevium, and lawrencium
kurchatovium and nielsbohrium.

There is still some controversy among scient-
ists as to the origin of the names of the elements
of antiquity, and nobody knows so far just why,
say, sulphur is called sulphur, iron—iron, or
tin—tin.

See how many curious things we find in the
register of the chemical elements!

Snake with Its Tail in Its Mouth

The Spirit of Chemical Science

Almost everything on the Earth around us consists of chemical compounds, of a great variety of combinations of the chemical elements.

However, the number of elements that exist on Earth in the form of elementary substances is not so small. Almost all of the Earth's atmosphere consists of the gaseous nitrogen and oxygen. It also includes the insignificant admixtures of argon, neon, helium, krypton and xenon. Oxygen and nitrogen, however, occur on our planet as part of a great number of different compounds as well, whilst no natural compounds of the noble gases have been discovered yet. Gold, silver, mercury and copper are also simple substances on Earth. They were the first to be discovered by man in times immemorial. Carbon is rather common in the form of coal and graphite, but most of it is a part of living organisms.

And yet compounds are the absolute champions.

A very long time ago the clot of cosmic matter which finally became our planet, consisted all of only the atoms of almost 100 chemical elements. Hundreds, thousands, millions of years passed. Conditions changed. The atoms reacted with one another. The gigantic laboratory of nature began to operate. During its long evolution nature, the chemist, learned to prepare all

kinds of substances, from the simple water molecule to infinitely involved proteins.

The evolution of the globe and of life on it is due largely to chemistry.

The great diversity of chemical compounds owes its existence to processes called chemical reactions. They are the true spirit of chemical science, and its principal subject matter. It is impossible to estimate even approximately the number of chemical reactions that occur in the world, say, in the course of only one second.

For instance, for a person to pronounce the word "second" many chemical processes must occur in his brain. We speak, think, enjoy ourselves, or worry, and all these actions are attended by millions of chemical reactions. We never see these reactions, but there is also an immense number of chemical reactions that we do observe daily just offhand, without stopping to think of them.

When we put a slice of lemon into a cup of strong tea, the tea becomes pale. We strike a match and a stick of wood bursts into flame and turns into charcoal.

These are all chemical reactions.

The primeval man who learned to light a fire was the first chemist. He accomplished at will the first chemical reaction, that of combustion. And this reaction is the most necessary, the most important in all the history of mankind.

It gave our distant ancestors the heat to warm their dwellings on cold days. In our time it has opened the way to outer space by propelling rockets weighing many tons into the sky. The legend of Prometheus who gave people fire is at

the same time the legend of the first chemical reaction.

When simple substances or compounds interact with each other, they usually let us know about it.

Drop a piece of zinc into a solution of sulphuric acid. Immediately gas bubbles begin to rise from it and after some time the metal disappears. The zinc dissolves in the acid, liberating hydrogen. You could see for yourself how it all happened.

Or light a lump of sulphur. It burns with a bluish flame and you can smell the asphyxiating odour of sulphur dioxide, the chemical compound which forms when sulphur combines with oxygen.

Moisten a white powder of anhydrous copper sulphate $CuSO_4$ with water, and it immediately turns blue. The salt combines with the water to form crystals of blue vitriol $CuSO_4 \cdot 5H_2O$. Substances of this kind are called crystal hydrates.

Do you know what quenching of lime is? Water is poured on quicklime and the result is slaked lime $Ca(OH)_2$. Though the substance does not change colour, it can easily be seen that a reaction has occurred, because when lime is quenched a great deal of heat is liberated.

The primary and invariable condition of all chemical reactions is that they are accompanied by the liberation or absorption of thermal energy. Sometimes so much heat is liberated that it can readily be felt. When the amount of heat evolved is small, special methods of measurement are used.

Lightning and Tortoises

An explosion is a terrible thing. It is terrible because the explosion occurs instantly, in a split second.

But what is an explosion? It is just an ordinary chemical reaction accompanied by the evolution of a large amount of gases. It exemplifies a chemical process which takes place instantaneously, such as the combustion of gun powder in a bullet shell or the explosion of dynamite.

But an explosion is a sort of extreme. Most reactions take some length of time to occur.

There are many reactions which proceed so slowly that they can hardly be detected.

Imagine a mixture of two gases, hydrogen and oxygen, the components of water, in a glass vessel. They may stand in it for a very long time: a month, a year, a hundred years, without a single drop of moisture being detected on the surface of the glass. One might think the hydrogen is not combining with the oxygen at all, but actually it is, though very slowly. It would take thousands of years for a hardly perceptible quantity of water to form at the bottom of the vessel.

Why is this so? Because of the temperature. At room temperature (15-20 °C) hydrogen reacts with oxygen only very slowly. But if we heat the vessel, its walls begin to sweat, and this is a sure sign that a reaction is occurring. At 550 °C the vessel flies apart in tiny fragments, because at this temperature hydrogen reacts with oxygen with explosion.

Why does heat accelerate this chemical process so, making the "tortoise" move like lightning?

In the free state hydrogen and oxygen exist as the molecules H_2 and O_2. To combine into a water molecule they must collide. The more often such collisions take place, the greater the probability that a molecule of water will form. At room temperature and ordinary pressure each hydrogen molecule collides with an oxygen molecule more than ten billion times per second. If each collision resulted in chemical interaction, the reaction would proceed faster than an explosion, in the course of one-ten-billionth of a second.

But we do not observe any change in our vessel: neither today, nor tomorrow, nor in ten years. Under ordinary conditions only very rare collisions result in chemical reaction. The trouble is that the hydrogen and oxygen collide as molecules.

Before they can react they have to break up into atoms. To put it more exactly, the chemical bonds between the oxygen atoms and the hydrogen atoms in their molecules must be weakened. They must be weakened to such an extent that they should not be able to prevent the combination of unlike hydrogen and oxygen atoms. Now the temperature is the whip which makes the reaction go faster. It increases the number of collisions many times over. It makes the molecules vibrate more strongly, and this weakens their chemical bonds. And when hydrogen and oxygen meet each other at the atomic level, they react instantly.

The Magic Barrier

Imagine this.

Hardly has hydrogen been mixed with oxygen that water vapour appears. Hardly does an iron plate come into contact with air that it becomes coated with reddish brown rust, and a few minutes later the solid lustrous metal has turned into a loose powder, iron oxide.

All the chemical reactions in the world proceed at a breath-taking speed. All molecules react with each other independent of the energy they possess. Each collision between two molecules results in their chemical union.

All the metals would disappear from the face of the Earth, because they would be oxidized. Organic compounds, including those constituting living cells would change into simple, but more stable compounds.

It would be a strange world, a world without life, a world without chemistry, a fantastic world of very stable compounds with no inclination to enter into chemical reactions.

Fortunately no such nightmare threatens us. There is a magic barrier which stands in the way of such a universal "chemical catastrophe".

This barrier is known as activation energy. Molecules cannot enter into chemical reactions unless their energy equals or exceeds their activation energy.

Even at ordinary temperature there will be molecules, among those, say, of hydrogen and oxygen, with energies greater than or at least equal to their activation energy. That is why water forms, though very slowly, under such con-

ditions. The reaction is slow because the number
of sufficiently energetic molecules is too small.
But a high temperature brings many molecules
up to the activation barrier, and the number of
instances of chemical interaction between hydro-
gen and oxygen grows enormously.

A Few Words About Equilibrium

Medicine has its specific symbol which has come
down to us from ancient times. Today military
doctors of many countries wear badges on their
shoulder straps in the form of a snake coiled
around a staff or the stem of a cup.

Now there is a similar symbol in chemistry.
It is a snake with its tail in its mouth.

The ancients had a cult of all kinds of mystic
signs, the meaning of which is often difficult to
explain today.

So much for mystic signs, but the "chemical
snake" has a quite definite meaning. It symbo-
lizes a reversible chemical reaction.

Two atoms of hydrogen and one of oxygen
combine to form a molecule of water. Simultane-
ously another molecule of water decomposes into
its component parts. Two opposite reactions
take place in the same instant: the formation of
water (the forward reaction) and its decomposi-
tion (the reverse reaction). A chemist would
represent these two contradictory processes as
follows: $2H_2 + O_2 \rightleftarrows 2H_2O$. The arrow pointing
to the right indicates the forward reaction, and
that pointing to the left, the back reaction.

Fundamentally, all chemical reactions without exception are reversible.

At first the forward reaction predominates. The scales tilt towards the formation of water molecules. Then the opposite reaction begins to increase. Finally, there comes a moment when the number of molecules formed equals the number of decomposed molecules, and both reactions, from left to right and from right to left, proceed at an equal rate.

A chemist would say that equilibrium has been established.

It is established sooner or later in any chemical reaction, sometimes instantaneously, or after several hours, days, or weeks, in others.

In its practical activities chemistry pursues two aims. First, it tries to make the chemical process go to completion, so that the initial substances react entirely with each other. Secondly, it strives to obtain a maximum yield of the products needed. To accomplish these aims the establishment of chemical equilibrium must be postponed as far as possible. Forward reaction— yes, reverse reaction—no.

And here the chemist has to become something of a mathematician. He finds the ratio between two quantities, between the concentration of the substances formed and the concentration of the initial substances entering into the reaction.

This ratio is a fraction. The larger the numerator, and the smaller the denominator of any fraction, the larger the fraction.

If the forward reaction predominates, the amount of the products will in time exceed the amount of the initial substances. The numerator

will then be greater than the denominator and the result will be an irregular fraction. In the reverse case the fraction will be a regular one.

The chemist calls the value of this fraction the equilibrium constant of the reaction and denotes it by K. If he wants the reaction to result in the largest amount of the product needed he must first calculate K for different temperatures.

For example, the most favourable conditions for ammonia synthesis are as low a temperature and as high a pressure as possible. This is the domain of another law acting in the realm of chemical reactions.

This law is known as Le Chatelier's principle, after the French scientist who discovered it.

Imagine a spring built into a fixed support. If it is neither compressed nor stretched it may be said to be in equilibrium. But if it is compressed or stretched, the spring comes out of its state of equilibrium. Simultaneously its elastic forces, those that counteract compression or stretching of the spring, begin to increase. Finally, there comes a moment when both forces again balance each other. The spring is once more in a state of equilibrium, but not the same as it was initially. Its new equilibrium is displaced towards compression or stretching.

The change in the state of equilibrium of a strained spring is an analogy (though rather a crude one) of the action of Le Chatelier's principle. Here is how it is formulated in chemistry. Let an external force act on a system in equilibrium. Then the equilibrium will shift in the direction indicated by the external influence.

It will shift until the reactive forces balance those applied externally. Have a look at the reaction of the ammonia synthesis $N_2 + 3H_2 \rightleftarrows \rightleftarrows 2NH_3$. The equation shows that four volumes of gases (three volumes of hydrogen and one volume of nitrogen) give two volumes of gaseous ammonia ($2NH_3$). Increasing the pressure tends to reduce the volume. In this case the influence is favourable. The "spring" is compressed. The reaction proceeds mainly from left to right: $N_2 + 3H_2 \rightarrow 2NH_3$, and the yield of ammonia increases.

Ammonia synthesis involves a release of heat. If we heat the mixture, the reaction will proceed from right to left, because heating increases the volume of the gases, and the volume of the reactants ($3H_2$ and N_2) is larger than the volume of the resultant ($2NH_3$). Hence, the reverse reaction will predominate over the forward one. The "spring" will stretch.

Both influences result in a new state of equilibrium, but in the first case it corresponds to an increase in the ammonia yield, whereas in the second case the yield will decrease sharply.

How to Make a Tortoise Go Like "Lightning" and Vice Versa

A hundred and fifty years ago a chemist carefully introduced a platinum wire into a vessel containing a mixture of hydrogen and oxygen.

The result was extraordinary. The vessel filled up with fog, that is, with water vapour. The temperature remained unchanged and so did

the pressure, but the reaction between hydrogen and oxygen, "calculated" to take thousands of years, occurred in a matter of seconds.

Nor was this all. The platinum wire, which had caused the two gases to combine instantly, had undergone absolutely no change. Its appearance, chemical composition, and weight, were exactly the same after the experiment as before it.

Now the scientist was by no means a magician, one of those who invents all kinds of clever tricks to amuse a curious public. This was a serious investigator, the German chemist Döbereiner. The phenomenon he observed is now called catalysis. Substances capable of "making tortoises go like lightning" are called catalysts. Catalysts are literally legion. They may be metals, solid or powdered, oxides of a great variety of elements, salts, or bases. They may be used as separate substances or as mixtures.

Without a catalyst the efficiency of ammonia synthesis is very low, no matter how we vary the pressure and temperature. But the presence of a catalyst makes things entirely different. Ordinary metallic iron with an admixture of aluminium and potassium oxides accelerates the reaction considerably.

Twentieth-century chemistry owes its unprecedented progress to the use of catalysts. Nor is this all. Various vital processes occur in animal and plant organisms owing to the presence of special catalysts called enzymes. The chemistry of all animate and inanimate nature—this is the range of these wonderful accelerators!

But what if we take a copper, aluminium or iron wire instead of a platinum one? Will the

vessel walls again become foggy? Alas! Hydrogen and oxygen display no inclination to react as they did when urged on by the magic platinum wand.

Not every substance can accelerate any particular process. Therefore chemists say that catalysts are selective in their action: they may influence one reaction vigorously without paying attention at all to another. Of course, there are exceptions to this rule. For example, aluminium oxide is capable of catalyzing several dozen different synthesis reactions of both organic and inorganic compounds. Finally, different catalysts may make a mixture of the same substances react differently, i.e. to form different products.

There are substances with no less surprising properties, called promoters. Taken by themselves, they do not influence the course of the reaction, neither accelerating nor decelerating it. But if added to a catalyst, they accelerate the reaction to a much greater degree than the catalyst itself. A platinum wire with "impurities" of iron, aluminium, or silicon dioxide, would produce a still more catalytic effect in the reaction between hydrogen and oxygen.

There is also another kind of catalysis, inside-out catalysis. There are anticatalysis and anticatalysts. Scientists called them inhibitors. Their purpose is to slow down rapid chemical reactions,

Chain Reactions

Suppose we have a mixture of two gases, chlorine and hydrogen, in a glass flask. Under ordinary conditions, they react very slowly. But try

lighting a magnesium ribbon near the flask.

An explosion occurs immediately (if anybody wants to try this experiment, be sure to shield the flask with a hood made of thick wire).

Now why does the mixture of chlorine and hydrogen explode under the action of bright light?

The answer is that a chain reaction is involved. If we heated the flask to about 700 °C, it would also explode: the chlorine and the hydrogen would combine instantly, in a split second. This would not surprise us, because we know that heat increases the activation energy of the molecule manifold. But in the experiment just mentioned the temperature did not change. This reaction was caused by light.

Quanta, these tiniest portions of light, carry a large amount of energy. Much more than that needed to activate molecules. Now when a chlorine molecule happens to get into the path of a light quantum, the quantum tears it apart into atoms and passes its energy over to them.

The chlorine atoms are now in an excited, energy-rich state. These atoms, in their turn, bear down upon the hydrogen molecules and tear them apart into atoms too. One of the latter combines with a chlorine atom and the other remains free. But it is excited. It craves to give away part of its energy. To whom? Why, to a chlorine molecule. And when it collides with the one, that is the end of the phlegmatic chlorine molecule.

And now again there is an active chlorine atom at large, but it does not take long for this atom to find an outlet for its energy.

Thus we get a long consecutive chain of reactions.

As soon as the reaction starts, more and more molecules are activated by the energy liberated as a result of the reaction. The rate of the reaction increases like an avalanche of snow rolling down a mountain. When the avalanche reaches the valley it dies down. The chain reaction dies out when all the molecules have been caught up by it, when all the hydrogen and chlorine molecules have reacted.

Chemists know multitudes of chain reactions. Our prominent scientist Nikolai Semyonov has studied how these reactions occur in great detail. Chain reactions are known to physicists too. The fission of uranium nuclei by neutrons is an example of a physical chain reaction.

How Chemistry Made Friends with Electricity

It was an odd thing, at first glance, for a respectable man held in high esteem by all his friends, to occupy himself with.

First he prepared little metallic discs. Dozens and dozens of discs, copper and zinc ones. Then he cut up several sponges into round slices and soaked them in salt water. After this he began to stack the pieces on top of each other in much the same way as a child builds a pyramid, but, observing a certain sequence: a copper disc, a slice of sponge, a zinc disc. And he repeated this sequence many times. In a word, as long as he could keep the stack from falling down.

The man touched the top of his original structure with a moistened finger, and jerked his hand away immediately: he had received what we would now call a substantial electric shock.

That was how in 1800 the famous Italian physicist Alessandro Volta invented the galvanic cell, a chemical source of current. The electricity appeared in the "volta column" as a result of chemical reactions.

This marked the birth of new branch of science called electrochemistry.

Scientists acquired an instrument by means of which they could produce electric current over a considerable length of time. The current would continue to flow until the chemical process in the "volta column" stopped.

It appeared interesting to find out how electricity would act on different substances.

Two Englishmen, Carlisle, a physician, and Nicholson, an engineer, decided to start with water. By that time chemists had sufficient grounds to state that water consisted of hydrogen and oxygen. But somehow they had been unable to obtain conclusive proof.

Carlisle and Nicholson used an electric battery consisting of 17 voltaic cells. It gave a very strong current. And the water began to decompose vigorously into two gases, hydrogen and oxygen; in other words, electrolysis set in. That is what we call the process of decomposition of substances by electricity.

Enemy Number One...

Hundreds and thousands of blast furnaces produce steel and iron all over the world. Economists of different countries scrupulously calculate how many million tons of metal were put out this year and predict the amount to be smelted next year.

And the same economists inform us of the astounding fact that every eighth blast furnace operates in vain. Each year about 12 per cent of the metal produced is ingloriously lost to mankind, falls victim to a merciless enemy... .

The name of this enemy is simply rust. Science calls it metal corrosion.

Not only iron and steel perish but the non-ferrous metals copper, tin and zinc too.

Corrosion means oxidation of metals. Most of them are not very stable in the free state. And even in the air the lustrous surface of a metallic article becomes coated after some time with ominous varicoloured oxide patterns.

When oxidized, metals and alloys lose their numerous valuable properties. They become weaker and less elastic and their thermal and electrical conductivities decrease.

Once started, corrosion never stops half-way. Slowly but surely the "brown devil" will completely demolish the metallic article. A few oxygen molecules hit the surface of the metal. The first few molecules of oxide are formed. What is called an oxide film appears. It is quite loose and the metal atoms pass through it like through a sieve only to become oxidized immediately in their turn. Also, oxygen molecules

pass through the pores of the film into the depths of the metal where they continue their destructive mission.

In a more aggressive chemical environment corrosion proceeds more rapidly. Chlorine, fluorine, sulphur dioxide and hydrogen sulphide are no less dangerous enemies to metals. When a metal corrodes under the action of gases, chemists call the phenomenon gas corrosion.

And what about various solutions? They are also terrible enemies of metals. For example, ordinary sea water. Huge ocean liners must from time to time be docked for general overhaul, to have the corroded platings of their bottoms and sides replaced.

Here is an instructive story about a disastrous blunder an American millionaire once made.

He wanted to have the best yacht in the world. He put in an order and thought up a romantic name "The Call of the Sea". He spared no money. The contractors did their utmost to please their client. It remained only to finish the interior decorations.

But the yacht never went to sea; it never had a chance to. A short time before the day the yacht was to be launched, its body and bottom were found to have completely corroded.

Why? Because corrosion is an electrochemical process.

The shipbuilders had decided to plate the bottom of the yacht with a nickel-copper alloy called German silver. It was a good idea because this alloy, though expensive, resists corrosion in sea water very well. It resists corrosion all right, but it is not very strong. And therefore

many parts of the ship had to be made of other metals, special steels.

And this was the undoing of the yacht. Powerful galvanic cells formed at the points of contact between the German silver and the steel and the bottom immediately began to disintegrate. The end was sad.

The millionaire's grief was indescribable, and the yacht builders remembered ever after one of the laws of corrosion, that its rate increases sharply if to the principal metal are added other metals capable of forming a galvanic cells with it.

. And How to Fight It

There is a remarkable column in Delhi which has stood there for many centuries. It is remarkable because it is made of pure iron. Time has no effect on it. Ages have passed, but the column still looks quite new. It does not rust. As if corrosion had in this case betrayed its habits.

How the ancient metallurgists succeeded in producing pure iron is quite a puzzle. Some hotheads have contended that it was not even made by man. That visitors from other worlds had put up this obelisk to commemorate their arrival on Earth.

But if we deprive the column of the mysterious aureole of its origin, there remains a fact which is very important to chemists, namely, that the purer a metal is, the slower it is attacked by corrosion. If you want to conquer corrosion, use the purest metals possible.

And not only purity is important; it is also necessary to give the surface of the metallic article as high a finish as possible. It appears that separate "hills" and "valleys" can play the part of foreign inclusions. Scientists and engineers have succeeded in obtaining almost ideally smooth surfaces. Articles with such surfaces have already found usage in the construction of rockets and spaceships.

And so is the problem of corrosion prevention solved? By no means. Very pure metals are expensive and difficult to obtain, especially in large quantities. Besides, engineering prefers alloys, because their range of properties is much wider. And an alloy is at least two metals.

Chemists have studied all kinds of corrosion mechanisms in sufficient detail. And when they intend to obtain a new alloy with predetermined properties, they thoroughly consider the "corrosion" aspect among others. There are at present many alloys which resist corrosion very well.

In our everyday life we often have to do with galvanized and tin-plated articles. Iron is coated with a film of zinc or tin to protect it from rust, which helps for some length of time. Besides, we have all seen iron house roofs coated with a dense layer of oil paint.

To weaken or decrease corrosion also means to decrease in some way the velocity of the electrochemical reaction constituting the corrosion process. Special organic and inorganic substances called inhibitors are used for this purpose.

At first they were sought by trial-and-error methods and were found by accident.

In old times Russian gunsmiths used a curious

method. To remove scale from gun barrels they would wash (pickle) them with sulphuric acid mixed with wheat husks. In this primitive manner they kept the acid from dissolving the metal.

The search for new inhibitors is now no longer an inspired art, nor a matter of luck, but an exact science. Hundreds of chemical corrosion inhibitors of all kinds are known today.

We must look after the "health" of metals before they are "infected" by corrosion. This is the main task of the "metal-doctor' chemists.

A Luminous Jet

How many states of matter are there? Three of them are widely known: gas, liquid, and solid. Strictly speaking, we practically never encounter any others in our daily life. Chemistry has also contended itself with these three for centuries. And only during the last decades has it begun to take an interest in the fourth state of matter, plasma.

Plasma is also a gas, if you like, but not an ordinary one. Besides neutral atoms and molecules it contains ions and electrons. An ordinary gas also contains ionized particles, and the higher its temperature the more of them it contains. Therefore there is no distinct boundary line between an ionized gas and plasma. But it is conventionally considered that a gas has turned into plasma when it begins to display the principal properties of the latter, say, high electrical conductivity.

Paradoxical as it may seem at first glance,

plasma is the master in the universe. The matter of the Sun and the stars, as well as the gases of outer space are in the plasma state. All this is natural plasma. On Earth it has to be prepared artificially, in special apparatuses called plasmotrons. In them various gases (helium, hydrogen, nitrogen, argon) are converted to plasma by means of an electric arc. The luminous plasma jet is compressed by the narrow channel of the plasmotron nozzle and by a magnetic field, so that a temperature of several tens of thousands of degrees develops in it.

Chemists had long dreamt of such temperatures, because the role of high temperatures for many chemical processes can hardly be overestimated. Now this dream has come true: a new branch of chemistry known as plasmochemistry, or the chemistry of "cold" plasma, has been born.

Why "cold" plasma? Because there is also "hot" plasma with a temperature of up to million degrees. This is the plasma with which physicists are trying to achieve thermonuclear synthesis, i.e. to accomplish the controlled nuclear reaction of transformation of hydrogen into helium.

But chemists are quite content with "cold" plasma. To investigate the course of chemical processes at a temperature of ten thousand degrees—what could be more alluring?

Sceptics thought this work would be in vain, because in such a hot atmosphere all substances without exception would share the same fate, they would all be destroyed, and even the most intricate molecules would be dissociated into separate atoms and ions.

Actuality is far more complex. Plasma not

only destroys, but creates too. New chemical compounds can readily be synthesized in it, some of which cannot be obtained by other means.

These are strange substances never described in any chemical textbook: Al_2O, Ba_2O_3, SO, SiO, $CaCl$, etc. In them the elements display unusual, anomalous valences. This is all very interesting, but plasmochemistry has set itself more important tasks, namely, the cheap and rapid production of already known valuable substances.

And now a few words about its achievements.

Acetylene is a very important starting material for many organic syntheses, e.g. for the production of plastics, rubbers, dyes, and medicines. But acetylene is still prepared as of old, by decomposing calcium carbide with water, which is expensive and inconvenient.

In the plasmotron everything is different. Plasma made from hydrogen has a temperature of 5000 °C. The hydrogen plasma jet carries its enormous energy into a special reactor to which methane is fed. The methane is mixed vigorously with the hydrogen and in the course of one ten-thousandth of a second more than 75 per cent of the methane changes into acetylene.

Isn't that ideal? We should say so! But alas, there is always a hitch somewhere. If we leave the acetylene for an extra instant in the high-temperature zone of the plasma it begins to decompose. Hence the temperature must be lowered swiftly to a safe level. There are different ways of accomplishing this, but it is the main technical difficulty. So far only 15 per cent of the acetylene formed can be saved from dissociation. But even that is not so bad!

A method of decomposing cheap liquid hydro-carbons plasmochemically to form acetylene, ethylene, and propylene has been developed in the laboratory.

A very important problem that has still to be coped with is the fixation of atmospheric nitrogen. The chemical production of nitrogen-containing compounds, e.g. ammonia, is a very laborious, involved and expensive operation. A few decades ago attempts were made to synthesize nitrogen oxides electrically on an industrial scale, but the economics of the process was too low. Here also plasmochemistry holds much more promise.

The Sun as a Chemist

Once Stephenson, the inventor of the steam locomotive, was taking a walk with his friend Beckland, a geologist, near the first railway in England. Presently they saw a train passing.

"I say, Beckland," asked Stephenson, "what do you think makes that train go?"

"Why, the hand of the driver of one of your wonderful locomotives."

"No."

"Well then, the steam that moves the machine?"

"No."

"The fire kindled under the boiler?"

"Wrong again; it is actuated by the Sun which shone in that far-off epoch when the plants were alive that afterwards changed into the coal which the driver is shovelling into the stoker."

All living things owe their origin to the Sun,

especially plants. Try and grow them in the dark, and all you will get are pale thin filaments instead of juicy green stalks. Under the action of solar light chlorophill (the colouring matter of green leaves) converts the carbon dioxide of the air into molecules of organic substances which constitute the bulk of the plant.

Hence, is the Sun, or rather its rays, the chief "chemist" synthesizing all the organic substances in plants? It would seem so. Not in vain has the process of assimilation of carbon dioxide by plants been named photosynthesis.

It is known that many chemical reactions occur under the action of light. There is even a special branch of chemistry which studies them, called photochemistry.

But so far the study of photochemical reactions has not resulted in the creation of either proteins or carbohydrates in the laboratory. And it is these compounds that are the primary products of photosynthesis in plants.

At the initial stage the plant uses only carbon dioxide, water and solar light for the synthesis of very intricate organic molecules. But maybe there is something else that plays a part in these processes? Imagine a factory with soda, petroleum, potassium nitrate, etc., being fed through pipes at one end and lorries loaded with bread, sausage, and sugar driving out of its gates at the other end. This is fantasy, of course, but it is just what happens in plants.

Plants have been found to have their catalysts, called enzymes. Each enzyme makes a reaction proceed only in a definite direction.

Though we cannot as yet deprive nature, and

particularly plants, of their "patents" for the production of many substances, but in some cases we can already make them operate in the direction we need. Of great value to scientists in this respect were their investigations of photosynthesis processes. It has recently been found that if light of different wavelengths is used to illuminate the plants during photosynthesis, chemically different substances are formed. For instance, illumination with red-yellow rays results in carbohydrates as the main compounds whereas blue rays give proteins.

It may therefore be expected that in the near future people will be able, with the aid of plants, to obtain organic compounds they need on a considerable scale. Indeed, instead of building factories, furnishing them with unique equipment and working out complex synthesis technologies, it will only be necessary to build hothouses and to regulate the intensity and spectral composition of the light rays used. Then the plants themselves will make everything required: from the simplest carbohydrates to the most complicated proteins.

Why Do Elements Combine?

Without the interaction of chemical elements chemistry as a science would not exist. But why do they combine? Why do they form such a large number of various compounds? What is the mechanism of their combining?

As far back as the 18th century the term "chemical affinity" was first mentioned. The greater

the affinity of one element to another, the more stable is the chemical compound formed.

The nature of this chemical affinity occupied many minds. Some scientists contended that the essence of this affinity lies in the electrical attraction of the positively and negatively charged parts that constitute the compound, like in the molecule of calcium sulphate, where CaO is charged positively and SO_3—negatively. That's what the electrochemical, or dualistic theory of the Swedish chemist Jons Berzelius was all about. It played a great part in the theoretical development of chemistry, but in the end, it collapsed under the attack of new experimental facts. Other investigators were of a different opinion, namely, that every chemical interaction is determined by a mechanical force of attraction similar to that of gravity. One of the advocates of this theory was Mendeleyev, who believed that the world of chemical interactions awaits its own Newton.

Today it is clear to everybody that all the attempts to account for the mechanism of chemical bonding could not produce any results as long as scientists knew nothing about the structure of the atom.

The appearance of the atomic model resulted in the emergence of the theories of chemical bonds. But after the discovery of the electron in 1897, more and more scientists became convinced that this elementary particle was bound to play a crucial role in the explanation of why atoms combine to form molecules, of which all simple substances and compounds are made.

The first "electron" theories were rather pri-

mitive from the modern point of view. It took some 20 years for everything to be settled.

Today even textbooks tell about the two main variants of the "chemical fetters" which bind the atoms into molecules.

Not all atomic electrons participate in chemical bonds, but only those situated in the outer shells.

Suppose, two atoms say, of sodium and fluorine, collide. The former has one electron in its outer shell, the latter has seven. Sodium can easily part with its only electron, whilst fluorine is willing to accept it to its outer shell. Thus, a positively charged ion of sodium and a negatively charged ion of fluorine are formed, each of them having eight electrons in its outer shell, just like the atom of the nearest inert gas, neon. This electron octet is a very stable structure. Electrical forces of attraction draw the oppositely charged ions together and the stable molecule of sodium fluoride is formed.

This type of chemical bond was called ionic. It "cements" lots of chemical compounds. But in its "pure form" it does not occur very often.

The ionic bond has a fully equal partner, the covalent bond. Its mechanism can be explained by the following example. How do the molecules of, say, fluorine, F_2, form? Fluorine atoms cannot part with their outer electrons, therefore no oppositely charged ions can be formed in this case.

The chemical bond between the fluorine atoms is formed by means of a common pair of electrons. Each of the atoms gives one electron to be available for common use. As a result, both of the atoms now have eight electrons, as it were, in

their outer shells, i.e. the same stable octet is formed. But the compounds with "purely covalent" bonds are not so many. The mixed ionic-covalent bond is formed for one reason or another.

The concept of the infallibility of the electron octet has long been predominant in the theory of chemistry. But, as we have already seen, the synthesis of chemical compounds of inert gases weakened the "octet principle" considerably.

The theories of ionic and covalent chemical bonds are rather graphical schemes of chemical interaction between different atoms than models, since they present only the qualitative pattern.

Modern chemistry demands quantitative descriptions. The present theories of chemical bonding, which are asserted by modern chemistry, are very complicated. They are based on the principles of quantum mechanics and make use of mathematics.

Chemistry and Radiation

So far chemists have not invented green leaves. But light is already used in practice for accomplishing photochemical reactions. Incidentally, photographic processes are an example of photochemistry in action. Light is the chief photographer.

But the interests of chemists are not confined to light rays. There are also X-rays and radioactive radiations. They carry immense energy. For instance, X-rays are thousands, and gamma-rays,

millions of times more "intensive" than light rays.

Now would chemists be likely to disregard them?

And so there appeared in encyclopaedias and textbooks, in special books and publications, in popular booklets and essays a new term "radiation chemistry". Such is the name of the branch of science which studies the action of radiations on chemical reactions.

Though it is a young branch of science, it can already boast of more than a few achievements.

For instance, one of the most common processes in petroleum chemistry is cracking. As a result of this process intricate organic compounds contained in petroleum split down into simpler ones. Some of the hydrocarbons they form are those contained in gasoline.

Cracking is a delicate process. It requires high temperatures, the presence of catalysts, and rather a long time.

All this refers to the old way. In the new way cracking needs neither heat nor chemical accelerators, and takes much less time.

The new way involves the use of gamma-rays. They carry out radiation cracking. They break down organic molecules. Here radiation is a destroyer.

But this is not always the case.

If a flow of electrons (beta-rays) is used to radiate light gaseous hydrocarbons—methane, ethane, or propane, the molecules are converted into heavier liquid hydrocarbons. This is an example of radiation synthesis.

The ability of radioactive rays to "stitch" mo-

lecules is utilized in polymerization processes.

We have all heard of polyethylene. But not all of us know that its production is a very complicated process, requiring high pressures, special catalysts and specific equipment. Radiation polymerization requires none of these and cuts the cost of the polyethylene by half.

These are only a few of the achievements of radiation chemistry, and they are becoming more impressive from day to day.

But radioactive radiation is not only man's friend. It is also his enemy, a subtle and merciless enemy, causing radiation sickness.

There are no universal remedies as yet for this grave disease. The best policy is to eliminate all possibility of exposure to radioactive radiation.

One of the Longest Reactions

Hundreds and thousands of various organic compounds have been made by chemists in their laboratories during recent years. Some of them are so intricate that it is not easy even to write their structural formulas on paper. It requires quite a lot of time in any case.

One of the greatest victories scored by organic chemists is unquestionably the synthesis of a protein molecule, of the molecule of one of the most important proteins.

We are referring to the chemical synthesis of insulin, the hormone which controls carbohydrate metabolism in the organism.

If we tried to tell you about the structure of

the insulin molecule, it would take us several pages. Remember that some of the details of structure of this protein molecule are still not very clear even to specialists in chemistry. Insulin is a real giant molecule, though the number of elements contained in it is rather limited. But they are arranged in very elaborate combinations.

And so, for the sake of simplicity, let us assume that the insulin molecule consists of two parts, or rather two chains—chain A and chain B. These chains are bound to one another by means of what is called a disulphide bond. In other words, they are bridged, as it were, by a crosslink consisting of two sulphur atoms.

The plan for the general attack on insulin was as follows. First, chains A and B were to be synthesized separately. Then they were to be connected with a disulphide crosslink between them.

Now for some arithmetic. To produce chain A the chemists had to perform almost a hundred different consecutive reactions. Chain B required more than a hundred. And so all this took many months of very painstaking work.

But finally both chains were obtained. Now they had to be connected. And this is where the main difficulties sprang up. Disappointment followed upon disappointment. Nevertheless, one fine evening there appeared in the laboratory log the laconic statement: "The synthesis of the insulin molecule is fully accomplished."

Scientists had to go through two hundred and twenty three consecutive stages to obtain insulin artificially. Just think of that figure: hitherto not a single known chemical compound had been

so difficult to prepare. It had taken ten men almost three years of incessant work to do it...

But biochemists report a very curious thing: in a living cell the synthesis of protein takes... from two to three seconds.

Three years, or three seconds! How far more perfect is the synthesis apparatus of the living cell than that of today's chemistry!

A Chemical Museum

Some General Ideas

Now we would like to acquaint you with some of the exhibits of the chemical museum. Of course, this museum exists in our imagination, so far. The exhibits are various chemical compounds. In every standard museum, each exhibit bears an inventory number. In the chemical one, seven-digit numbers would be required to inventory all the exhibits.

What is the exact number of combinations chemical elements can form? It is unlikely that the answer to this question will ever be found. Had all the possible chemical compounds been synthesized, that would mean, to a certain degree, the exhaustion of chemistry as a science.

There are two main sections in our imaginary museum, one displaying organic, the other— inorganic compounds. The indispensable constituent of every organic compound is the element carbon, which occupies flat No. 6 in the Big House. It is rightfully called the principal element of life. As a matter of fact, it was the first element that mankind became familiar with.

The number of organic compounds is incomparably larger than that of inorganic. And the system of their classification is far more regular. This regularity is really remarkable. The reason for this lies in one peculiarity of carbon atoms.

The Reason for Diversity and Its Consequences

The chemical bond between carbon atoms is rather strong. This enables carbon atoms to form long chains. For instance, a compound with 70 carbon atoms arranged in one line has been obtained. Of course, we are discussing ordinary substances here, and not polymers. In the latter case the carbon chains can be extremely long.

As to the other elements, they do not possess such ability to form chains. Only carbon's analogues, silicon and germanium, reveal some properties distantly resembling those of carbon. A chain of six units is known for silicon, and of three—for germanium.

The bond between carbon atoms may be single, double or triple, depending on the number of electron pairs participating in its formation. Graphically, these bonds are expressed as follows: $C-C$, $C=C$, $C\equiv C$, or $C:C$, $C \quad C$, $C \quad C$.

The simplest of all the compounds with a single bond is the hydrocarbon ethane. Its chemical formula is written like this: H_3C-CH_3. Ethane belongs to a large class of organic compounds known as saturated hydrocarbons (alkanes). Their "father" is methane, CH_4, which has only one carbon atom. The composition of any saturated hydrocarbon can be expressed by an extremely simple formula: C_nH_{2n+2}.

These hydrocarbons are called saturated because their capacity to combine with other elements is completely exhausted.
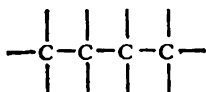
The other, no less multiple class of hydrocarbons, is that of the unsaturated (including al-

kenes and alkynes), the simplest of which are ethylene, $H_2C=CH_2$, and acetylene $HC\equiv CH$.
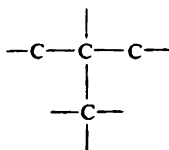
The compounds consisting of carbon and hydrogen make up a cornerstone of foundation of organic chemistry. A vast variety of different organic compounds can be obtained due to them.

It should be added, that the above types of chemical bonds between carbon atoms can alternate, which considerably increases the possibilities of organic synthesis.

Another important peculiarity of the carbon chains is their ability to branch. Let's take butane, C_4H_{10}, as an example. Its carbon atoms can be arranged not only in one line:

$$-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-$$

but also like this:

$$-C-\overset{|}{\underset{|}{C}}-C-$$
$$\underset{|}{-C-}$$

This compound is called isobutane and its properties differ from those of butane.

Out of five carbon atoms, it is possible to make five branching chains of different configurations. A separate chemical compound, specific hydrocarbon with characteristic properties, will correspond to each of them. Such varieties of chemical compounds which consist of the same number

of identical chemical elements but arranged differently are called isomers.

The phenomenon of isomerism is rather common in chemistry, and not only in organic chemistry.

The number of isomers grows as the number of carbon atoms in the molecules increases. For instance, the saturated hydrocarbon with the formula $C_{13}H_{28}$ can give 802 isomers, and if it has the formula $C_{20}H_{42}$, the number of isomers will exceed 366 000. Of course, this does not mean that all these isomers can be obtained in their pure forms. And there is not any great necessity in this.

But this illustrates the diversity of organic compound very vividly.

But this is not all.

Carbon chains are capable of not only branching, they can close up to form characteristic cycles or polygons, which may consist of three, four, five, six or more carbon atoms. These are cyclic hydrocarbons. Single and double bonds can alternate in these closed chains. This is the class of aromatic hydrocarbons. They also provide the "raw material" for a wide range of different organic compounds.

Besides carbon and hydrogen, only a few other elements of the Periodic System can be used as building material for organic compounds. If we named first of all oxygen, halogens, nitrogen, sulfur and phosphorus we would virtually exhaust the list.

Chemical Rings

No few legends are told about how great scientists made their great discoveries.

It is said that Newton was once absorbed in thought in his garden, when suddenly an apple fell to his feet. This gave him the clue to the law of gravity.

It has been said that Mendeleyev first saw the Periodic System in his dreams. All he had to do was to wake up and put his "dream" down on paper.

In a word, all kinds of stories have been thought up about discoveries and discoverers.

But the idea that occurred to the famous German chemist Kekulé was really suggested by a rather curious picture.

Scientists had long known about benzene, one of the most important organic compounds. They knew that it consisted of six atoms of carbon and six atoms of hydrogen. They had studied many of its reactions.

But they did not know the main thing, namely, how the six carbon atoms were arranged in space.

This problem gave Kekulé no peace. And here is how he solved it. Let him speak for himself: "I was at my desk writing a textbook, and was getting nowhere. My thoughts were far away. Atoms danced before my eyes. My mind's eye could distinguish long rows of them writhing hither and thither like snakes. But lo! One of the snakes suddenly caught hold of its own tail and began rotating before my eyes as if teasing me. I started as if awakened by a stroke of lightning..."

The casual image conjured up in Kekulé's mind suggested that carbon chains could close up into cycles.

After Kekulé chemists began to represent the structure of benzene like this:

The benzene ring has played a tremendous role in organic chemistry.

Rings can contain different numbers of carbon atoms. Rings may also grow together, forming weird geometrical figures. The world of rings has just as wide a range of structures as open carbon atom chains. Any book on organic chemistry bears some resemblance to a textbook of geometry, because "geometrical figures"—the structural formulas of organic compounds—are found on almost every page.

Here are two of the amusing patterns benzene rings can form:
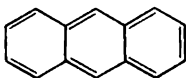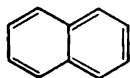
The pattern on the left is the structural formula of naphthalene. The one on the right is anthracene, a constituent of hard coal.

A Third Possibility

It was thought that the element carbon was a union of three substances. Scientists called this "triune" allotropy. In other words, one and the

same element can exist in three allotropic modi-
fications.

The three carbon substances were diamond,
graphite, and carbon black. They differ greatly
from one another: the "king of hardness", dia-
mond, soft scaly graphite, and dull carbon black.
The difference between them is due to dissim-
ilar arrangement of the carbon atoms in their
molecules.

In diamond they occupy the vertices of a geo-
metrical figure called a tetrahedron and are
bound very strongly. That is what makes dia-
mond so hard.

In graphite, on the contrary, the carbon atoms
are arranged in planes and the bonds between
the planes are weak. That is why graphite is so
soft and scales off so easily.

As to the structure of carbon black there has
been much controversy. For a long time the
dominating opinion was that carbon black is
not a crystalline substance. It was regarded as
an amorphous variety of carbon.

But comparatively recently it was found that
graphite and carbon black are practically the
same and have the same molecular arrangement.

And so there remained only diamond and graph-
ite and no third.

But scientists decided to make a third variety
of carbon artificially. The task was formulated
as follows.

In diamond and graphite the chains of carbon
atoms are closed, though arranged differently
in space. Now could the carbon atoms be made
stretch out in a long linear chain? In other words,
is it possible to produce a polymeric molecule

consisting only of carbons arranged in a straight line?

The first thing required to prepare any chemical product is the starting material. The only raw material that could serve for the preparation of "carbon No. 3" is acetylene, a compound of two carbon atoms and two hydrogen atoms, C_2H_2.

Why acetylene? Because in its molecule the carbon atoms are tied up with the least possible number of hydrogen atoms. Extra hydrogens would be an obstacle to the synthesis.

Acetylene has another important feature: it is very reactive, as the chemists say. The carbon atoms in its molecule are held together by three chemical bonds ($H—C\equiv C—H$), and two of them are comparatively easy to break, and can be used subsequently to connect the carbons with the atoms of other molecules, for instance, with molecules of the same acetylene.

Thus, the first step in the planned operation was to prepare the polymer polyacetylene from monomeric acetylene.

This was not the first attempt. In the 19th century the German chemist Baeyer tried to accomplish this reaction. But the best he could produce was tetraacetylene, a combination of four acetylene molecules. But even so this compound proved very unstable. The same path was tried by other chemists in various countries. But all their efforts ended in disappointment.

Only the powerful present-day methods of organic synthesis have finally made it possible to produce polyacetylene. Soviet scientists produced a new class of organic compounds known as polyynes. These new-born substances imme-

diately found practical usage, because they turned out to be excellent semiconductors.

Now the second step had to be made towards synthesis of the third variety of carbon. This was to exclude the hydrogen atoms from the polyacetylene molecules, and to exclude them in such a manner as to preserve a chain consisting only of carbon atoms.

In the language of chemistry the process by means of which the hydrogen atoms were to be excluded bears the long and tedious name. There is no point in trying to explain the essentials of this process; in laboratory logs the description of the process took up scores of pages, because the removal of hydrogen from polyacetylene proved no easy task.

But finally, carbyne was obtained. The encyclopaediae present this substance as an allotropic modification of carbon with a linear structure of molecules. It is common to distinguish two types of carbyne: α-carbyne and β-carbyne. In α-carbyne, single and double bonds alternate: $C-C=C-C=C-$, whereas in β-carbyne, carbon atoms are linked together only by means of double bonds: $C=C=C=C=$. Incidentally, carbyne was found in nature in the form of a rather rare mineral whose characteristic white inclusions sometimes occur in natural graphite.

Carbyne has already found practical application; it is used as a semiconductor.

A Few Words About Complex Compounds

There were many great chemists in the nineteenth century. But three of them were peerless. They accomplished more for their science than anyone else. They laid the foundations of modern chemistry.

Two of them were Dmitry Mendeleyev, the creator of the Periodic Law and the Periodic System of Elements, and Alexander Butlerov, the author of the theory of structure of organic compounds.

The third was the German chemist Alfred Werner. His discovery is covered by the two words "coordination theory", but it was epoch-making for inorganic chemistry.

It all started when chemists took up the study of reactions between metals and ammonia. To a solution of an ordinary salt, such as copper chloride, they added ammonia solution. Evaporation of the solution resulted in beautiful blue-green crystals. Analysis showed these crystals to be of a simple composition, but it was a puzzling simplicity.

The formula of copper chloride is $CuCl_2$. The copper is divalent, and everything is quite clear. Nor were the crystals of the "ammonia" compound too complex: $Cu(NH_3)_2Cl_2$.

But what forces combine the two ammonia molecules so stably with the copper atom? Both valences of this atom are already used up in the bond with the chlorine atoms. It appears that copper must be tetravalent in this compound.

Another example is the analogous cobalt com-

pound $Co(NH_3)_6Cl_3$. Cobalt is a typical trivalent element, but in this compound it seems to be nonavalent!

Multitudes of such compounds were synthesized, and each of them was like a delayed-action mine nested in the foundation of the theory of valence.

The situation defied logical explanation. Many metals displayed quite preposterous valences.

Alfred Werner succeeded in accounting for this strange phenomenon.

His idea was that after saturating their ordinary, main valences, atoms can still display additional valence. For instance, after copper has spent its two main valences on chlorine atoms, it can find two additional ones to combine with ammonia.

Compounds such as $Cu(NH_3)_2Cl_2$ are called complex. In this compound the cation $[Cu(NH_3)_2]^{2+}$ is complex. There are many substances in which the anion is of complex structure; for example, $K_2[PtCl_6]$ contains the complex anion $[PtCl_6]^{2-}$.

But how many secondary valences can a metal display? This depends on its coordination number. The smallest value of the latter is 1, and the largest 12. In the copper-ammonia compound mentioned above it is 2, showing how many molecules of ammonia are combined with the copper atom. Most commonly the coordination numbers 4 and 6 are realized.

Thus was solved the riddle of unusual valences. A new branch of inorganic chemistry sprang up, the chemistry of complex compounds.

Over a hundred thousand complex compounds

are known at present. They are studied in chemical institutions and laboratories all over the world. They are of interest not only to theoretical chemists who try to find how all things are built and why they are built so.

Without complex compounds there would be no life. Both haemoglobin, an important component of the blood, and chlorophyll, the basis of all plant life, are complex compounds. Many ferments and enzymes are of complex constitution.

Analysts use complex compounds for carrying out very complicated analyses of a wide range of substances.

Many metals can be obtained in a very pure state with the aid of complexes. They find application as valuable dyes, and for softening water. In a word, complex compounds are omnipresent.

A Surprise in a Simple Compound

In our days it is more than easy to learn to make photographs. Even a child of under-school age can make them. He may not know all the secrets of the process (between ourselves, some of them are not known even to specialists), but to take snapshots and to develop them all he needs is a little practice and some good advice from adults.

And so there is no need to go into the details of what a photographer does.

He knows well, for instance, that sometimes brown spots appear on photographs, especially if they are kept in the light for a long time. The

photographer could explain that they are due to underfixing of the paper (or plate).

In scientific terms, this means that the plate or paper had not been held long enough in the fixing solution.

What is the fixer needed for? Anyone who has ever taken the least interest in photography can answer that.

It is needed to remove the silver bromide left undecomposed on film surfaces after exposure.

Many different fixers have been invented. But the cheapest and most popular of them is hypo. Chemists call it sodium thiosulphate.

But first a few words about sodium sulphate. It was discovered by the German chemist Johann Glauber and has been known for a very long time. That is why another name for sodium sulphate is Glauber's salt. Its formula is $Na_2SO_4 \cdot 10H_2O$.

Chemists are fond of drawing the structural formulas of compounds. They draw anhydrous sodium sulphate like this:
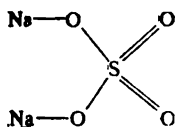
A glance at this formula makes it clear even to a greenhorn in chemistry that the sulphur in it is positively hexavalent, and the oxygen, negatively divalent.

The constitution of the thiosulphate is almost the same. Except for a trifle, namely, that one of the oxygen atoms is replaced by a sulphur

atom:
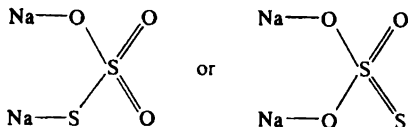
Simple, isn't it? But what a curious compound thiosulphate is! It contains two sulphur atoms of different valences. One of them has the charge $6+$, and the other $2-$. It is not so very often that chemists come across such phenomena.

We not infrequently find the unusual in the most ordinary things.

What Humphry Davy Did Not Know

The list of scientific works of the famous English chemist Humphry Davy is very long indeed.

He was not only a talented scientist, but an ingenious investigator as well. Whatever problem Davy undertook he almost always solved it successfully. He prepared not a few new chemical compounds and developed several new methods of investigation. Finally, Davy discovered four elements, namely: potassium and sodium, magnesium and barium, which he obtained from the long-known compounds by means of electrolysis.

One of his works is a short paper reporting the preparation of a simple chemical compound, chlorine hydrate, in which six molecules of water are combined with the chlorine molecule: $Cl_2 \cdot 6H_2O$.

Though Davy studied the properties of this substance very thoroughly, he never knew that he had obtained a compound of an entirely new type, a compound without chemical bonds.

This became clear only to chemists of the twentieth century. They attempted to account for the existence of chlorine hydrate according to the modern conception of valence. But they failed: the substance was too hard a nut to crack, nor was it the only one.

For decades chemists sought the answer to the question whether the inert gases were really so hopelessly inert, or whether they could somehow be made to enter into chemical reactions. We already know the answer to this question. But while it was still a question scientists succeeded in preparing several hydrates of argon, krypton, xenon, and radon.

These hydrates contained no ordinary chemical bonds. Yet many of them are comparatively stable substances.

The simple organic compound urea was another riddle to chemists. It combined readily with many hydrocarbons and alcohols. This strange "friendship" evoked surprise: what forces could cause urea and alcohol to attract each other? Anything but chemical forces....

Be that as it may, but the new class of compounds, substances not containing chemical bonds, grew at a terrific rate.

However, there turned out to be nothing supernatural about it.

The two combining molecules are not equal. One of them acts as the "host", and the other as the "guest".

Host-molecules form a crystal lattice. There are always interstices in this lattice not filled with atoms. The "visiting" molecules enter these interstices. But the hospitality is of a rather strange kind. The strangers stay with their host for a very long time, because it is not easy for them to leave the interstices of the crystal lattice.

In this way, molecules of the gaseous chlorine, argon, krypton and others get trapped, as it were, in the interstices of the crystal lattice of water.

Now chemists call these and a number of other substances not having chemical bonds between different molecules clathrate (or cellular) compounds.

26, 28, or Something Quite Remarkable

These substances are called catenanes, from the Latin "catena" meaning a chain.

So what of it? The word chain doesn't tell us much. It is no less common in the organic chemist's vocabulary than any other term.

But there are chains and chains. We have had occasion to see that they may be linear or branched and sometimes form rather intricate patterns.

But now stop and think a moment: in organic compounds the notion chain is a graphic, but not very strict conception. According to its everyday meaning, the word chain signifies something different. Its links have no rigid mechanical bond but pass freely through one another. In organic compounds the cycles are "soldered" by chemical bonds, so to say, to one

another, as, for instance, the three benzene rings in anthracene. It resembles a chain of cycles, but still it is not quite a chain.

And so chemists began to puzzle over the question whether separate cycles could be connected like the links in an ordinary chain, like this:
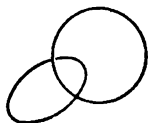
In short, what they wanted was to connect cyclic molecules without a chemical bond in a purely mechanical fashion, so to say.

This attractive idea matured for many years in the minds of scientists. Theory was on their side. It set no unsurmountable obstacles to such a synthesis. Chemists were even able to calculate theoretically the number of carbon atoms the cycles would have to consist of to be interlaceable.

As regards practice, however, the situation for a long time was anything but bright. The synthesis would go into a deadlock at some stage each time. And the chemists had to keep thinking up all kinds of new tricks.

The new compound was born on a fine April morning in 1964. It was brought to life by two German chemists, Lüttringhaus and Schill. This required twenty consecutive chemical operations, twenty stages.

The compound consists of two cyclic molecules interlaced like the links of a chain. One of the

links contains 26, and the other, 28 carbon atoms. Hence, the prosaic name of the substance: catenane 26, 28.

Two interlaced rings is now already the past of catenane chemistry. Now scientists are working on more intricate ring combinations, such as:
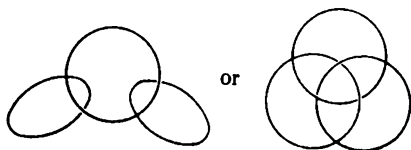
These are models of three-linked catenanes. In the one at the left, the middle link must contain 26 carbon atoms, and the outer ones, 20 each. To give a complex interlacing of three rings (the catenane on the right) they must consist of at least 30 atoms each.

The external appearance of the first-born in the new family, catenane 26, 28, is surprisingly commonplace: it is a white crystalline powder melting at 125 °C.

Do catenanes occur in nature? In nature everything is expedient; it exerts no abilities in vain. If natural catenanes do exist, there must be some specific function they fulfill.

It is up to the scientists to find this out.

A Eulogy to Cadet's Liquid

In 1760 the little known French chemist Cadet made history without suspecting it.

In his laboratory he performed the following

chemical experiment (we have no idea what for).

Cadet heated potassium acetate with arsenic oxide. What the result was he never found out, because the substance that formed was of a truly diabolical disposition.

It was a black, thick liquid. It fumed in the air, and burst into flame readily. Besides, it had an utterly unbearable odour.

Cadet's "concoction" was analysed about seventy years later. Its main components were found to be arsenous compounds of a very singular nature.

To understand what was so singular about them it must be recalled that all organic compounds have a very important feature in common: they are based on chains of carbon atoms, straight, branched, or cyclic. True, atoms of some other elements may wedge into these chains. But there are very few such elements (they are called organogens): oxygen, nitrogen, hydrogen, sulphur, and perhaps, phosphorus.

Arsenic is decidedly not one of them.

Cadet's liquid contained a substance called dicacodyl (from the Greek "kakodes" meaning ill-smelling). Its constitution is such that the arsenic atoms have wormed themselves firmly in between the carbon atoms, thus:

$$H_3C \diagdown \atop H_3C \diagup As\!\!-\!\!As \diagup CH_3 \atop \diagdown CH_3$$
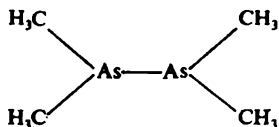
Organic compounds whose carbon chains include atoms of inorganogenic elements (metals

or nonmetals) are now called hetero-organic compounds (organometallic, if the element is a metal).

Thus, Cadet synthesized the first hetero-organic compound in the world.

Nowadays tens of thousands of such substances are known. Hetero-organic, and especially organometallic chemistry has become a large independent branch of chemistry, one of its more important chapters.

It has bridged the gap between organic and inorganic chemistry and has shown once again how conventional the subdivision of the sciences is in our times.

Indeed, what kind of organic chemistry is it that deals with compounds in which metals, typical representatives of inanimate nature, play the most important part?

And, contrariwise, can it be called inorganic chemistry if a large number of its subject substances are in many respects purely organic derivatives?

Of major interest to science are organometallic compounds. Their compulsory attribute is the bond between a metallic atom and a carbon atom.

Almost all the metals of the main subgroups of the Big House may be contained in organometallic compounds.

The properties of these substances are very diverse.

Some explode with a terrible force even at temperatures far below zero. Others, on the other hand, possess great resistance to heat.

Some are chemically very active, while others

respond reluctantly to all kinds of external influences.

The range of application of hetero-organic compounds is very broad, and practically, inexhaustible. They are used in the preparation of plastics and rubbers, in the manufacture of semiconductors and superpure metals; as medicines and agricultural pesticides, and as components of rocket and motor fuels; finally, they are very variable chemical reagents and catalysts, enabling the successful accomplishment of many important processes.

Our country has a large school of hetero-organic chemists, founded by Academician Alexander Nesmeyanov.

The Story of TEL

TEL is an abbreviation. It is the name of a compound which is very useful in the practical activities of man. It helps to save petrol. Nobody has ever counted up exactly how many litres of petrol TEL has saved throughout its history, but it doubtlessly amounts to a very impressive figure.

What is this mysterious TEL? A chemist would say: an organometallic compound of the hydrocarbon ethane with the metal lead. Remove a hydrogen atom from each of four molecules of ethane (C_2H_6) and add the resulting hydrocarbon radicals (ethyls C_2H_5) to a single lead atom, and you get the molecule of a substance with the fairly simple formula $Pb(C_2H_5)_4$. It is called tetraethyllead, or TEL for short.

TEL is a heavy liquid slightly greenish in colour with the hardly perceptible odour of fresh fruit, but it is far from harmless. It is one of the most potent poisons.

In itself TEL is nothing to speak of. It is much like any other substance; chemists know of far more remarkable compounds. But add only half of one per cent of TEL to a tank of motor petrol, and the wonders begin.

The heart of any automobile or aeroplane is its internal-combustion engine. Its principle of operation is simple. A mixture of petrol and air is compressed in a cylinder. Then it is ignited by means of an electric spark. An explosion occurs and energy is evolved, making the engine work.

Much depends on the compression ratio of the mixture. The higher this ratio the greater is the power of the engine, and the more economically is the fuel used. That is the theory. In practice, however, we cannot compress the mixture as greatly as we should like to. This results in "disorders" of the engine: owing to incomplete, nonuniform combustion of the fuel the engine becomes overheated, its parts wear out rapidly, and it consumes petrol at a prohibitive rate.

Improvements in engine design and purer grades of petrol alleviated the "disorder" somewhat, but did not cure it. Motors continued to "knock" and overheat; nonuniform explosions of the mixture (detonations) shortened their service life.

After a great deal of thought scientists concluded that detonation could be suppressed and the mixture could be made to burn uniformly only by altering the properties of the fuel.

But how?

Thomas Midgley, an American chemist, put a great deal of effort into the study of this question. The first solution he suggested came as a complete surprise. He claimed that if the petrol were coloured red it would be able to absorb more heat and would become more volatile. This would enable stronger compression of the fuel-air mixture.

Midgley "coloured" petrol by adding a little iodine to it. And what was his delight to find that the petrol actually began to detonate less. But when ordinary paint was substituted for the iodine the motor again fell victim to its old troubles.

Hence, colour had nothing to do with it. However, Midgley's chagrin was short-lived. He hit on the brilliant idea that there probably must be substances, insignificant additions of which could improve the quality of petrol considerably.

Iodine did this only slightly. Other substances, simple or compounds, had to be sought. Scientists tested tens and hundreds of compounds. Scientists and engineers worked side by side. Finally the scientists came to the very important conclusion that antiknock agents must be sought among the compounds of elements of high atomic weight. For instance, lead compounds might be tested.

But how can lead be introduced into petrol? Neither the metal itself nor any of its salts are soluble in petrol. The only possible way is to use some organic compound of lead.

It was then that the word "tetraethyllead", TEL, was first pronounced. That was in 1921.

Insignificant additions of TEL to petrol worked

wonders. Fuel quality improved sharply. Fuel-air mixtures could now be compressed twice as much as before. This meant that with the vehicle moving at the same speed the petrol consumption would be only half of what it was formerly. Misfires were eliminated from automobile and aeroplane motor operation.

And here is a curious economic note: the world production of TEL is now so high that the natural resources of lead are under hazard.

A very troublesome property of TEL is its high toxicity. You have probably seen tank trucks with the inscription: "ETHYL PETROL. POISON". Petrol containing TEL must be handled with great care.

TEL was the pioneer among antiknock agents, and is still the most important of them. But scientists are giving serious thought to the problem of replacing it by some other substance just as effective, but harmless.

One such substance has already been discovered. It is called CMT. If you want to know what this means, read the next story.

Unusual Sandwiches

The number of organometallic compounds known today has by far exceeded ten thousand. But some forty years ago there was an annoying gap in organometallic chemistry. Chemists could find no way to implant the so-called transition metals in organic molecules. The transition metals are those arranged in the secondary subgroups of the Periodic System. The number of

these metals is just under fifty. When chemists
did finally succeed in preparing organic com-
pounds of these metals, they were found to be
very unstable, kinds of "organometallic freaks".

In 1951, as has happened more than once in the
history of science, His Majesty Chance stepped
in. The English chemist Pauson gave his student
Kealy an assignment, which was anything but
complicated. Kealy was to synthesize a hydro-
carbon with the rather long name of dicyclopenta-
dienyl. To do this it would be necessary to couple
two five-membered carbon cycles. In other words,
from two compounds with the formula C_5H_6
he was to obtain one: $C_{10}H_{10}$ (it was assumed
that two hydrogen atoms would split off).

Cyclopentadienes   Dicyclopentadiene
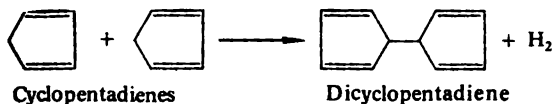
Kealy knew that this reaction could take
place only in the presence of a catalyst, and
selected ferrous chloride for the purpose.

One fine morning Pauson and Kealy raised
their hands in surprise. Instead of the expected
colourless liquid, the reaction products were
beautiful orange crystals, and very stable ones
to boot. They were thermally stable up to 500 °C,
which is rather unusual in organic chemistry.

But professor and student were even more
surprised when they analysed the mysterious
crystals, and they had reason to be. The crystals
contained carbon, hydrogen and... iron. The
typical transition metal iron had combined with
typical organic substances!

The formula of this organo-iron compound also proved to be unusual:
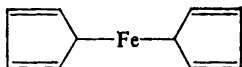
Both rings (cyclopentadienyls) are flat regular pentagons, rather like two slices of bread with an iron atom between them as the filling. Compounds of this kind are now called "sandwiches"

Ferrocene (so our organo-iron compound was christened) became the first representative of the "sandwich" family.

For the sake of simplicity we have depicted the structure of ferrocene schematically in a single plane; actually, its molecule possesses a more complex spatial structure.

The synthesis of ferrocene was one of the greatest sensations in modern chemistry. Both theoreticians and practitioners had to reconsider many of their ideas of the possibilities of organo-metallic chemistry, that they had hitherto thought infallible.

Ferrocene was born in 1951. Today several dozen such "cenes" are known. "Sandwich" compounds have been obtained for almost all the transition metals.

So far they are of interest only to theoretical chemists. As to their practical use, not everything is clear as yet. But...

And now is the time to make the acquaintance of CMT. The full name of this substance is a very long one, but it is easy to remember because it rhymes:

Cyclopentadienyl-manganesetricarbonyl

And the structure of its molecule is easy to write:
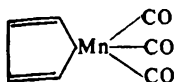
Instead of the other "slice of bread" (cyclopentadienyl ring) the filling (the manganese atom) is linked with three molecules of carbon monoxide.

CMT is an excellent antiknock agent, better than our old friend TEL in performance and better also because it is almost harmless.

Strange Whims of Carbon Monoxide

There is nothing tricky about this compound: one atom of carbon and one of oxygen. It is called carbon monoxide. It is very poisonous and takes part in chemical reactions reluctantly; such is a brief characteristic of the substance with the simple formula CO.

Believe it or not, an event of no great interest occurred in 1916 at a German chemical plant. Somebody decided to make use of a very old steel cylinder (in which a mixture of two gases, hydrogen and carbon monoxide, had been kept under pressure for about five years running). It was opened, the gases were let out and at its bottom was found some light brown liquid with an unpleasant, kind of "dusty" odour.

The liquid proved to be a known, but very rare chemical compound consisting of one iron atom and five molecules of carbon monoxide.

Its name, as given in chemical handbooks, was iron pentacarbonyl $Fe(CO)_5$.

(Incidentally, speaking of the fates of scientific discoveries. Iron pentacarbonyl was obtained on exactly the same day, June 15, 1891, by two scientists: Berthelot in France and Mond in England. Such coincidences are not so frequent, are they?)

An investigation of how the substance had formed in the cylinder showed that nothing supernatural had happened. The hydrogen had made the inner iron surface of the container very active by reducing the iron oxides to the metal. Under pressure, the carbon monoxide had reacted with the iron. After studying the mechanism of the reaction the chemists of the same plant designed an apparatus in which kilograms of the substance could be produced.

As a matter of fact, the iron pentacarbonyl had found practical usage. It had proved to be not a bad antiknock agent (we seem to be getting them by the dozen, don't we?). A special fuel containing iron pentacarbonyl was produced and it was called Motaline. But motor cars did not use Motaline very long. The pentacarbonyl decomposed too easily into its components, and the resulting iron powder clogged the piston rings of the engines. And just at this time TEL was discovered.

Now make a mental note of the easy decomposition of iron pentacarbonyl, and let us turn our attention to other matters for a little while.

A large number of carbonyls are now known: of chromium and molybdenum, of tungsten and uranium, of cobalt and nickel, of manganese and

rhenium. These compounds have various properties: some are liquids, others solids; some decompose easily, others are fairly stable.

But they all have a common and very curious property: the usual conception of valence does not apply to carbonyls.

It will be recalled that in complex compounds different numbers of neutral molecules combine with the metal ions. That is why coordination numbers are used instead of valence in the chemistry of complex compounds. The coordination number shows how many molecules, atoms, or complex ions are linked to the central atom.

Carbonyls are still stranger fruits of nature's invention. In them neutral atoms are combined with neutral molecules. The valence of the metals in these compounds must be considered to be equal to zero because carbon monoxide is a neutral molecule.

This is another paradox of chemistry, and, to tell the truth, it has found no theoretical explanation so far.

And so we now leave off our little excursion into theory.

Practice found the metal carbonyls a dainty morsel. As catalysts, for one thing. But carbonyls have much more important uses.

Reverting to the plant in the storehouse of which the old cylinder was found, at the bottom of which a strange liquid was observed that turned out to be iron pentacarbonyl, that...

To make a long story short, that went into production on almost an industrial scale. But once, while the operator in charge of the synthesis apparatus was day dreaming, the penta-

carbonyl began leaking out. The vapours of the substance deposited on a steel sheet which happened to be lying nearby. The operator soon discovered the leak and quickly eliminated it, but in doing so he accidentally pushed the sheet off the platform and it fell to the ground floor.

Hunters have a saying: "Once a year even a stick will fire." The steel sheet, which had lain peacefully in the sun for so long, exploded when it hit the ground.

A special "Inquest Commission" held more than one sitting before the experts were able to conclude that the sheet had "exploded" because it had been coated with a very fine iron powder. All finely divided powders in general are likely to explode; for example, explosions have been known to occur with flour dust and powdered sugar.

The iron powder had formed on the sheet as a result of the decomposition of the pentacarbonyl.

The preparation of very fine metallic powders by the decomposition of metal carbonyls strongly attracted the interest of scientists.

They established that such powders have very specific properties. Their particles are very small, just over a micron in diameter. For instance, iron powder can be obtained in the form of fluffy iron "wool" consisting of strong metallic chains. Deposited on a hot surface, carbonyls form a very strong and thin film on it. Such powders and films possess very valuable magnetic and electrical properties and this has gained them extensive usage in radio engineering and electronics. Carbonyl powders are attractive to powder metallurgy,

Oxygen Plus Fluorine

"So, what about it?" any chemist would have exclaimed several decades ago. "The compound of oxygen and fluorine, the two most reactive nonmetals? That's mere nonsense! Oxygen and fluorine do not react with one another..."

Today's researcher would only be surprised to hear that such a delusion ever really existed.

It was just because the investigators were not skilled enough to work with elemental fluorine and the experimental techniques that are widely used in modern chemistry today were not highly developed. For example, the use of electrical discharge or superlow temperatures had not been introduced into experimental work yet.

When the researchers learned to carry out the experiments under such "extreme", so to say, conditions, compounds of fluorine and oxygen were synthesized.

The compound of any element with oxygen is called an oxide. But it would be incorrect to say "fluorine oxides". One of the essential characteristics of elements is their electronegativity. It gives a quantitative account of the ability of the atom in a molecule to attract electrons which participate in chemical bonding. Its value gradually increases throughout the periods of Mendeleyev Table from alkali metals to halogens. There exist certain rules for naming chemical compounds in conformance with which we say boron carbide, phosphorus sulphide, nitrogen oxide. The electronegativity of the second elements in these compounds is greater than that of the first ones. The electronegativity

of fluorine atom reaches its maximum value, therefore, its oxygen compounds should be called oxygen fluorides rather than fluorine oxides.

The first attempts to obtain compounds of oxygen and fluorine were made by Henri Moissan shortly after he had successfully prepared fluorine in a free state. But he never drew any definite conclusion. He just established that some very unstable compounds are formed as a result of the reaction of fluorine with water.

Over the next 100 years, rather extensive scientific literature dedicated to the oxygen fluorides was published.

Six compounds of the kind are known by now and all of them can be referred to as chemical rarities. Their general formula is O_nF_2, and all of them are extremely unstable compounds. Only oxygen difluoride OF_2 can exist at room temperature. It is a gas insoluble in water which can be prepared as a result of the chemical reaction of fluorine with a sodium hydroxide solution. All the rest of the oxygen fluorides are prepared by one method, namely, by passing an electric discharge through a mixture of oxygen and fluorine (mixed in a certain proportion) at low temperatures.

However, most of their properties remain obscure, and there is nothing surprising about this such a substance as O_6F_2 is only stable up to a temperature of minus 213 °C!

Oxygen fluorides are not capable of forming oxygen acids, and as a matter of fact, fluorine is one of the nonmetals (along with helium, neon and argon) which cannot form acids containing oxygen atoms in their molecules.

However, there is no doubt that those phantasmal compounds will present scientists with many surprises.

Red and Green

They are both very intricate organic substances. Their structural formulas would take up a whole page of our book. Both of them are complex compounds, and unusual ones: their only metallic atom loses itself, as it were, at the centre of an intricate framework consisting of several cycles. Chemists call such compounds chelate compounds.

By "they" we meant haemoglobin and chlorophyll. The red colour of the blood and the green colour of plants are due to them. These two substances hold the keys to all animate things on Earth.

The "core" of haemoglobin is an iron atom. The blood of different animals contains different haemoglobins, but they all have the same basic structure. The blood of a man contains about 750 grams of haemoglobin.

Haemoglobin transfers oxygen from the respiratory organs to the tissues of the organism.

Chlorophyll has almost the same structure. The difference is that metal atom in it is a magnesium atom. The vital function of chlorophyll is very responsible and complex. It enables the plant to assimilate carbon dioxide from the atmosphere.

Chemists are just beginning to learn the essentials of the mechanism of operation of haemoglobin and chlorophyll. Evidently, the central

metal atoms, those of iron and magnesium, play a very important part.

But it appears that nature's imagination is very lavish. Iron and magnesium are by no means the only metals that can get inside the porphinic skeleton (such is the name of the organic framework common to haemoglobin and chlorophyll). The metallic "core" may also be copper, manganese or vanadium.

There are creatures on Earth which have blue blood. These are some species of mollusks. The haemoglobin of their blood contains copper instead of iron.

See what remarkable exhibits you can find in our chemical museum!

The Most Unusual Atom, the Most Unusual Chemistry

The symbol of this remarkable atom is Ps. But in vain will you search Mendeleyev's Table for it. It is not the symbol of any chemical element.

And its lifetime is only an instant, less than a ten-millionth of a second. Still, it cannot be said to be radioactive.

Ps stands for positronium. Its structure is very simple.

Take a hydrogen atom, the simplest of all the atoms of chemical elements. One electron revolves about a single proton.

The positronium atom appears in certain types of radioactive transformations accompanied by the emission of a positron. For a very

short time the positron forms a stable system with an electron.

In positronium the part of the proton is played by an elementary particle known as the positron. It is the antipode of the electron. The positron has the same size and the same mass as the electron, the difference being that its charge is of the opposite sign (positive).

A collision between a positron and electron is the end of both of them. As the physicists put it, they annihilate each other. In other words, they turn into nothing, or to be more exact, into a radiation.

But just before disappearing these two unreconcilable enemies exist side by side for a short instant giving rise to the ghost positronium atom. It is an atom with no nucleus, for the electron and the positron revolve about a common centre of gravity.

Now who could be interested in positronium? Only theoretical physicists, it would seem; or maybe science-fiction writers searching for new types of fuel for their stellar spaceships. However, in our days the enormous literature is dedicated to positronium.

During its brief lifetime, positronium is capable of entering into chemical reaction. It reacts especially readily with chemical compounds which have free valence bonds left. These unused vacancies are occupied by positronium atoms.

By means of special instruments chemists can trace the nature of decay of positronium which has got into the molecule of a substance. It is found to decay differently, depending on the structure of the molecule. This enables chemists

to study the intricacies of molecular designs and to solve many sophisticated and controversial problems where other methods have failed.

Diamond Again

Diamond is not the most important exhibit in our chemical museum. It is too simple to be unique. Its specific carbon skeleton surprises no one today. Back in the seventeenth century scientists burned diamond crystals in the sun's rays using an ordinary magnifying glass.

Chemists have long had something else on their minds, namely, how to transform graphite into diamond. Both of these are carbon, and all that had to be done was to find a way of rearranging the graphite carbon framework into that of diamond, and the hardest material in existence would thus be made from one of the softest, with nothing removed and nothing added.

A way was finally found. It is a very amusing story and we shall tell it in its place. For the time being we shall remark only that what was needed to prepare artificial diamond was tremendous pressures.

And so, the hero of this story will be pressure. And not an ordinary pressure of a mere one, two or ten atmospheres, but superhigh pressures, when each square centimetre of surface area supports tens and hundreds of thousands of kilograms.

Thus, superhigh pressures make it possible to obtain hitherto unknown substances.

The alchemists knew two varieties of phospho-

rus, white and red. Now there is a third variety, black phosphorus. The heaviest, the densest, it is as good a conductor of electricity as many metals. Phosphorus, a typical nonmetal, was converted by superhigh pressures into an almost metallic substance, and a stable one at that.

The example of phosphorus was followed by arsenic, and then by some other nonmetals. And each time the scientists observed striking alterations in properties. The heavy arm of superhigh pressure altered these properties before their very eyes.

From the standpoint of physics nothing extraordinary had happened. Simply the superhigh pressure had rearranged the crystal structure of the elements and their compounds, making them more metallic.

Thus appeared the purely physical term "pressure metallization".

Astronauts have already visited the Moon. Mars and Venus are now in the order of the day. Then will come the turn of other more distant and still more mysterious worlds. Men will time and again encounter the unusual, the unexpected, the unknown.

But just now we are interested in a particular question.

Are the chemical elements the same everywhere? Does the might of the Periodic Law and Mendeleyev's Table extend to all cosmic bodies without exception? Or does the ingenious creation of the Russian scientist apply only on Earth?

We hope we are not annoying the reader with our endless question marks. But really, it is

much easier to ask questions than to answer them.

Philosophers are of a definite opinion. They believe that the Periodic Law and the Periodic System are the same throughout the entire universe. That is where they are universal. They are the same, but with one essential reservation: only where ambient conditions do not differ too much from terrestrial conditions, where the temperature and the pressure are not multidigit numbers.

And that is where they are limited.

The Unknown Underfoot

"Before counting the stars have a look underfoot," runs an Oriental saying.

Do we know our own planet so well? Unfortunately, we know very little about it. We have very little information about the structure of the inside of the globe and about the substance its distant depths consist of.

All we have is an enormous number of various hypotheses and preference can be given to none.

True, oil wells have already gone down seven kilometres! And the depths to be drilled in the near future seem impressive—fifteen to twenty kilometres. But it must not be forgotten that the Earth's radius is 6,300 kilometres.

There is another Oriental saying: "Yoy have to crack a nut to find out what its taste is like."

Roughly speaking, our planet bears some resemblance to a nut in structure. A shell—the Earth's crust—outside, and a kernel—the Earth's core—

inside. The Earth has a very thick layer between the crust and the core, called the mantle.

We know more or less what the Earth's shell consists of. Rather, not even its shell but just that thin dainty film that envelops a green nut. What the mantle, and the more so, the core, is built like, is still an equation with many unknowns.

There is only one thing that can be said quite definitely. The substances constituting the Earth's inner strata are quite unusual. The closer to the centre of the Earth, the higher the pressure of the overlying layers. Pressures at the core reach the enormous value of three million atmospheres.

Incidentally, about the Earth's core. Its structure has been a point of controversy among scientists for more than one century. So many scientists, so many hypotheses.

Some hold that the planet has an iron-nickel core. Others think differently. In their opinion the structural material of the core is the mineral olivine. Under ordinary conditions it is a mixture of magnesium, iron, and manganese silicates. The tremendous pressure inside the core changes the olivine into a sort of metal-like matter. There are scientists who go still further. They claim that the central part of the core consists of hydrogen compressed to complete solidification and therefore possessing unusual metallic properties. There are still others....

But we had better stop here. "You have to crack a nut to find out what it tastes like." But it will take a long time to get through to the Earth's core.

We know much less about its structure than

about the composition of the atomic nucleus. Now is not that a paradox?

Yes, the unknown is underfoot! A real storehouse of wonders for the chemist: elements in unusual crystalline states; nonmetals transformed into metals; a great variety of compounds whose properties are difficult even to imagine.

The wondrous chemistry of the depths!

But for the time being, as the Soviet scientist A. Kapustinsky pointed out, our chemistry still remains a very "superficial" science.

Does the Periodic System remain valid in the greatest depths as well? Yes, as long as the electronic structure of the atoms remains unchanged. As long as the electrons are arranged in the shells they should be in.

But that "status quo" is preserved only for so long.

When the Same Is Not the Same at All

No, we have not yet done with superhigh pressure. It is about to bring us a new surprise.

An atom is a rather strong structure. It may lose a few electrons, and then the atom becomes an ion. This process is occurring all the time during chemical interactions.

It may lose many electrons, and finally, it may lose them all so that only the "bare" nucleus is left. This is observed at million-degree temperatures, e.g., in the stars.

But here is a different riddle. Suppose the total number of electrons remains unchanged, but they arrange themselves differently in the elec-

tron shells. Such a change is bound to alter the properties of the atom, and hence of the element.

This is, so to say, the text below the illustration. Now for the illustration itself.

You should have no difficulty in depicting the potassium atom. It has four shells. The closest to the nucleus (K and L) are full: the first contains two, and the second eight electrons. Under ordinary conditions, no more electrons will go into them. But the other two shells are far from complete. The M-shell has only eight electrons (though it may have 18), and the N-shell has just been started (it has one electron), and this occurs before the previous one is complete.

Potassium is the first atom to display inconsistent, stepwise formation of its electron shell.

But it is not difficult to imagine that instead of entering the fourth shell, potassium's electron might continue the third one (for this shell still has ten vacancies).

Fantastic? Quite—under ordinary conditions. But superhigh pressures give rise to an extraordinary situation.

Under superhigh pressures the electron shells surrounding the nucleus contract greatly and the outer electrons can "fall" into the underlying incomplete shells.

For example, suppose the outer electron in the fourth shell of the potassium atom were imbedded in the third, making nine electrons in its M-shell.

What would this amount to? The atomic number of potassium (19) would be the same as before, and so would the number of electrons and no transformation of elements would have occurred.

Just the same, our old friend the alkali metal

potassium would no longer be our old friend. It would be a stranger with three shells instead of four and with nine electrons in its outer shell instead of one. And so the chemical properties of "neopotassium" would have to be studied anew.

What these properties would be we can only guess, because not a speck of "werewolf potassium" has ever been available for investigation.

At still higher pressures, the elements following potassium would also lose their usual aspect. With a stepwise filling of electron shells, the law in the Mendeleyev's Table would no longer be observed. As long as one shell is incomplete, the following one remains empty.

This would also be a periodic system, but not Mendeleyev's. Its inhabitants (except for the elements of the first three periods) would be different. Its "alkali" metals would be copper and promethium and its "noble gases" nickel and neodymium in which the corresponding outer shells would be completed.

This is what the chemistry of superhigh pressures may turn out to be! Unusual valences, strange properties, surprising compounds

Attractive? Oh, yes! Real? Who knows

What is wanted here is again probably some "crazy" idea, since the preparation of an entirely new type of matter is involved. Even if it does exist at superhigh pressures, it should reassume the form of the conventional elements under ordinary conditions. Incidentally, science-fiction writers have alredy taken up this idea. The question is how to preserve or "freeze" this transition. If we succeed in solving this question, we shall have a new chemical science, chemistry No. 2.

With Its Eyes

A Word on the Use of Analysis

Mikhail Vasilievich Lomonosov once said: "Chemistry stretches wide its arms... ." Almost two hundred years ago his ingenuity sensed the significance of this science for future generations.

The twentieth century has brought this out vividly. Chemistry is now a "many-armed creature". Not every academician can even enumerate all its branches right on the spot. And new ones keep appearing almost every year.

But there is one thing without which any of these chemical "arms" would hang lifeless.

That thing is chemical analysis.

It has helped chemists to discover very many of the elements existing on Earth and to determine their atomic weights—important chemical characteristics.

It has enabled them to establish the constituent parts of simple substances and chemical compounds from table salt to proteins.

It has deciphered the compositions of rocks and minerals and has helped geochemists to count scrupulously the Earth's reserves of chemical elements.

Chemistry owes much to analysis, in particular, its becoming an exact science. Analysis is the first helper in various spheres of human activity, as is seen from an untold number of examples.

For instance, suppose iron is being smelted from its ore in a blast furnace. Its properties depend largely on the amount of carbon in the resulting metal. If there is more than 1.7 per cent carbon in it, we get cast iron; the interval from 1.7 to 0.2 per cent represents various grades of steel, and if the metal contains less than 0.2 per cent carbon it is called wrought iron.

What is the difference between iron and steel, brass and bronze? How much copper is there in blue vitriol? Is there much potassium in the mineral carnallite? Only chemical analysis supplies the answers to these and similar questions. Two main questions confront it: what elements are contained in the substance under investigation, and in what proportion? The former is the scope of qualitative, and the latter, of quantitative analysis.

As to how many different kinds of analyses there are, no one, not even an experienced specialist, can say right off the bat.

To Make Good Gunpowder

Who invented gunpowder? Legend says that it was the German monk Berthold Schwarz. There is evidence that the Chinese used gunpowder long before.

Gunpowder is not difficult to make: all you have to do is mix sulphur, saltpetre and finely powdered charcoal in definite proportions. But the components must be of high quality.

How can their quality be judged?

In the old days gunpowder makers tested saltpetre by tasting it.

Here is a curious procedure for analysing saltpetre by taste, found in the archives: "Saltpetre that is salty and bitter is no good; only if it bites the tongue and some sweetness can be felt, is the saltpetre good."

One could say of a good gunpowder maker that he had "eaten a peck of salt", couldn't one?

The method of testing sulphur was still more original.

A piece of sulphur taken in the fist was brought close to the ear. If a slight crackling sound could be heard, the sulphur was considered suitable. Otherwise, it was discarded as impure.

Why does pure sulphur crackle? Its thermal conductivity is very low. The fist warms the sulphur and different parts of it acquire different temperatures and, being brittle, it breaks up into small pieces, making slight crackling sounds as it does so. The thermal conductivity of impure sulphur is much higher and it is therefore more stable. Such is the scientific grounding, so to say, of chemical analysis by ear.

To make a long story short, the principal analytical instruments of the chemists of the past were their sense organs. This fact is even reflected in the names of some simple substances and compounds. For example, beryllium formerly used to be glucinum, because its salts have a sweetish taste. The name glycerine also comes from the Latin for "sweet". And natural sodium sulphate is called mirabilite, which means "bitter",

How Germanium Was Discovered

In the beginning of March 1886 D. Mendeleyev
received a letter which read:

"Dear Sir,

Allow me to present you with the reprint en-
closed herein of a report from which it is evident
that I have discovered a new element named
'germanium'. At first I thought this element
would fill the gap between antimony and bis-
muth in your remarkable and profoundly com-
posed periodic system, and that the element
would coincide with your eka-antimony, but the
facts indicate that here we have to do with eka-
silicon.

I soon hope to render you more detailed in-
formation on this interesting substance; today
I content myself with informing you of a very
probable new triumph of your ingenious investi-
gation and take the opportunity to express my
deep respect for you.

Faithfully yours,
Clemens Winkler

Freiberg, Saxony,
February 26, 1886."

Not in vain, it appears, did Henry Cavendish
almost a hundred years before the discovery of
germanium, repeat time and again that "every-
thing is determined by measure, number and
weight". In analysing argyrodite, a rather rare
mineral discovered not long before in Saxony,
Clements Winkler found it to contain mainly
silver and sulphur with small quantities of
iron, zinc and mercury. But what surprised him

was that the percentages of all the elements
found in argyrodite added up to only 93 and
stubbornly refused to make 100.

What could the elusive 7 per cent be? The meth-
ods of analysis of most of the elements known
by that time were well worked out and not one
of them should have escaped the chemist's eye.
Then Winkler made the daring assumption that
since these 7 per cent had escaped him with the
existing analysis procedures, they must belong
to an unknown element. His assumption was
fully confirmed. By slightly changing the pro-
cedure of the analysis Winkler isolated the elusive
7 per cent and proved them to belong to a new
element, unknown at that time, which he named
germanium in honour of his native land.

Gravimetric analysis played an important part
in the discovery of one more element, namely
argon, the first representative of the noble gases.

In the early nineties of the last century the
English physicist Rayleigh undertook a deter-
mination of the density of gases of single ele-
ments and hence of their atomic weights. All
was well until the investigator came to nitro-
gen. Here strange things began to happen. A litre
of nitrogen separated from air weighed 0.0016
gram more than the same amount of nitrogen
produced from chemical compounds, the type of
compounds having no effect on the final result.
The ill-starred litre of nitrogen obtained from
ammonium nitrite, nitrous or nitric oxides,
urea, ammonia, or other compounds, invariably
proved to be lighter by the same amount than
atmospheric nitrogen.

Not having found the reason for this strange

difference, Rayleigh published an article in the London journal "Nature", describing his results. Soon the chemist Ramsay responded and the investigators combined their efforts in an attempt to solve the riddle. In August 1894 they reported the discovery of a new element, the cause of Rayleigh's first failures. Its content in the air was found to be about one per cent.

Thus ordinary gravimetric analysis helped scientists to discover new elements. Not a single chemical laboratory can get along without it even today. In the long run ordinary weighing helps to determine the percentages of elements in complicated compounds and minerals. Of course, it must be preceded by painstaking chemical operations of separation of the elements from one another.

Light and Colour

On each major Soviet holiday you hear the Moscow Radio announcer say: "Order of the Minister of Defence... 'In Honour of ... I order a salute shall be fired in the capital of our country, Moscow, in the capitals of the Union Republics and in the Hero cities'..."

The sky is magnificent during the salute with yellow, green, and red lights flashing through it under the thunder of the salvoes.

The tradition of celebrating holidays by salvoes and fireworks is very old. The art of pyrotechnics was known in China as far back as two thousand B.C. But only comparatively recently did it

occur to scientists to utilize coloured flames for chemical analysis.

Almost a hundred and fifty years ago the German physicist Kirchhoff noticed that the salts of different metals coloured a colourless gas-burner flame differently. Sodium salts make the flame yellow, calcium salts colour it carmine-red, barium salts—green, etc.

Kirchhoff soon realized that this offered a quick and reliable method of detecting chemical elements in substances. However, his glee was premature. All was well as long as pure salts were used. But if salts of, say, sodium and potassium were mixed, the violet colour of potassium was practically indiscernable against the background of the bright yellow burner flame (due to the presence of sodium).

The physicist Bunsen came to the aid of the chemist Kirchhoff. He suggested examining the burner flame with the mixture of salts introduced into it through a special instrument called a spectroscope. The main element of this instrument is a prism which resolves the white light passed through it into a spectrum, i.e., into its components. The name "spectroscope" means "to observe a spectrum".

The idea was a great success. Unlike other sources of light, the gas-burner flame into which the salt under test was introduced, gave a line spectrum instead of a continuous one, and the lines of the spectrum were always in strictly constant positions. Thus, a sodium salt introduced into the flame yielded two closely spaced intense yellow lines in the spectrum. Potassium salts gave one red and two violet lines, etc.

Kirchhoff and Bunsen found that the lines of any particular chemical element always appeared in exactly the same positions in the spectrum. No matter whether sodium was introduced into the flame in the form of sodium chloride, sulphate, carbonate, or nitrate, the positions of the sodium lines were always the same. Even mixing the sodium salts with other salts, say, of potassium, copper, iron, strontium, or barium, did not affect the positions of the sodium lines.

Inspired by their discovery Kirchhoff and Bunsen worked indefatigably. They tested a very large number of elements and compounds "in the flame". After some time they drew up a list of the chemical elements with the characteristics of their lines in the spectrum. Now scientists could unerringly analyse many complex mixtures of substances.

Thus was born spectroscopic or spectrum analysis. It proved not only an excellent method for qualitative determination of various known chemical elements in mixtures. It also helped in the discovery of the new elements: rubidium, cesium, indium, gallium, and the noble gases owe their discovery to spectrum analysis mainly. And when it was found that the intensity (brightness) of the lines depends on the concentration of substance present in the mixture, spectrum analysis took up an honourable position among quantitative methods.

Chemical Analysis of   the Sun

In anticipation of the solar eclipse of 1868 astronomers, as always, prepared a great deal of equipment. This time the list included a spectroscope, the instrument which had not long before enabled the discovery of several new elements.

The eclipse passed, and everything settled back to normal. But on October 26, 1868, the Paris Academy of Sciences received two letters simultaneously, one from the shores of distant India from the Frenchman Janssen, and the other from England, from the Englishman Lockyer.

Both scientists reported in their letters that each of them by means of his own method had observed the spectrum of solar prominences, the gigantic emissions of solar matter, whose nature was not known at that time. The most interesting thing here is that Janssen and Lockyer succeeded in observing the spectrum of the solar prominences at a time other than during a solar eclipse, whereas all other observations had been during eclipses. In honour of this prominent astronomical event, Paris Academy passed a decision to coin a special medal.

Since then many astronomers have concentrated their efforts on studying solar prominences and it soon became known that there was a certain yellow line in their spectra which could not be attributed to any of the known elements existing on Earth. The Italian astronomer A. Secchi denoted this line by the symbol D_3. But he believed that it was due to hydrogen which exists on the Sun under superhigh temperature conditions. Lockyer and his compatriot Frankland

did not agree with Secchi and firmly asserted that the line in the spectrum belongs to some chemical element present on the Sun but not on Earth and gave it the name "helium", which means "solar".

For nearly 30 years helium remained a hypothetical element. Apart from its spectrum, nothing else was known of it. Scientists went on establishing the presence of other elements on the Sun, which were long known on Earth. But helium remained a mystery. Only in 1895 was helium discovered on Earth, and this fact proved once again the power of the method of spectrum analysis.

After the Sun came the turn of other stars, near and distant. The glitter of stellar atmospheres reached the spectroscopes on Earth and in the silence of their laboratories scientists studied the intricate palisade of all kinds of spectral lines. In the heavenly bodies scientists found the elements that were already known on Earth.

Only eighty years later did solar helium pass on the relay of scientific surprises to the element technetium, the one that occupied box 43 in the Mendeleyev Table. A ghost in terrestrial ores, technetium was first discovered in the spectra of certain stars, and only after that were traces of the element found on Earth. In the stars technetium is by no means a rare element. It forms in them continuously as a result of nuclear reactions.

No more new elements were discovered on the Sun or in any of the stars.

But the curious thing is that the "balance" of

chemical elements in the skies is different from what it is on Earth. Not oxygen and silicon predominate in outer space, but hydrogen and helium. The amount of these first two representatives of the Periodic System in the universe is many times greater than that of all the rest of the elements taken together. See what a surprising paradox stellar chemistry brings us: our galaxy is primarily a kingdom of hydrogen.

Waves and Substance

The number of colour hues in nature is infinite. Chemists know that as well as anybody else. And not infrequently the fantastic gamut of colours leaves them nonplussed.

"What colour is a solution of neodymium nitrate?"

"Pink", replies the chemist.

"And what colour will a solution of trivalent iron salt turn if potassium thiocyanate is added to it?"

"Red."

"And what colour does phenolphthalein turn if a solution of alkali is added to it?"

"Crimson."

We could continue almost indefinitely: very many chemical reactions involve colour of a definite hue. Probably if we were to name a dozen more compounds whose solutions are coloured some shade of red, we should get entirely confused. It is said that artists and textile workers who dye fabrics can distinguish about two dozen

shades of red. Now that is what acquiring an
eye for colour means!

But such an "intuitive" way of distinguishing
hues and shades is of little use to chemists. Even
a solution of the same substance may have an
infinite number of shades depending on its con-
centration. How could they all be remembered?

There appear to be people on Earth who can
distinguish colours with their eyes blindfolded
by using their fingertips. Doctors say that such
people have highly developed cutaneous vision.
The famous writer Jonathan Swift wrote sarcas-
tically of the Laputan Academy of Sciences that
the blind mixed various colours for the painters
there to ironize on the "scientific" subjects they
studied.

Today the sarcasm of the English satirist is no
longer appropriate. Now chemists can name the
colour of a solution without seeing it. They do
it with the aid of what is known as spectrophoto-
metry. This distinctive method of analysis derives
its name from an instrument called the spectro-
photometer with which the colour of a chemical
compound or its solution can be analysed.

But what is light? It is electromagnetic vibra-
tions or waves. Each wave has a definite length
(usually denoted by the Greek letter "lambda").
The wavelength exactly characterizes any colour
or shade. For example, chemists say: "a red
colour of the wavelength 620 millimicrons" or:
"a red colour of the wavelength 637 millimicrons"
(a millimicron is one thousandth of a micron, or
one millionth of a millimetre). This eliminates
the need to give definite names to the separate
shades, such as "crimson", "red", "bordeau",

"scarlet", "vermilion", etc. Just name the wave-
length and all the scientists in the world will
know quite definitely the colour and shade meant.
Each compound has now received a kind of
"certificate" with "Lambda equals so much" filled
in under the item "colour". Believe us, it is
a very reputable document.

But this is only half the matter. The colour
of a compound depends on the wavelengths of
the rays it absorbs and those of the rays it trans-
mits. For instance, if a solution of a nickel salt
is green, it absorbs light of all the wavelengths
except those which correspond to the green hue.
A yellow solution of potassium chromate is trans-
parent only to yellow rays.

The spectrophotometer gives beams of light
rays of definite wavelengths and makes it pos-
sible to determine how they are absorbed by
various substances. A great number of compounds,
organic and inorganic, have been investigated
with spectrophotometers.

Besides visible light there is light that is in-
visible, that the human eye does not see. These
kinds of light "from the beyond" lie outside the
limits of the visible light spectrum, and are called
ultraviolet and infrared rays. Chemists have
learned to use them too. They studied the spectra
of various chemical substances in the ultraviolet
and infrared ranges and discovered a very inter-
esting phenomenon. They found that each chemi-
cal compound (or ion) has its own distinctive
absorption band spectrum. Each substance has
its own "colour (infrared or ultraviolet) certifi-
cate".

Absorption spectra can be used not only for

qualitative, but for quantitative analysis as well. This is due to the fact that in many cases the higher the concentration of a chemical compound in a solution, the more intense its colour, i.e., the stronger it absorbs colour of a definite wavelength. Hence, by determining the absorption of light by a solution (one usually says, "by determining its optical density"), one can easily find the concentration of any particular element.

It's Only a Drop of Mercury that Does It

From hoary antiquity comes the saying "All things of genius are simple".

Only once was the Nobel Prize awarded for a discovery in the field of chemical analysis. The discovery was made in 1922 by Yaroslav Heyrovský, the famous Czech scientist. Since then Prague has become a kind of Mecca. Numerous pilgrims have travelled to Prague to learn Heyrovský's new method, polarography.

Today over a thousand papers are published yearly all over the world on polarographic analysis. The ABC of the method is as follows. Some mercury is placed at the bottom of a glass beaker containing the solution in which the concentration of a given substance has to be determined. The mercury layer serves as an electrode. Drops of mercury falling at definite intervals from a capillary into the beaker are the other electrode.

The electrodes are connected to the source of electricity. This should cause electrolysis in the

solution. But electrolysis will occur only if the potential on the mercury drop is high enough. If the potential is small, no current will flow through the circuit. When the potential is increased above some threshold, the ions contained in the solution begin to discharge. Then current begins to flow through the circuit.

If there are ions of different elements in the solution, each species will be discharged at a different potential value characteristic of those particular ions.

The chemists plot graphs, marking off the potential values along the abscissa axis, and the currents that appear along the ordinates. The resulting curve resembles a staircase, each step corresponding to the discharge of a definite species of ions.

The staircase obtained is compared with a standard curve, one which has been plotted beforehand for a solution containing known concentrations of known substances.

Thus the solution can be analysed qualitatively and quantitatively at the same time. By means of special devices the analysis can be made automatic.

The first epithet that occurs to you respecting the polarographic method is elegant. But elegance is not the only thing. Polarography is simple, rapid, and precise; moreover, it surpasses many other methods of analysis in these qualities. For example, as little as a millionth of a gram of zinc chloride in one cubic centimetre of solution can be quantitatively determined polarographically. This analysis takes less than ten minutes.

Heyrovský's original idea has now been per-

fected and many new versions have been suggested. One of these is adsorption polarographic analysis which has a very high sensitivity. It can readily be used to determine organic substances in concentrations as low as thousand-millionths of a gram per cubic centimetre of solution.

Where is polarography needed? Why, practically everywhere: for automatic control, and for analysis of minerals and alloys. Polarography gives an idea of the contents of vitamins, hormones and poisons in the organism.

A Chemical Prism

By strange coincidence, this scientist's name and profession are consonant with his discovery.

He was a botanist and his name was Mikhail Tsvet. Tsvet is the Russian for colour. The botanist Tsvet was interested in chlorophyll which, as we know already, is the colouring matter of green leaves.

But Professor Tsvet also knew many chemical procedures. In particular, he knew that there were substances (adsorbents) which could retain (adsorb) many gases and liquids on their surfaces.

He ground a leaf into a green paste and treated it with alcohol. The paste lost its colour, which meant that all its colouring matter had been extracted by the alcohol.

Then he filled a glass tube with chalk moistened slightly with benzene; into this tube he poured the solution containing the chlorophyll.

The upper layer of the chalk powder turned green.

The scientist washed the chalk in the tube with benzene, adding it drop by drop. The green ring budged and then began to move downwards. And then—oh wonder!—it separated into several bands of different colours. There were a yellow-green, a green-blue and three yellow bands of different shades. It was a curious sight that the botanist Tsvet observed. And this sight proved to be a most important find for chemists.

It indicated that chlorophyll was a complex mixture of several compounds, different, though close, in molecular structure and properties. What is now called chlorophyll was only one of them, true, the most important one. All these substances had now been separated from one another by a very simple method.

All of them had been adsorbed by the chalk, but each in its own way. The strength of retention of each compound by the surface of the chalk powder was different. And when the benzene (the eluent) passed through the tube, it carried off the substances in a definite sequence. First those that were held less strongly, and then those that were retained more strongly. This caused the separation.

The column of adsorbent (the "chemical prism") had separated the complex mixture of substances into its component parts like a prism resolves solar light into the colours of the spectrum. This new method of analysis discovered by Tsvet in 1903 was christened chromatography by its author. This word comes from the Greek for "colour writing".

Today the method of chemical "colour writing" is one of the most important instruments in all analytical laboratories the world over.

But the fates of many scientific discoveries are inscrutable. Some are forgotten, sometimes for many years, only to shine afterwards on the scientific horizon like stars of the first magnitude. So was it with chromatography. It was actually remembered only in the forties, and nobody ever regretted this.

How Promethium Was Discovered

Strictly speaking, it was discovered many times, this element with the atomic number 61. And each time it was given a different name: illinium, florentium, cyclonium. But each time the discovery proved false, and the name of the still-born became history.

Then scientists proved that there simply was none of the sixty-first element on Earth. Not due to some strange whim of nature by which it had deprived the Periodic System of one of its representatives, but because all the isotopes of element No. 61 are radioactive, very unstable, and had long since decayed into isotopes of its neighbouring elements.

Finally, it was produced artificially in 1945, in the course of operation of a nuclear reactor. Fission of the nuclei of uranium, the reactor "fuel", results in a large number of fragments, these being nuclei of lighter elements. They include promethium (now the real name of this elusive element).

Theoretical physicists might have signed this report. But chemists would have to "feel" promethium with their hands, and to see with their eyes at least a tiny speck of the new metal, or at least its compounds.

However, it would have hardly been possible to separate more than tenths or even hundredths of a gram of element No. 61 from the mixture of fragments of uranium fission.

Is that so little? Chemists had more than once had to deal with still smaller amounts of substance, and they had been successful.

The difficulty was one of a different nature. Promethium is a rare-earth element, and we have already spoken of the resemblance in this family. Now the mixture of nuclear fragments contained a substantial amount of promethium's closest neighbours, neodymium and samarium.

It was from them primarily that promethium had to be separated, but that was no easy job! Chemists who devoted their lives wholly to the rare-earths performed a real scientific feat. It was torment—there is no other word for it— to separate the fourteen twins and to obtain each of them separately.

(The French chemist G. Urbain decided to prepare pure thulium. And he did. But it took him five years and he had to carry out over fifteen thousand monotonous and very tedious chemical operations.)

Of course, separating pure promethium was easier, but not much. It must be remembered that it is radioactive and decays rapidly. And so it might have happened that there was nothing left of it by the time it was separated.

Hence, quicker methods were needed, methods by which it would not take years, or months or even weeks to separate the lanthanides, but not more than a few hours. Chemistry knew no such methods.

Then it was that chromatography was remembered.

Tsvet's separating tube (it now goes by the more sedate name of chromatographic column) is filled with an adsorbent (not chalk as before, but special ion-exchange resins). A solution of salts of the rare-earth elements is passed through the resin layer. Though they resemble each other greatly, the lanthanides are not identical. Each forms a complex compound with the resin. These compounds differ in stability, and moreover, in a definite order. Lanthanum, the first in the family, forms the strongest compound; the last, lutetium, forms the weakest.

After this the resin is washed with a special solution. The drops of the solution encompass the resin grains and wash off the ions of the rare-earth elements, as it were—again in a strict sequence.

And solutions of pure rare-earth salts begin to issue from the column drop by drop: lutetium salts first, and lanthanum salts last.

It was by this method that the American scientists J. Marinsky, L. Glendenin and C. Coryell separated promethium from neodymium and samarium. And it took them only a few hours.

Aromas of a Wild Strawberry Patch

A glade in a pine forest... . A hot day in July.
And strawberries, strawberries everywhere—ripe,
rugged, bright red berries, so tasty, they melt
in your mouth.

But what do they smell of, these strawberries?
You must confess that you have never stopped
to think about it. You just enjoyed the aroma
of the pine forest, the smell of the sunny glade.

But odour is a very complex phenomenon. There
is a whole science of odours. Scientists still have
to work out a uniform opinion as to why some
substances have a strong odour while others
have hardly any; why some odours are pleasant,
and others disgusting.

There is no doubt that the odour of a substance
is related to the structure of its molecules. But
how? That is what we cannot say for certain. There
is no strict physical theory of odours as yet.

Chemists have an easier time of it. They can
identify the different molecules "responsible" for
various odours, and can tell you exactly what
strawberries smell of.

The odour of strawberry is a very complex mix-
ture of ninety six odours differing over a wide
range. Even the most experienced perfumer might
well envy nature for being able to create such
splendid "strawberry" perfume.

How were scientists able to "dissect" this
"strawberry" perfume?

By the method of gas-liquid chromatography.

The adsorbent in this method is specially
prepared silicon dioxide, SiO_2, moistened with

a nonvolatile liquid. The moving medium is an inert gas (argon). And that is just about all.

Otherwise, a glass tube may simply be moistened with the nonvolatile liquid. The tube must be very long. To "catch" the entire aroma of fresh strawberries researchers had to use a tube 120 metres long.

Of course, it had to be wound into a coil and placed in a special apparatus called a thermostat where the temperature could be raised slowly and uniformly. This was necessary because the different components of strawberry odour differ in volatility, some evaporating more readily, and others less. The components arranged themselves in a definite sequence along the tube. Then they were forced out by passing argon through the tube. At the outlet a complicated apparatus registered the passage of the different substances. The odour of strawberries proved to contain ninety six of them, although their total weight was only about 10^{-12} gram!

Chemists have investigated quite a number of very intricate natural substances by this method. How many components do you think petroleum contains? No less than two hundred and thirty! Moreover, they have not only been counted but each of them has been identified.

The Diagnosis After Three Centuries

The biography of Sir Isaac Newton including even some intimate and curious sides of his life is known in detail. It is said that being a member of the House of Commons, the great

scientist gave a speech only once ... when he requested that the window be closed.

But until recently there remained a blank spot in the Newton's biography. In 1692 he fell seriously ill: he lost his appetite, suffered from insomnia, was not happy to see his friends, nothing seemed to work right, his memory failed him. The letters he wrote at that time were, to put it mildly, rather strange both in their style and content.

Fortunately, the mysterious illness passed after a year and the renowned physicist lived for another three decades.

Neither Newton himself nor his biographers could account for what had happened to him. It was presumed that he had a nervous breakdown. There had been some extreme situations in his life, but they occurred long before 1692.

Some years ago, British scientists suggested another version, namely, that the real cause of the illness was severe mercury poisoning. Thorough studies of the contents of Newton's letters where he mentioned the symptoms of his ailment, studies of his diaries and laboratory logs in which he described his experiments and named the chemical reagents involved confirmed the suspicions.

It should be said that Newton never shunned chemistry and even set alchemical experiments. He often tasted what he obtained as a result of his chemical manipulations. The notes dating back to 1692 contained descriptions of "alchemical" experiments involving mercury, antimony and other poisonous substances. Having linked these facts with the symptoms of Newton's

illness the investigators came to the conclusion that, most likely, he had been poisoned with mercury.

But how can one prove this diagnosis after almost three hundred years?

There had already been a precedent in the past of uncovering historical mysteries with the aid of modern scientific methods. In the fifties, scientists subjected a tuft of hair of Napoleon to special analysis. It was suspected that Napoleon had been poisoned with arsenic while in exile on the Island of St. Helena. The hairs were irradiated by neutrons in the nuclear reactor. By the character of the radioactive emission, it was established that the hairs contained a high content of arsenic.

Fortunately, some locks of hair of Isaac Newton were preserved. The Earl of Portsmouth, who was in possession of one of these precious relics, granted fifteen hairs to the Oldermaston Nuclear Centre in England.

Each hair underwent "neutron processing". The tiniest concentrations of different chemical elements were determined by means of the most precise apparatus. Special attention was paid to the elements which were considered highly toxic.

After more than a month of hard work, it became quite obvious that the content of poisonous metals in Newton's hair was far above normal. The concentration of mercury was particularly high. Its normal content in the human hair does not exceed, on the average, 0.0005%, whereas it reached 0.02% in Newton's hair, which exceeds the permissible limit by 400 times.

Indeed, Newton's alchemical experiments were

not in vain. And we ought to thank fate that he took measures in time. So many unknown researchers fell victims to harmful chemical reagents.

This is how modern science managed to diagnose an illness of one of the greatest scientists of all times.

Activation Analysis

A sensitive method of analysis helped solve those historical riddles. The essence of it is as follows.

Natural arsenic is a very stable element. In any case, nobody has ever detected radioactivity in it.

Arsenic has another peculiar feature. It is what one might call a "lone" element. Many of the others are mixtures of two, three, or more isotopes. For example, tin consists of ten stable isotopes and they are all found in nature.

But arsenic is single. Its nucleus contains 33 protons and 42 neutrons, and this combination is a very stable one.

But if an extra neutron is in some way forced to enter this nucleus, its stability vanishes, and a radioactive isotope of arsenic forms, an isotope that can be detected without chemical methods. All that is needed is an instrument for registering radioactive emission. The larger the amount of active arsenic, the more intensive will be its radiation.

Such is the basic principle of the simple but very important method of activation analysis. It enables the determination of infinitesimal amounts of substances, fractions of a gram re-

presented by numbers with 10 or 12 zeros after the decimal point. To do this, the object under study had only to be irradiated with a beam of neutrons, and the intensity of the radiations emitted by the resulting radioactive isotopes measured.

In this respect mercury is similar to arsenic: its irradiation with neutrons also results in formation of radioactive isotopes.

To modern analysts activation analysis is an all-seeing eye. It easily discerns what hardly any other analytical method can detect.

Pure germanium is commonly known to be an excellent semiconductor. But if it contains only a few atoms of such an impurity as, say, antimony, as little as one antimony atom per million million germanium atoms, in fact, the semiconducting properties of germanium entirely disappear.

That is why germanium has to be checked very carefully for impurities, and this can be done only with the aid of activation analysis.

And so neutrons speed on their way to a plate of germanium. Chemists know that it contains some amount of antimony. Maybe so little that it can be neglected, but maybe so much that the "pure" germanium will have to be rejected. The atomic nuclei of germanium and antimony react differently to neutrons. The former allow them to pass by quite indifferently, but the latter absorb them avidly. For this reason only radioactive isotopes of antimony are formed. The rest is done by radiation counters. Then we can tell for sure whether there is much or little antimony in the germanium.

The Chemistry of Single Atoms

There were times when chemists bewailed the difficulty of studying the properties of a new element available only in milligrams.

Since then the "criterion of smallness" has had to be revised more than once. In 1937 the Italian scientists Perrier and Segrè quite successfully studied the properties of the just then obtained element No. 43, called technetium, having at their disposal only one ten-thousand-millionth of a gram of this new representative of the Periodic Table.

Their experience was of benefit to others. When working with the transuranium elements chemists had to forget entirely such weight units as grams, milligrams or even micrograms. "Imponderable, invisible amounts"—such were the terms that appeared on the pages of scientific papers devoted to the transuranium elements. The deeper investigators delved into this region of the Periodic System, the greater were the difficulties they encountered.

Finally came the turn of the hundred and first element, called mendelevium in honour of the great Russian chemist.

Since the new transuranium element received a name, scientists must have been quite convinced that it had actually been obtained.

It had been comparatively easy to calculate the conditions under which one could hope to synthesize element No. 101. There was not much difficulty in writing the equation of the corresponding nuclear reaction. Which isotope

of the new transuranium element would form could also be foreseen.

Such was theory. But what had been obtained in practice needed confirmation, to prove that isotopes of precisely the hundred and first element, and none other, had formed as a result of the nuclear process.

What followed was fantastic. "During one experiment of synthesis of the hundred and first more than one atom of the new element cannot be expected to form"—such was the verdict of strict physical and mathematical reasoning, and so it turned out in reality. Only one single atom, an unknown atom, announced its birth. But was it an atom of the hundred and first element?

Sensitive radiometric instruments enabled determination of the half-life of the atom, but not of its chemical nature.

And in general, is it possible to study even the main chemical properties of a single atom?

Chromatography came to the rescue.

Now follow our reasoning closely. The hundred and first element must belong to the actinide family. In some of their properties the actinides resemble the elements of another similar family of elements called the lanthanides, especially when being trivalent. Separation of the lanthanides was accomplished by ion-exchange chromatography, the individual lanthanides separating out of the mixture in a strict sequence, the heavier ones first, and then the lighter ones.

In the actinide series the hundred and first element was to follow einsteinium (No. 99) and fermium (No. 100). If we wish to separate einsteinium, fermium and element No. 101 chroma-

.tographically, the last-named element should appear in the first drops of the liquid issuing from the chromatographic column.

Many times scientists repeated the experiment of mendelevium synthesis. Many times they used ion-exchange chromatography to establish the chemical nature of the new man-made atom. And in each case the mendelevium atom appeared exactly in the drop of solution in which it was to appear according to theory. Formerly only fermium and einsteinium came out in these drops. Hence, the atomic number of mendelevium is 101 and it is most likely to be a typical actinide in properties.

An Amazing Number

In their calculations scientists often have to do with what they call constants, i.e., numerical values characterizing some quality or property. We wish to draw your attention to one of them.

It is called Avogadro's number, after the famous Italian scientist who put this constant into use. Avogadro's number is the number of atoms in a gram-atom of any element.

It will be recalled that a gram-atom is the number of grams of an element equal to its atomic weight. Gram-atom of carbon is (roundly) 12 g, that of iron, 56 g, and of uranium, 238 g.

The number of atoms in each of the quantities named is exactly equal to Avogadro's number.

Written on paper it can be represented approximately by a numeral six followed by twenty three naughts; more exactly, it is 6.025×10^{23}.

That is how many atoms are contained in

twelve grams of carbon, fifty six grams of iron, or two hundred and thirty eight grams of uranium. Avogadro's number is so large that it is difficult even to imagine. Still, let us try.

The human population of the globe is about three thousand million. Now suppose all the inhabitants of the Earth decided to count up the number of atoms in a gram-atom of some element. Suppose each man worked eight hours daily and made one count each second. How much time would it take for all the inhabitants of the Earth to count up all the 6.025×10^{23} atoms?

A very simple calculation, which you can easily do yourself, shows that it would take about 20 million years. Impressive, isn't it?

The immensity of Avogadro's number is evidence that the idea of the omnipresence of all the chemical elements has a sound footing. We can always detect at least a few atoms of any chemical element everywhere. It is obvious that all attempts to obtain an absolutely pure substance would be futile. It is utterly impossible to catch a single atom of an impurity among 10^{23} atoms without introducing new impurities.

Indeed, a gram of, say, iron, contains about 10^{22} atoms. If it contains only one per cent (10 milligrams) of copper atoms as the impurity, that still makes not less than 10^{20} atoms. Even if the impurity content is reduced to one ten-thousandth of a per cent, the number of atoms of the impurity per 10^{23} atoms of the principal substance remains 10^{16} atoms. If the impurity includes all the elements of the Periodic System, there will be an average of 10^{14}, i.e., one hundred trillion atoms of each element,

Chemistry Spreads Wide...

Diamonds Once More

A raw, unfaced diamond is the champion of "all the minerals, materials, etc." in hardness. Modern engineering would have a hard time without diamonds.

A faced and ground diamond becomes a brilliant, which has no equal among gems.

Greyish-blue diamonds are especially priced by jewellers. They occur "once in a blue moon" and this makes their price truly fantastic.

But after all, gem diamonds are not so very important. If only there were more ordinary diamonds, so that we should not have to worry over every tiny crystal!

Alas, there are very few diamond deposits on Earth, and still less rich ones. One of them is in South Africa and it still gives up to ninety per cent of the world's diamond production outside of the Soviet Union. In this country a very large diamond-bearing region was discovered in the fifties in Yakutia, and now diamonds are produced there on an industrial scale.

The formation of natural diamonds required extraordinary conditions, namely, immense temperatures and pressures. Diamonds were born in the deeper layers of the Earth's crust. At places diamond-bearing melts subsequently broke

out on to the surface and froze, but this happened very rarely.

But can't we get along without nature's help? Can't man make diamonds himself?

The history of science knows of numerous attempts to produce diamonds artificially. (By the way, one of the first "fortune seekers" was Henri Moissan, the first to isolate fluorine in the free state.) Not one of them was successful. Either the method was fundamentally wrong, or the experimenters did not have at their disposal equipment which could provide the combination of exceedingly high temperatures and pressures.

Only in the middle fifties of this century did modern engineering finally find the key to the problem of producing artificial diamonds. As might have been expected, the starting material was graphite. It was subjected simultaneously to a pressure of 100 thousand atmospheres and a temperature of about three thousand degrees. Now diamonds are produced in many countries of the world.

But in this case chemists could only rejoice together with everybody else. They played but a minor part, most of the credit for this accomplishment being due to the physicists.

However, the chemists scored in another way, having helped substantially to perfect diamonds.

To perfect diamonds? Can anything be more ideal than diamond? Its crystal structure is the most perfect in the world of crystals. It is the ideal geometric arrangement of carbon atoms in diamond crystals that makes them so hard.

Diamonds cannot be made any harder, but a substance harder than diamond can be made.

Chemists have created the starting material for producing such a substance.

There is a chemical compound of boron and nitrogen called boron nitride. It is nothing much to look at, but what puts one on the alert is its crystal structure, which is the same as that of graphite. That is why boron nitride has long been known as "white graphite". True, nobody has ever tried to make pencil of it...

Chemists found a cheap way to synthesize boron nitride. Physicists put it to severe tests involving hundreds of thousands of atmospheres and thousands of degrees of Celsius... The logic they followed was quite simple. Since "black" graphite could be changed into diamond, why could not a substance similar to diamond be obtained from its "white" counterpart?

The result was borazon, a substance that exceeds diamond in hardness. It leaves scratches on smooth diamond faces, and can withstand higher temperatures: it is not so easy to burn borazon.

Borazon is still too expensive. It will take some effort to bring its price down. But the most important part has already been done. Man has again proved more capable than nature.

It was reported not long ago that Japanese scientists have succeeded in preparing a substance considerably harder than diamond. They subjected magnesium silicate (a compound consisting of magnesium, silicon, and oxygen) to a pressure of 150 tons per square centimetre. For obvious reasons the details of the synthesis are not advertised. The newborn "king of hardness" has no name as yet. But that does not matter,

What does matter is that diamond, which has for centuries headed the list of the hardest substances, will in the near future be far from the top of this list.

Endless Molecules

Everyone knows what rubber is. It is balls and galoshes. It is the hockey puck and the surgeon's gloves. It is automobile tyres and hot-water bottles, waterproof raincoats and hoses.

Rubber and rubber goods are put out nowadays by hundreds of factories and plants. A few decades ago all rubber goods were made of natural rubber, otherwise called caoutchouc. The word "caoutchouc" comes from the Tupi* "caou-uchu" meaning "tears of the Hevea". The Hevea is one of the most important trees whose sap is used to make rubber.

Many useful things can be made from rubber, and it is too bad that its production is very labour-consuming, and that the Hevea grows only in the tropics. All this has made it impossible to meet the demands of industry for the natural raw material.

Here again chemistry came to the rescue. First of all chemists tried to find answer to the question of why rubber is so elastic. After studying the "tears of the Hevea" for a long time they finally found the answer. It proved that the rubber molecules have a very peculiar structure. They

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* Tupi is the language spoken by a group of South American Indian tribes inhabiting mainly the valley of the Amazon.—*Tr.*

consist of a large number of recurring identical units linked into immense chains. Of course, a long molecule consisting of about fifteen thousand units, can bend in all directions and is elastic. It was found that the units making up the chain are residues of the hydrocarbon isoprene, C_5H_8, which has the following structural formula:

$$
\begin{array}{cccccc}
 & H & & H & H & \\
 & | & & | & | & \\
H-C & = & C-C & = & C-H \\
 & | & & & \\
 & H-C-H & & \\
 & | & & \\
 & H & & \\
\end{array}
$$
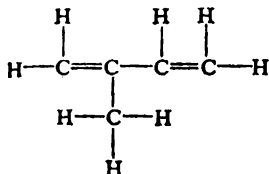
It would be more correct to say that isoprene is a sort of initial natural monomer. In the course of polymerization the isoprene molecule undergoes a slight change: the double bonds between the carbon atoms break, and the freed bonds link up the units into the gigantic rubber molecules.

The problem of producing synthetic rubber drew the attention of scientists and engineers long ago.

At first glance the job did not seem very tricky. One had to produce isoprene and then make it polymerize, i.e., make the isoprene units combine into long and flexible chains of artificial rubber.

But reality was disappointing. Chemists succeeded with some difficulty in synthesizing isoprene, but when it came to polymerizing it, rubber did not result. The units combined with each other, but did so haphazardly rather than in

a definite order and the result was artificial pro-
ducts which resembled rubber slightly but
differed from it in many respects.

And so the chemists had to invent methods of
making the isoprene units connect up into a
chain in the right way.

The world's first industrial synthetic rubber
was produced in the twenties in the Soviet Union.
Academician S. Lebedev chose a different sub-
stance, butadiene, for the chain unit:

$$H-\overset{\displaystyle\overset{H}{|}}{C}=\overset{\displaystyle}{C}-\overset{\displaystyle}{C}=\overset{\displaystyle\overset{H}{|}}{C}-H$$
$$\underset{\displaystyle\underset{H}{|}\ \underset{H}{|}}{}$$

It greatly resembles isoprene in composition
and structure, but its polymerization is easier
to control.

At present quite a large number of synthetic
rubbers are known (they are now often called
elastomers to distinguish them from natural
rubber).

Natural rubber and goods made from it have
substantial shortcomings. For example, it swells
greatly in oils and fats, displays little resistance
to many oxidants, particularly ozone, traces
of which are always present in the atmosphere.
Articles made of natural rubber have to be
vulcanized, i.e., treated with sulphur at a high
temperature. That is how raw rubber is converted
into cured rubber or ebonite. In service, goods
made of natural rubber (e.g., automobile tyres)
evolve a large amount of heat which causes aging
and rapid wear,

That is why scientists had to create new synthetic rubbers possessing better properties. For instance, there is a family of rubbers known as "Buna". The name is derived from the initial letters of two words "butadiene" and "natrium" (the Latin for "sodium"), sodium playing the part of the catalyst during polymerization. Some of the elastomers of this family possess excellent properties and are used mainly for the production of vehicle tyres.

Of especially great importance is butyl rubber, produced by the joint polymerization of isobutylene and isoprene. First of all, it is the cheapest rubber. Secondly, in contrast to natural rubber it is almost indifferent to ozone. Besides, butyl rubber vulcanizates used extensively at present for the manufacture of tyre tubes are ten times as impervious to air as vulcanizates made of natural rubber.

Of special interest are polyurethane rubbers. They possess high tensile strength and are almost unaging. Polyurethane elastomers are used to make foam rubber for upholstery.

Rubbers have been developed in recent years about which scientists once could not even dream. These are primarily elastomers based on organosilicon and fluorocarbon compounds. The thermal stability of these elastomers is twice as high as that of natural rubber. They are resistant to ozone, and rubber based on fluorocarbon compounds resists even fuming sulphuric and nitric acids.

But this is not all. The carboxyl-containing rubbers, i.e., copolymers of butadiene and organic

acids, have been obtained. They have a very high tensile strength.

It is thus evident that in this field too nature has yielded its superiority to man-made materials.

An Adamantine Heart
and the Hide of a Rhinoceros

There is a class of compounds in organic chemistry called hydrocarbons. And that is just what they are, because their molecules contain hydrogen and carbon atoms, and nothing else. Their best known typical representatives are methane (constituting about 95 per cent of natural gas) and petroleum, from which various grades of petrol, lubricants, and many other valuable products are made.

Take the simplest hydrocarbon, methane CH_4. Now if we replace the hydrogen atoms in methane by oxygen atoms, what do we get? Carbon dioxide CO_2. And if we replace them by sulphur atoms? A volatile poisonous liquid called carbon disulphide CS_2. If we replace all the hydrogen atoms by chlorine atoms, we also get a well-known substance, carbon tetrachloride. But what if we take fluorine instead of chlorine?

Not so long ago hardly anybody could answer this question intelligibly. But in our time the chemistry of fluorocarbon compounds is already an independent branch of chemistry.

In physical properties fluorocarbons are almost complete analogues of hydrocarbons. But that is as far as their common properties go. In contrast to hydrocarbons, fluorocarbons are very

unreactive substances. Besides, they are very thermally resistant. That is why they are sometimes called substances with "an adamantine heart and the hide of a rhinoceros".

The chemical explanation for their stability compared to hydrocarbons (and other classes of organic compounds as well) is relatively simple. Fluorine atoms are much larger than hydrogen atoms and therefore render the carbon atoms they surround inaccessible to other reactive atoms.

On the other hand, fluorine atoms transformed into ions are very reluctant to yield their electrons and "dislike" to react with any other atoms. Fluorine, as we know, is the most active nonmetal, and there is practically no other nonmetal which can oxidize its ion (i.e., remove an electron from it). Again, the carbon-carbon bond is itself very stable (remember diamond).

Owing to their inertness fluorocarbons have found a wide range of applications. For instance, fluorocarbon resins called Teflon can withstand temperatures of 300 °C and are indifferent to sulphuric, nitric, hydrochloric and other acids. They resist boiling alkalis and are insoluble in all known organic and inorganic solvents.

Not for nothing are fluoroplastics sometimes called "organic platinum": they are splendid materials for making chemical laboratory ware, various industrial chemical equipment, and pipes for a great variety of purposes. Believe us, very many things in this world would be made of platinum, were it not so expensive, but fluoroplastics are comparatively cheap.

Fluoroplastics are the most slippery substances in the world. A fluoroplastic film thrown on a

table will literally "flow off" it on to the floor. Bearings made of fluoroplastics require practically no lubrication. Finally, fluoroplastics are excellent dielectrics, and very heat-resistant materials too. Fluoroplastic insulation can withstand heating to 400 °C, which is above the melting point of lead!

Such are fluoroplastics, which are among the most remarkable man-made materials.

Liquid fluorocarbons are noncombustible and freeze at very low temperatures. These compounds are not attacked by fungi or insects, and are very resistant to corrosion.

Union of Carbon and Silicon

There are two elements in nature which can claim a special position. The first is carbon. It is the basis of all animate things. Its claim is valid primarily because carbon atoms are capable of combining strongly with one another to form chain-like compounds:

$$-\overset{|}{C}-\overset{|}{C}-\overset{|}{C}-\overset{|}{C}-\overset{|}{C}-\overset{|}{C}-\overset{|}{C}-$$
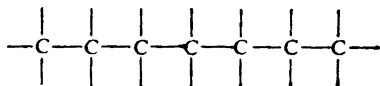
The second is silicon. It is the basis of all inorganic nature. But silicon atoms cannot form such long chains as carbon atoms, and besides the number of silicon compounds found in nature is smaller than the number of carbon compounds, though they are much more numerous than the compounds of any other chemical element.

Scientists decided to "correct" this shortcoming of silicon. Indeed, silicon is tetravalent just like carbon. True, the bond between carbon atoms is much stronger than that between silicon atoms, but silicon makes up for this by being less active.

Now if we could obtain compounds similar to organic compounds but with silicon instead of carbon, what wonderful properties they might possess!

At the beginning the scientists were unlucky. True enough, they proved that silicon could form compounds in which its atoms alternate with oxygen atoms:

$$-\overset{|}{\underset{|}{Si}}-O-\overset{|}{\underset{|}{Si}}-O-\overset{|}{\underset{|}{Si}}-O-\overset{|}{\underset{|}{Si}}-O-$$
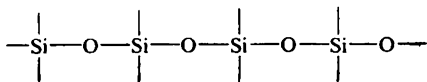
but these compounds were not stable.

They scored their first success when they decided to combine silicon atoms with carbon atoms. Such compounds, which have become known as organosilicon compounds or silicones, indeed have a number of unique properties. Various resins have been made on the basis of silicones, and from them plastics can be obtained which can resist high temperatures over long periods.

Elastomers based on organosilicon polymers possess very valuable qualities, one of which is heat resistance. Some grades of silicone rubber are stable up to 350 °C. Now imagine a tyre cover made of such a rubber.

Silicone rubbers do not swell at all in organic solvents. They are now used for making various kinds of hose for fuel transport lines.

Some silicone liquids and resins hardly change their viscosity over a wide range of temperatures. This made them eligible as lubricants. Owing to their low volatility and high boiling point silicone liquids have found extensive usage in high-vacuum pumps.

Organosilicon compounds are water-repellant and this valuable property is utilized in the manufacture of water-repellant fabrics. But that is not all. Water is said to wear away stone. Tests made at important construction projects have shown that it is useful to impregnate structural materials with various organosilicon liquids.

Strong heat-resistant enamels have been developed recently based on silicones. Copper or iron plates coated with such enamels can withstand several hours' heating at 800 °C.

And this is only the beginning of the peculiar union of carbon and silicon. But this "dual" union no longer satisfies chemists. They have set themselves the task of introducing other elements into the molecules of organosilicon compounds, such as aluminium, titanium, or boron. This problem has also been successfully solved and has resulted in an absolutely new class of substances known as polyorganometallosiloxanes. The chains of these polymers may consist of different kinds of links: silicon-oxygen-aluminium, silicon-oxygen-titanium, silicon-oxygen-boron, etc. Such substances melt at temperatures of 500-600 °C, competing in this respect with many metals and alloys.

Remarkable Sieves

These sieves are of quite a singular construction. They are immense organic molecules possessing a number of interesting properties. First, like many other plastics, they are insoluble in water and organic solvents. Second, they consist of what is known as ionogenic groups, i.e., groups capable of producing different kinds of ions in a solvent (water, in particular). These compounds may therefore be classed as electrolytes.

The hydrogen ion in them can be replaced by some metal, a process known as ion exchange.

Accordingly, these unique compounds are known as ion exchangers. Those capable of interacting with cations (positively charged ions) are called cation exchangers, and those which interact with negatively charged ions are called anion exchangers. The first organic ion exchangers were synthesized in the middle thirties of our century and immediately gained wide recognition. This is not surprising, because with the aid of ion exchangers hard water can be made soft and salt water fresh.

Imagine two columns, one filled with a cation exchanger and the other with an anion exchanger. Suppose we want to purify water containing table salt. We first let the water through the cation exchanger. In it all the sodium ions are replaced by hydrogen ions, so that instead of sodium chloride our water will now contain hydrochloric acid. Then we let the water through the anion exchanger. If it is in hydroxyl form (i.e., the anions in it capable of exchanging are hydroxyl ions) all the chloride ions in the solution will be re-

placed by hydroxyl ions. And the hydroxyl ions immediately form water molecules with the free hydrogen ions. Water which originally contained sodium chloride can be completely desalinated by passing it through ion-exchange columns. The product is not inferior in properties to the best grades of distilled water.

But the demineralization of water is not the only thing that made ion exchangers widely known. It was found that ion exchangers retain different ions with different strengths. Lithium ions are held more strongly than hydrogen ions, potassium ions, more strongly than those of sodium, rubidium ions, more strongly than those of potassium, etc. Ion exchangers offered an easy way of separating metals. At present ion exchangers play an important part in various branches of industry. For example, for a long time photographic laboratories had no suitable method of recovery of precious silver from their wastes. This important problem was solved with the aid of ion-exchange filters.

Well, and will man ever be able to use ion exchangers for extracting valuable metals from sea water? The answer is yes. And though sea water contains a large amount of different salts, the recovery of the noble metals from it is evidently a thing of the near future.

Just now the difficulty is that when sea water flows through the cation exchanger the salts contained in it virtually prevent the small amount of valuable metals from depositing on the cation exchanger. However, recently resins of a new type known as electron-exchange resins were synthesized. These not only exchange their ions for

the metal ions in the solution, but also reduce the metal by donating electrons to it. Recent tests have shown that if a solution containing silver is passed through such resins, metallic silver, rather than silver ion, soon begins to deposit on the resin, and the properties of the latter remain for a considerable length of time. Thus, if a mixture of salts is passed through the electron exchanger, the ions which are reduced the most readily can be converted into atoms of a pure metal.

Chemical Claws

According to an old joke there is nothing simpler than catching lions in a desert. Since the desert consists of sand and lions, all you have to do is to take a sieve and sift the desert through it. The sand will pass through the mesh leaving the lions on the sieve.

But what is to be done if a valuable chemical element is mixed with a large amount of others which are of no use? Or if a harmful impurity has to be removed from a substance which contains a very small quantity of it?

This problem is not a rare one. The amount of hafnium contained in zirconium to be used for the construction of nuclear reactors must not exceed a few ten-thousandths of a per cent, whereas its content in ordinary zirconium is about two-tenths of a per cent.

Hafnium and zirconium are very close in chemical properties so that ordinary methods are useless. Even the remarkable chemical sieve we

were just talking about is powerless. Still the
zirconium has to be very pure.

For ages chemists have followed the simple
formula: "Like dissolves in like." Inorganic sub-
stances dissolve readily in inorganic solvents,
and organic substances in organic solvents. Many
salts of mineral acids dissolve well in water,
anhydrous hydrofluoric acid, liquid hydrocyanic
(prussic) acid. Very many organic substances are
fairly readily soluble in the organic solvents:
benzene, acetone, chloroform, carbon disulphide,
and others.

But what about a substance intermediate be-
tween organic and inorganic compounds, how would
it behave? Chemists knew of such compounds,
more or less. For example, chlorophyll (the col-
ouring matter of green leaves) is an organic com-
pound containing magnesium atoms. It dissolves
well in many organic solvents. A large num-
ber of organometallic compounds which are un-
known in nature have been synthesized artificial-
ly. Many of them are soluble in organic solvents,
their solubility depending on the metal they con-
tain.

Chemists decided to take advantage of this.

During the operation of nuclear reactors it be-
comes necessary from time to time to replace spent
uranium fuel rods, though the quantity of
impurities (uranium fission fragments) in them
is usually not more than a thousand of a per
cent. The fuel rods are first dissolved in nitric
acid. All the uranium and other metals formed as
a result of the nuclear transformations are con-
verted into nitrates. Some of the impurities,
such as xenon and iodine, come out as gases or

vapours. Others, such as tin, remain in the sludge.

Still, apart from uranium, the resulting solution contains many impurities, particularly, plutonium, neptunium, the rare-earth metals, technetium and some others. Now this is where organic substances come in. The solution of nitric acid containing uranium and other impurities is mixed with a solution of an organic substance called tributyl phosphate. Practically all the uranium passes into the organic phase while the impurities remain in the nitric acid solution.

This process is called extraction. After two extractions the uranium is almost entirely free from impurities and can again be used to make uranium fuel rods. The impurities thus extracted are then separated to recover the most important of them, particularly plutonium and certain other radioactive isotopes.

Zirconium and hafnium can be separated in a similar way.

Extraction is now widely used in engineering. It is employed for purifying not only inorganic compounds, but many organic ones as well, notably, vitamins, fats, and alkaloids.

A Little Excursion into the History of Chemistry

Among other names of distinguished representatives of chemistry of the last century, the name of the German professor Herman Kopp is commonly mentioned. In addition to many other merits, he was a historian of chemistry and left

for his successors a four-volume treatise dedicated to the science's long-term development. Kopp was the first to divide the history of chemistry into several periods. During the initial stage which lasted from ancient times to the 4th century A.D., there was the accumulation of experimental facts. It was followed by the era of alchemistry which lasted for nearly twelve centuries. The birth of modern chemistry (or, to put it more exactly, the development of quantitative methods of analysis), Kopp dates back to the last quarter of the 18th century. It was preceded by two comparatively short periods: the predominance of the phlogiston theory and the flourishing of iatrochemistry. The former claimed that during the combustion of substances, a certain kind of matter, phlogiston, was formed. It took just over 100 years for this to be disproved.

Iatrochemistry literally means "medical chemistry" from the Greek "iatros" meaning physician. Its practical goals were the preparation of medicines and the treatment of all sorts of ailments.

One of the most prominent iatrochemists was Paracelsus. This was not his surname but a nickname. His true name was long and pompous: Theophrastus Bombastus von Hohenheim. By the age of thirty he had gained the reputation of an excellent physician and was rumoured to be a wizard at healing.

He was not only a physician but a chemist as well, and a rather learned one for that time. His works contained valuable facts about the properties of the widest range of substances. Paracelsus also gave the descriptions of many chemical

procedures in his works, but the trouble is that his works are not easy to read because his style is bombastic and unclear.

And still Theophrastus Bombastus von Hohenheim is one of those relatively rare figures in the history of science who gradually prepared the ground for the birth of chemistry by refuting the mystical beliefs of the alchemists who dreamt of turning base metals into gold...

Chemistry in a White Coat

As Paracelsus once said, the genuine goal of chemistry lies not in the preparation of gold but in the preparation of medicine.

As the philosophers would have noted, this was a thesis of great practical value, particularly in the Middle Ages when constantly repeating epidemics took away lots of human lives.

In different towns drugstores opened, which, in fact, were chemical laboratories. Many outstanding chemists started their activity in drugstores.

Drugs and various curatives were often prepared using the hit-or-miss method, pharmacology was still too young to be called a science. The century-old traditional remedies like different kinds of roots, extracts, infusions, decoctions, etc., were more beneficial to the patient than the drugs from the drugstores.

As time passed, the union of chemistry and medicine became stronger which gave rise to pharmaceutical chemistry, the science of drug preparation.

Paracelsus can rightfully be considered one of the first pharmacists. Many of his "decoctions" sank into oblivion long ago, and it is hard to say now whether they brought more good or harm. But the list of his medicines included mercurial and sulphur ointments, which are used to this day for treating skin diseases, and also iron and antimony salts and various herb tinctures. All of them existed in pharmacopoeias for a long time.

Incidentally, even in our time, approximately a quarter of all present medicines are natural preparations. The rest are obtained artificially in chemical laboratories. And we would like to tell you about some of them.

The curative properties of salicylic acid for rheumatism have been known for a long time. But it was previously obtained from vegetable materials, which was a very long and labour consuming operation. Only in 1874 was a simple method of preparing salicylic acid from the easily available phenol developed.

Salicylic acid forms the basis of many medicinal preparations, one of which is the well known aspirin. As a rule, the "lifetime" of a drug is rather short: old medicines are replaced by new ones, more perfect and more suited for curing various ailments. Aspirin seems to be "eternal". The demand for this drug does not decrease and it is likely to be the most popular among "simple" drugs. It is a good antipyretic and a good remedy for headache as well. The range of its application does not diminish with time. Pyramidon, which was synthesized 90 years ago, is still available in every drugstore, and can be compared with aspirin.

One of the greatest achievements in pharmaceutical chemistry was the synthesis of salvarsan, the drug containing derivatives of the chemical element arsenic. Many arsenic compounds are potent poisons. But salvarsan appeared to be an effective remedy against syphilis, a dangerous and highly contagious disease. (It might be of interest that if translated word-for-word from the Latin, salvarsan means "long live arsenic".) The creator of salvarsan was the German pharmacist and microbiologist Paul Ehrlich. He had to cover a lot of ground before he accomplished its synthesis. Only on his six hundred and sixth attempts did Ehrlich obtain an effective remedy. Salvarsan was even called "preparation-606" some time back. And Ehrlich's 914th attempt resulted in a still more powerful medicine which he called "neosalvarsan".

Another remarkable group of medicinal preparations is that of the sulphonamides that have saved so many human lives.

Who is not familiar with white streptocid? Older generations must also remember more efficient red streptocid which was used before World War II. But it was found to be toxic and its production was stopped.

The sulphonamide boom was initiated by the efforts of chemists and industrial workers in the development of the paint and varnish industry. It has been a long time since dyes were derived from plants. Now it has become easier and more advantageous to synthesize them using the methods of organic chemistry.

In 1908 it was established that the basis of a number of valuable dyes is sulphanilic acid.

The structure of its molecule is rather simple: to one "apex" of the benzene ring an NH_2 group is attached, to the other—SO_2OH. If in the latter the OH group is replaced by NH_2, the result will be the amide of the sulphanilic acid, which played an important part in the manufacturing of dyes.

But only a quarter of a century later did it become clear that sulphanilic dyes are simultaneously potent medicines which kill many pathogenic microbes. Among them are the pathogenic agents of suppuration and streptococci. Hence the name streptocid.

Sulphonamides haven't lost their value up to now. Who hasn't heard of such names as sulfazol, sulfaethidole, sulfadimesine, sulfadimethoxyne?

Behind the name of any medicine prescribed to you by your doctor or even available at the drugstore without a prescription stands the tremendous work done by many specialists in different fields.

New medicinal preparations are the result of joint efforts of highly qualified chemists, microbiologists, pharmacists, toxicologists and physicians. It takes from 8 to 10 years on the average to produce a new medicine. Thousands of different substances are studied during this long period of time before the most effective of them is chosen. But then the preparation must be tested from all aspects in order to reveal its side effects, which may be harmful to the organism.

If these rules are disregarded, tragedy may happen. In the early sixties, West German firms widely advertized a new soporific called thalido-

mide, which was claimed to be particularly good for pregnant women since it allegedly ensured a deep and refreshing sleep. But the properties of this drug were not studied properly, and it soon turned out that it was the fatal cause of tens of thousands of babies being born with congenital anomalies.

An analysis of "drug policies" uncovers peculiar things. For example, how many types of drugs are used today in medical practice? It appears, about 2000. But about 200-300 of them are the most popular ones commonly used by physicians, though sometimes rather rare and specific drugs are needed and are used by medical specialists in certain specific fields.

Each year the number of names of medicinal preparations increases considerably. Will this growth remain as rapid as it is now? The answer is yes, at least in the nearest future. At present about 30,000 different ailments are known to physicians, of which only a third can be cured more or less successfully with the help of drugs. Hence, the demand for new and more effective drugs will remain high.

It is important to know not only the mere fact of treatment of a certain disease by a certain drug, but it is no less essential to have an idea of the fine mechanism of the drugs action. This requires thorough chemical investigations.

For example, a present derivatives of the organic barbituric acid are used as soporifics. Their molecules consist of carbon, hydrogen, oxygen and nitrogen atoms. One of its carbon atoms has two alkyl groups attached to it, these being hydrocarbon molecules deprived of one of their hy-

drogen atoms. It turned out that the more car-
bon atoms are contained in the alkyl groups, the
more efficient the preparation is. In any case,
the amount of carbon atoms should be no less
than four.

In our troublesome times the demand for so-
porifics increases incessantly. The number of so-
called tranquilizers, the drugs that alleviate ir-
ritation, is really large. The most potent of them
are used for treatment of psychic disorders. Chemo-
therapy is now the cardinal method of treating
mental disorders.

According to modern statistics, one of the main
causes of human mortality is cardio-vascular
diseases. The immence arsenal of medicinal prep-
arations that help to cure such serious ailments
is at the disposal of physicians.

Having synthesized pamaquine, chemists helped
physicians in their struggle against malaria.
Pamaquine is far more effective than the former-
ly used quinine, which was derived from the bark
of the cinchona tree. The products of the compli-
cated chemical synthesis of PASA and tubazid
helped a great deal in the fight against tuberculo-
sis. Finally, many forms of cancer (particularly
skin cancer) are cured by "chemical means".

At the beginning of our century the average
human life-span was 46 years, whereas, as we ap-
proach the year 2000 it will exceed 70. And this
is, perhaps, one of the most remarkable achieve-
ments of the twentieth century that is partly
due to "chemistry in a white coat".

A Miracle from Mould

This word was known long ago to physicians and microbiologists, and was mentioned in special books. But until fairly recently it meant absolutely nothing to anyone not involved in biology or medicine. Nor did many chemists know its meaning. Now everybody knows it. The word is "antibiotics".

But before the layman came to know the word "antibiotics", he learnt the word "microbes". It was established that a number of diseases such as pneumonia, meningitis, dysentery, typhus, tuberculosis and others, are due to microorganisms. Antibiotics were needed to fight these microorganisms.

The curative action of some kind of moulds was known as far back as the Middle Ages. True, the ideas of the medieval Aesculapii were rather peculiar. For instance, it was thought that the only kind of mould that helped in curing diseases was that taken from the sculls of men hanged or executed for a crime.

But this is of no great significance. What does matter is that the British chemist Alexander Fleming was successful in isolating the active principle from a species of fungus mould he was studying. This resulted in penicillin, the first antibiotic.

Penicillin proved to be an excellent weapon in the fight against pathological microorganisms: streptococci, staphylococci, etc. It even vanquishes the Spirochaeta pallida, the microbe that causes syphilis.

But though Alexander Fleming discovered pen-

icillin in 1928 its formula was established only in 1945. By 1947 penicillin had been synthesized in the laboratory. It seemed that man had finally caught up with nature. But this was not quite so. The laboratory synthesis of penicillin is no simple thing; it is much easier to produce it from mould.

But the chemists were not to be daunted. Here too they had their say and were able to put out a good showing. The "productivity" of the mould from which penicillin was usually prepared was very low, and the scientists decided to raise its efficiency.

They found substances which, inculcated into the hereditary apparatus of the microorganism, altered its characteristics. Moreover, these new characteristics became hereditary. The result was a new strain of fungi, which produced penicillin much more actively.

The present-day assortment of antibiotics is quite impressive: streptomycin and terramycin, tetracycline and aureomycin, biomycin and erythromycin. Altogether about one thousand different antibiotics are known today and around one hundred of them are used for treating different maladies. Chemistry plays a major part in their preparation.

After the microbiologists have accumulated what is known as the liquid culture medium containing colonies of microorganisms, the chemists take over.

It is their task to isolate the antibiotics, the "active principle" Various chemical methods are employed for extracting intricate organic compounds from natural "raw materials". The an-

tibiotics are taken up by special adsorbents. Investigators use "chemical claws", i.e., extract the antibiotics by means of various solvents. They purify them with ion-exchange resins, and precipitate them from solutions. This results in a raw antibiotic which is then subjected to a lengthy cycle of refining operations until it finally becomes a pure crystalline substance.

Some of them, such as penicillin, are still synthesized with the aid of microorganisms. But the production of others is only half due to nature.

But there are antibiotics, such as synthomycin, which chemists produce without the aid of nature at all. Such preparations are synthesized from beginning to end at chemical plants.

Without the powerful methods of chemistry the word "antibiotic" could never have become so widely known, nor would the veritable revolution in medicine, caused by these antibiotics, ever have happened.

Microelements—the Vitamins of Plants

The word "element" has many meanings. For example, it may mean atoms of one species having the same nuclear charge. But what are "microelements"? These are chemical elements contained in animal and plant organisms in very small quantities. The human organism contains 65% of oxygen, about 18% of carbon, and 10% of hydrogen. These are macroelements, since they are present in large quantities. But titanium and aluminium may be called microelements be-

cause their content is only a thousandth of a per cent each.

At the dawn of biochemistry nobody ever paid any attention to such trifles. A mere hundredth or thousandth of a per cent was really nothing to speak of, the more so that at that time such small quantities could not even be determined.

As engineering and analysis methods progressed, scientists began to find more and more elements in living matter. However, for a long time the role of microelements remained unknown. Even today, though chemical analysis enables determination of millionths and even hundred-millionths of a per cent of impurities in practically any sample, the importance of many microelements for the vital activities of plants and animals has not yet been established.

But there are some things that have been established. For instance, it is known that various organisms contain such elements as cobalt, boron, copper, manganese, vanadium, iodine, fluorine, molybdenum, zinc, and even ... radium. Yes, radium, though in trace amounts.

Incidentally, about 70 chemical elements have been detected so far in the human organism and there are grounds to believe that the human body contains the whole Periodic System. Moreover, each element plays a certain definite part. There is even an opinion that many disorders are due to a disturbance of the microelemental balance in the organism.

Iron and manganese play an important part in plant photosynthesis. If a plant is grown in a soil not containing even traces of iron, its leaves and stem will be white as paper. But if such a

plant is sprayed with a solution of iron salts it immediately acquires its natural green colour. Copper is also needed for photosynthesis and affects the assimilability of nitrogen by plant organisms. A deficiency of copper in plants results in poor formation of proteins which contain nitrogen.

Intricate organic molybdenum compounds are constituents of various enzymes. They promote nitrogen assimilation. Molybdenum deficiency may result in leaf blight owing to excessive accumulation of nitrates, which are not assimilated by the plants in the absence of molybdenum. Molybdenum also influences the phosphorus content in plants. In its absence inorganic phosphates do not change into organic phosphates. Molybdenum deficiency also affects the accumulation of pigments (colouring matter) in plants; the leaves become spotted and pale.

In the absence of boron plants assimilate phosphorus badly. Boron also promotes better transfer of various sugars through the plant's system.

Microelements play an important part in animal organisms too. It has been found that the complete absence of vanadium in the food of animals causes a loss of appetite and may even prove lethal. On the other hand, increasing the amount of vanadium in pigs' food results in rapid growth and in the formation of a thick layer of fat in them.

Zinc plays an important part in metabolism and is a constituent of animal erythrocytes.

When an animal (or a human being) is in a state of excitement, its liver secretes manganese, silicon, aluminium, titanium and copper into

the general blood circulation, but if the central nervous system is inhibited only manganese, copper, titanium are secreted, the secretion of silicon and aluminium being retarded. Besides the liver, the cerebrum, kidneys, lungs and muscles regulate the content of microorganisms in the blood.

Elucidation of the role of microelements in the growth and development of plants and animals is an important and very exciting task of chemistry and biology. Solution of this problem will undoubtedly yield substantial results in the near future and will present science with more possibilities.

What Plants Eat and
What Chemistry Has to Do with It

Even in ancient times there were cooks who were famed for their culinary achievements. The tables of royal palaces were heaped with all kinds of dainty dishes. Well-to-do people became particular about their food.

It would seem that plants were not so particular. Herbs and bushes have survived in hot-deserts and in the polar tundra. They may be stunted and wretched to look at, but they have survived.

There was something they needed for their development, but what? Scientists sought this mysterious "something" for many years.

Despite all their experiments, in spite of all their discussions nothing definite was found.

The answer was finally supplied in the middle

of the last century by the famous German chemist Justus von Liebig. He was aided by chemical analysis. He "resolved" a great variety of plants into their separate chemical elements. At the outset there were not so many of them, ten in all: carbon and hydrogen, oxygen and nitrogen, calcium and potassium, phosphorus and sulphur, magnesium and iron. But these ten elements gave rise to the vast ocean of foliage on Earth.

It followed therefore that for plants to stay alive they had somehow to assimilate, to "eat" these elements.

But how? Where are the food stores of plants? Obviously, in the soil, in the water, and in the air.

There were some strange things, however, that had to be explained. In some soils a plant might develop rapidly, blossom and bear fruit, whereas in others it would droop, wither and turn into a sickly freak. Evidently the latter soils lacked some element.

Even before Liebig men knew that if the same agricultural crops were sown year after year on even the most fertile soil, harvests would become worse and worse.

The soil became impoverished. The plants gradually "ate up" all the chemical elements in it that they needed.

The soil had to be "fed", that is, the supply of substances removed from it had to be replenished. In other words, it had to be fertilized, as we usually say. Fertilizers were used way back in hoary antiquity. They were introduced into the soil intuitively, on the basis of experience handed down from generation to generation.

Liebig raised the use of fertilizers to the rank of a science and this science was named agrochemistry. Chemistry became servant to plant growing. It was confronted with the tasks of teaching people the right way to use known fertilizers and of inventing new ones.

Dozens of different fertilizers are known today. The most important of them are potassium, nitrogen, and phosphorus fertilizers, because potassium, nitrogen and phosphorus are the elements without which not a single plant can grow.

A Little Analogy,
or How Chemists Fed
Potassium to Plants

There was a time when uranium, which is very well known now, dwelt in the back lanes of chemical science. Only glass staining and photography laid timid claims to it. Then radium was found in uranium. Thousands of tons of uranium ores yielded an insignificant speck of the silvery metal but the wastes containing immense quantities of uranium continued to block up storage sites for a long time. However, uranium's hour struck at last when it proved to be the key to man's power over atomic energy. The wastes became a treasure.

The Stassfurt salt deposits in Germany have been known since ancient times. They contained many salts, chiefly those of potassium and sodium. The sodium salt, which is table salt, immediately found usage. The potassium salts were discarded without regret and great mountains of

them grew up around the mines. Nobody knew what to do with them. Though agriculture was in dire need of potassium fertilizers, the Stassfurt wastes could not be used because they contained a great deal of magnesium. Though beneficient to plants in small doses, magnesium is fatal in large amounts.

Again chemistry came to the rescue. A simple method was found for removing the magnesium from the potassium salts and the mountains around the Stassfurt mines began to disappear like snow in spring. Science historians report that the first plant for treating potassium salts was built in Germany in 1811. A year later there were already four of them and by 1872 thirty three German plants were processing more than half a million tons of the impure salt yearly.

Potassium fertilizer plants sprang up shortly in many countries. Today the production of potassium salts in many countries exceeds their table salt output by many times.

The "Nitrogen Crisis"

About one hundred years after the discovery of nitrogen a prominent microbiologist wrote: "Nitrogen is more valuable from the point of view of general biology than the rarest of the noble metals." And he was quite right. Nitrogen is a constituent of practically all protein molecules, whether of plant or animal origin. Without nitrogen there is no protein, and without protein there is no life. Engels said that "life is the form of existence of proteins",

To produce protein molecules plants need nit-
rogen. But where do they get it? The chemical
activity of nitrogen is low and it does not enter
into reactions under ordinary conditions. Hence,
plants cannot use atmospheric nitrogen. Truly,
"there's many a slip 'twixt cup and lip". There-
fore, the plant's entire store of nitrogen is in the
soil. Alas, this store is meagre. It holds few com-
pounds containing nitrogen. That is why the soil
loses its nitrogen rapidly and requires the addition
of nitrogen fertilizers.

The name "Chile saltpetre" has now become a
thing of history. But about seventy years or so
ago it was talked about everywhere.

The vast territory of Chile includes a wild
uninhabited dismal Atacama desert which
stretches over hundreds of kilometres. At first
glance it is just an ordinary desert, but there is a
curious thing that distinguishes it from all the
other deserts of the globe: a comparatively thin
layer of sand overlies thick deposits of sodium
nitrate known also as sodium saltpetre. These
deposits were known a long time ago, but the first
time they were thought of seriously was probably
when a deficiency of gunpowder began to be felt
in Europe. It must be remembered that previous-
ly gunpowder was made of charcoal, sulphur
and saltpetre.

An expedition was sent out at short notice to
fetch this overseas product. However, the entire
cargo had to be thrown out into the sea. It proved
that only potassium saltpetre could be used for
the production of gunpowder. Sodium saltpetre
absorbed moisture avidly from the atmosphere,
making the gunpowder damp and useless.

That was not the first time Europeans had had to throw overseas cargoes overboard. In the seventeenth century grains of a white metal subsequently called platinum were found on the banks of the River Platino-del-Pinto. When platinum was first brought to Europe in 1735 nobody knew what to do with it. Of the noble metals only gold and silver were known at that time, and platinum had no outlet. But some clever people noticed that the densities of platinum and gold were rather close, and making use of this fact they began to add platinum to the gold used for making coins. Now this was forgery. The Spanish government forbade any further import of platinum, and as to the reserves already accumulated in the country, they were collected and thrown out into the sea in the presence of numerous witnesses.

But the history of Chile saltpetre was not ended. It was found to be an excellent nitrogen fertilizer which nature kindly placed at man's disposal. At that time no other nitrogen fertilizers were known. Intensive mining operations were started at the Chilean deposits and ships loaded with the valuable fertilizer left the port of Iqueque daily to deliver it to all parts of the globe.

In 1898 Sir William Crookes's sombre prediction struck the world with awe. In one of his speeches he prognosticated death to mankind from nitrogen starvation. The fields are annually being deprived of nitrogen together with the crops, said he, and the deposits of Chile saltpetre are gradually nearing exhaustion. The treasure house of the Atacama desert was but a drop in the ocean.

It was then that scientists thought of the atmosphere. Probably the first man to draw attention to the unlimited supply of nitrogen in the atmosphere was the famous Russian scientist Timiryazev, who believed firmly in science and in the power of human genius. He did not share Crookes's misgivings. He was certain that mankind would overcome the nitrogen crisis and would find some way out of the situation. And he was right. Not later than in 1908 two Norwegians, the scientist Kristian Birkeland and the engineer Samuel Eyde accomplished the fixation of atmospheric nitrogen on an industrial scale by means of an electric arc.

At about the same time the German chemist Fritz Haber developed a process for the production of ammonia from nitrogen and hydrogen. This finally solved the problem of fixed nitrogen so necessary for plant nourishment. There is plenty of free nitrogen in the atmosphere. Scientists have calculated that if all the nitrogen in the atmosphere were transformed into fertilizers there would be enough to nourish all the plants in the world for more than a million years.

What is Phosphorus for?

Justus Liebig held that a plant could absorb atmospheric nitrogen and that the soil had to be fertilized only with potassium and phosphorus. But he was out of luck with these elements. His "patent fertilizer" which an English firm undertook to produce failed to boost harvest. Only many years later did Liebig understand and appreciate

his error. He had used insoluble phosphate salts out of fear that the soluble ones would soon be washed out of the soil by rain. But it turned out that plants could not assimilate phosphorus from insoluble phosphates. And man was obliged to provide a sort of "semi-finished product" for the plants.

Each year the harvests of the world carry off about 10 million tons of phosphoric acid from the fields. What do plants need phosphorus for? It is a constituent of neither fats nor carbohydrates, nor do most protein molecules, especially the simplest ones, contain phosphorus. Still, without phosphorus none of these compounds would form.

Photosynthesis is not simply a process of carbohydrate synthesis from carbon dioxide and water, which the plant can accomplish "with its little finger", it is a very complex process.

Photosynthesis takes place in what is known as the chloroplasts of the plant cells, these being special "organs" for the purpose. Chloroplasts contain a great deal of phosphorus compounds. Crudely chloroplasts can be compared to the stomach of an animal in which the food is digested and assimilated, because it is they that deal directly with the "building bricks" of the plant, namely, carbon dioxide and water.

The plant absorbs carbon dioxide from the air with the aid of phosphorus compounds. The inorganic phosphates transform the carbon dioxide into carbonate anions from which the intricate organic molecules are subsequently built.

Of course, this does not exhaust the role of phosphorus in the vital activities of plants. Nor

can it be said as yet that its importance for plants
is wholly understood. However, even what
is known already shows that the part it plays is
very important.

Chemical Warfare

Now this is a real war, though no cannon, tanks,
rockets or bombs are used. It is a "quiet" war,
often unnoticed by many, but a war to the death.
And victory in this war spells happiness for all
people.

Does, say, the common gadfly do much harm?
It has been calculated that the damage done in
the Soviet Union alone by this noxious creature
amounts to millions of rubles per year. And what
about weeds? They cost the USA four thousand
million dollars. Or take locusts; they are really
a catastrophe, transforming flowering fields in-
to bare, lifeless deserts. If we assess all the harm
done to world agriculture by vegetable and ani-
mal robbery only in the course of a year, the sum
is difficult even to imagine. The money would
suffice to feed 200 million persons free of charge
for a whole year!

There is a suffix "cide" which means killing.
Now chemists have for some time been making
all kinds of "cides". They have made insecticides
which kill insects, zoocides for killing rodents,
and herbicides for killing weeds. All these "cides"
are now used widely in agriculture.

Prior to World War II mainly inorganic toxic
chemicals were used. Various rodents, insects
and weeds were killed with arsenic, sulphur, cop-

per, barium, fluorine, and many other poisonous compounds. However, since the middle forties organic toxic chemicals have been finding ever wider application. This switchover to organic compounds was quite deliberate. They are not only less harmful to man and livestock, but are more universal and are required in much smaller quantities than inorganic chemicals to obtain the same effect.

Until recently chemicals used to protect plants and animals were applied externally. However, it is easy to see that a good rain storm or a strong wind will wash or blow away these protective chemicals and they have to be applied all over again. And so scientists began to work on the problem of how to introduce chemicals internally. The effect would be something like that of vaccination on man: a vaccinated person has nothing to fear from the disease he is vaccinated for. As soon as the microbes get into such an organism they are destroyed by invisible "health guards" which appear in it as a result of the vaccination.

It was found quite possible to prepare chemicals for internal use. Scientists made use of the difference in structure of the insect pest and the plant. Such a chemical is harmless to plants but a deadly poison to the insect.

Chemistry protects plants not only from insects, but from weeds as well. Chemicals called herbicides were invented which depress weeds but practically do not interfere with the development of the cultured plant.

Strange as it seems, the first herbicides were probably fertilizers. It was noted long ago by

farmers that if increased amounts of superphos-
phates or potassium sulphate are applied to the
fields the cultured plants grow intensively, but
weed growth is depressed. But, as with insecticides,
organic compounds have become the leading her-
bicides.

The Farmer's Helpers

Grass is intolerable on a railway bed. And so
people "shave it" with sickles and scythes from
year to year. But take the Moscow-Khabarovsk
railway. It is nine thousand kilometres long, and
to cut all the grass on it (which has to be done
several times each summer) almost a thousand
full-time workers would be needed.

Could any chemical method of "shaving" be
invented? It appears there could.

To cut the grass on one hectare 20 men have
to work a whole day. Herbicides complete this
operation over the same area in a few hours,
wiping out the grass completely.

Do you know what defoliants are? "Folium" is
the Latin for leaf. A defoliant is a chemical which
makes leaves fall. The use of defoliants has made
it possible to mechanize cotton harvesting.
Year after year, century after century, men used
to go out into the fields and pick the cotton bolls
by hand. Anybody who has not witnessed manual
cotton picking can hardly imagine what hard
labour it is, especially when it is performed in the
sun at a temperature of 40 or 50 °C. Now every-
thing is much simpler. A few days before the cot-
ton bolls open the cotton plantation is treated

with defoliants. The simplest of these is $Mg[ClO_3]_2$. The leaves fall off the bushes and then cotton combines come out into the field. Incidentally another chemical that can be used as a defoliant is $CaCN_2$, and the part of it that falls on the ground when the bushes are treated is a nitrogenous fertilizer to the soil.

But chemistry has gone still further in helping agriculture to "rectify" nature. Substances called auxins, which are referred to as plant hormones stimulating plant growth, have been discovered. At first only natural compounds were used for this purpose, but now chemists have learnt to synthesize the simplest of them, heteroauxin, in the laboratory. These substances not only accelerate growth, blossoming and fruiting of plants, but also improve their resistance and vitality. However, it was found that in elevated concentrations auxins have the opposite effect: they retard the growth and development of plants.

Here we have an almost full analogy with medicinals. There are medicines which contain arsenic, bismuth, and mercury, but in large (rather, elevated) concentrations all these substances are poisonous. For instance, auxins can delay the blossoming period of decorative plants, flowers. In case of sudden spring frosts they can retard the budding and blossoming of trees, and so on and so forth. On the other hand, in the cold regions where the summer is short they make it possible to grow many fruits and vegetables at accelerated rates. And though these properties of auxins have not yet been realized on a mass scale, there is no doubt that in the near future these farmers' helpers will find extensive usage.

Chemical Sources of Energy

Coal, gas, petroleum products and other types of natural fuel are extensively used to produce electrical energy. The appearance of current in the circuit is due, in the end, to chemical processes.

The classical scheme of successive transformations of one type of energy into the other forms the operational basis of any power-station. According to this scheme, chemical energy which evolves as a result of the combustion of fuel, is transformed into heat, which in its turn is converted into mechanical energy, the latter finally being turned into electricity. How all this happens in particular every schoolchild knows.

The scheme is simple but it involves many stages. Can't it be made somewhat shorter? Say, can't some of the intermediate stages be excluded so that chemical energy be transformed directly into electrical one?

There is nothing extraordinary about this!—the reader might exclaim. Indeed, such direct conversion has been known for nearly 150 years. An example of this is the electric battery used in a flashlight or transistor radio. In this rather simple device, the energy of reduction-oxidation reactions between the chemical reagents specially selected for this purpose is converted directly into electricity. The first chemical source of electricity was designed back in the 1830's and was called Daniell-Jacobi cell in honour of its inventors.

Today many types of galvanic cells (disposable) and storage batteries which can be recharged are manufactured by different enterprises. One

of their greatest virtues is high efficiency, close
to 100%, and the principal shortcoming is the
high costs of metals and other chemical reagents
used. Their voltage is not very high either.

So the problem of so-called fuel cells became
the order of the day.

The principle of their operation is just about
the same as that of ordinary cells, the only differ-
ence being that instead of oxidizable and reduci-
ble metals, cheaper and more available gaseous
combustible materials are used. Just like ordi-
nary cells, the fuel cells include electrodes, though
they do not participate in the production of
energy but only act as catalysts. Fuel is con-
stantly delivered to the electrodes. It is oxidized
at the anode whereas the reduction of the oxi-
dizing agent occurs at the cathode. The po-
tential difference arises between the electrodes.
That's about all, as far as the functioning of the
fuel cell is concerned. It can work as long as the
fuel and oxidizing agent are supplied.

The fuel most commonly used at present is
hydrogen; oxygen is used as the oxidizing agent.
Why hydrogen? Because for this gas the problem
of materials for the electrodes has been success-
fully solved. The cell can operate at relatively
low temperatures.

The hydrogen-oxygen fuel cell could have found
wide applications. For example, it could have dis-
placed the internal-combustion engine of millions
of motorcars. How clean the environment would
become! But there is always a hitch somewhere. The
combustion of one kg of hydrogen gives energy
10 times as much as the combustion of the same
amount of petrol in the internal-combustion en-

gine. Hence, to complete with petrol, the price of hydrogen should be no higher than 10 times that of petrol. However, the actual price of hydrogen is much higher. No cheap and effective methods of obtaining hydrogen in sufficient quantities are known so far. Problems connected with its accumulation, storage and transportation haven't been solved yet.

And still, fuel cells are the energy sources of the future.

Ghosts that Serve

Many elements of the Periodic System are far from cheap even today, which limits the range of their practical applications. But we are certain that this situation will not last. Chemistry and physics will "cut the prices" of the elements more than once. They are sure to do this because practice is drawing more and more inhabitants of the Periodic Table into the sphere of its activities.

But there are elements which either do not occur in the Earth's crust or occur in such insignificant quantities that one might say there was practically none of them. Such are astatine and francium, neptunium and plutonium, promethium and technetium...

However, these elements can be prepared artificially.

So far, the practically most important artificial element is plutonium. And accordingly, its world production now exceeds that of many of the "ordinary" elements of the Periodic System.

It may be added that chemists consider plutonium as one of the best known elements, though it is only a little over a quarter of a century "old". This is no accident, because plutonium is an excellent "fuel" for nuclear reactors, not inferior to uranium.

And what about promethium, which has not been found so far in terrestrial ores? It has gone into the manufacture of miniature batteries a little larger in size than the head of an ordinary thumb tack. The very best chemical batteries last for not more than half a year. The promethium atomic battery operates continuously for five years, and its applications range from hearing aids to guided missiles.

Astatine offers its services to physicians for fighting diseases of the thyroid gland. Attempts are now being made to cure thyroid disorders with the aid of radioactive radiations. Iodine is known to accumulate in the thyroid and astatine is the chemical analogue of iodine. Introduced into the organism, astatine concentrates in the thyroid gland, and its radioactive properties do the rest.

Thus, some of the artificial elements are by no means devoid of practical uses. True, their service to mankind is one-sided, because people can make use only of their radioactive properties. But this is only because chemists have not yet got down to their chemical properties. An exception is technetium. The salts of this metal have been found to make iron and steel articles very resistant to corrosion.

18 *

A Long Afterword

It was interesting and at the same time difficult to write this book. Interesting because every story, no matter whether it was about the past, present or future of chemistry, reminded us of what a fascinating science chemistry is. The difficulties were of a rather subjective nature. What should be discussed in the first place? How can we concentrate on major things without paying too much attention to minor issues? Those were the main problems we faced when writing this book.

And, surely, other authors would have chosen a different style of writing. But we made our choice and it is up to the reader to judge our style.

Books usually end with brief afterwords. But there are no strict rules of how to write an afterword. Generally speaking, to finish the book on the right note is probably no less difficult than to find an appropriate beginning.

In our opinion, it would be appropriate to tell the reader of the main features of modern chemistry in conclusion—just briefly, without going into detail. This is far from easy, because the present-day chemistry is a very complex scientific "organism". Specialists in its various fields are often unable even to understand one

another as if they speak different languages.

That is why we could not confine ourselves to just a few phrases in conclusion.

So What Is Chemistry?

"The science of substances and their transformations"—one can read in school textbooks. Such definitions are called canonical. Nobody ever dares to challenge them. In principle, everything in this definition is correct. Chemistry really does study substances—simple substances and compounds, their properties and transformations occurring as a result of chemical reactions.

We are not going to dispute this definition of chemistry, the more so since a popular-science book is not the appropriate medium for such a polemic.

But still ...

Physics, the old "colleague" of chemistry, also studies substances and their physical properties, but in its own fashion and by its own methods. It also studies their transformations: one and the same substance can occur in three different states of aggregation—solid, liquid and gaseous. There is also the fourth one—plasma. All this lies within the scope of the interests of physics. We are sure that the interested reader, having read these lines, feels an urge to peep into a physical textbook.

So, physics also studies substances and their transformations? Well, yes, but not only this. The range of interests of physics is much wider. As a matter of fact, the former definition of chem-

istry can be used to formulate one of the tasks of physics.

D. Mendeleyev called chemistry the science of elements. And there was good reason for his doing so, because substances are nothing but combinations of different atoms of chemical elements.

We have mentioned the word "atoms", and perhaps here lies one of the keys to the understanding of the essence of chemistry. All chemical transformations are connected with rearrangements of the electron configurations of atoms in one way or another. The outermost areas of these configurations, to be more exact. So, why shouldn't we define chemistry as the science of electron configurations and their rearrangements in the process of chemical interaction of atoms? The properties of substances can be studied only when they chemically interact with each other. But this interaction inevitably causes the rearrangement of electrons.

But substance is not only the unity of atoms. Atomic nuclei are also the form of existence of matter. These are not within the scope of ordinary chemistry, they are studied by the science which bears perhaps somewhat appropriate name of nuclear chemistry: it is pure physics, as a matter of fact.

Hence, the range of meanings of the term "transformations" in our canonical definition of chemistry is restricted within certain limits. Chemistry has to do only with such transformations which involve rearrangements of the electron shells but not the nuclei of the atoms. In other words, when quoting the conventional definition

of chemistry, one should specify what is implied by the terms "substances" and "transformations".

We have no intention of making any revisions. What we wanted to say is that the natural sciences including chemistry develop so rapidly that, figuratively speaking, there are not enough words to describe all recent scientific achievements in precise terms.

And let chemistry remain "the science of substances and their transformations"   . We shall be content in our little heresy of subjecting it to critical analysis.

Nobody can even tell for sure where the word "chemistry" originated from. Some historians contend it is related to the ancient name of Egypt—"chem", which means "black", because that was the colour of the soil in the valley of the Nile. Others seek similarities with the Greek words χῦμα meaning "moulding" (perhaps smelting of metals is meant here) or χυμευιξ which means "mixing". Still others think that it has something to do with the old Chinese word "chim" meaning "gold". One shouldn't be skeptical about such philological research, because it had happened more than once in the history of science that the correct explanation of the origin of the term has revealed the key to the understanding of the essence of the process or the phenomenon denoted by the given term.

Two Revolutions in Chemistry

Over the course of many centuries, mankind has accumulated chemical knowledge. But specific theoretical concepts began to form only in the 18th century. They look very primitive from the modern point of view, but all of them helped chemistry to obtain the status of an independent science.

In any sphere of human knowledge, during the course of its progressive development there are periods of revolutionary changes. As a rule they are connected with the outstanding theoretical or experimental discoveries.

In this respect chemistry is no exception. But its revolutions have some peculiar features.

Since chemistry is the science of substances, the following question inevitably arises: what are those substances made of? The thinkers of antiquity affirmed they were composed of atoms, the smallest indivisible particles. Actually, the knowledge about atoms was restricted to this notion, for atoms could be neither seen nor weighed.

At the very beginning of the 19th century, the great British scientist John Dalton was the first to attribute quantitative characteristics to the atoms having introduced the concept of atomic weight. This value showed how many times an atom of any particular element was heavier than an atom of hydrogen, the atomic weight of hydrogen being equal to unity.

Now the ancient teaching about atoms, atomistics, acquired a quantitative measure, which enabled it to speak not only of qualitative differ-

ences among chemical elements but of quantitative differences as well.

This event in chemistry was highly valued by Friedrich Engels, who used to call Dalton the initiator of the new era in chemistry and the father of modern chemistry. Thus, the true revolution in chemistry began.

Subsequently the concept of molecules as the smallest particles of which all chemical compounds are made had shaped. All this made the foundation for the atomic-molecular theory, which became dominant in chemistry in the last century. Not even a single more or less significant achievement in chemistry would have been possible without the basis of the atom-molecular teaching.

The more advances chemistry made, the more obvious became the limits of the atomic-molecular theory.

But the principal thing remained unknown, namely, how the atom is built. Without a scientifically grounded atomic model many daring ideas and generalizations remained unexplained, such as the Periodic Law and the Periodic System of elements, for example. When Mendeleyev noted with regret that the reasons of periodicity still remained obscure, he clearly understood the necessity of research on the atomic structure.

At the very end of the nineteenth century, X-rays, the electron, and the phenomenon of radioactivity were discovered. They constituted the basis on which the planetary, or nuclear, model of the atom was created two decades later, which was closely connected with the name of the British physicist Ernst Rutherford. On the

basis of this model, the Danish physicist Niels Bohr could account for the relationship between the chemical and physical properties of elements and the structure of their atoms, and thus the theory of the Periodic System was born.

The creation of the atomic model meant the beginning of a new revolution in chemistry. Having this theory at their disposal, scientists could account for lots of different things, such as the reasons for the diversity of properties of chemical elements, for similarities and differences among them and for peculiarities of certain chemical reactions. It also enabled them to develop theories of the chemical bond.

The model of the structure of the atom now forms the core of modern chemistry. The model has been continuously improving due to new physical ideas and methods. Today it is backed by one of the most fundamental contemporary sciences, quantum mechanics.

The atom, which was presumed to have such a simple structure, appeared to have a far more complicated structure. As the atom itself was understood better, its role in the understanding of the regularities of chemical transformations became more significant.

The Main Feature of Modern Chemistry

All sciences have long been subdivided into descriptive and exact. The essence of the former ones is clear from their name. They precisely described the processes or phenomena observed in nature and tried to explain them. As a result, va-

rious theories and hypotheses were put forward. Maybe it would be more correct to say "were invented" instead of "put forward", because they were not preceded by any precise calculation.

Such calculation was the basis of the exact sciences. The first of them became physics, which remained the only one of its kind for a long period of time. Each of the newly discovered physical regularities was immediately translated into the language of mathematics, every physical theory was given a mathematical footing.

D. Mendeleyev once figuratively said that chemistry became a true science when it began to use balance extensively. Quantitative analysis is impossible without weighing. Without such an analysis, it is impossible to determine the proportions of elements that constitute a given compound, and hence, the formula of the latter.

The atomic-molecular theory introduced more order into chemistry. But chemistry gained its full status as an exact science when the model of the atomic structure was proposed.

In modern chemistry the experiment is preceded by precise mathematical calculation.

For a long time, the usual way of doing research in chemistry was as follows: the new compound was first synthesized and then the structure of its molecule, its main properties and the practical value determined.

In our days things are different. Preliminary theoretical research and mathematical calculation (often with the aid of computers) enable the investigators to choose the right methods for obtaining compounds and materials with definite, preset properties, which are of practical value.

Inorganic Chemistry
Plus Organic Chemistry

All of chemistry can roughly be divided into two vast areas—inorganic chemistry and organic chemistry. All the elements of the Periodic System have traditionally been considered to be within the "scope of activity" of inorganic chemistry, whereas organic chemistry used to be defined as the chemistry of carbon and its compounds. To be quite honest, such a definition is not quite precise, but it will do for the time being. Organic compounds also include hydrogen, oxygen, nitrogen, halogens, sulphur, phosphorus and some other elements. But the "basis" of all organic compounds is carbon.

Today about 5 million organic compounds are known, though different sources provide different data. This number is increasing rapidly: according to estimates, about one hundred new chemical compounds are synthesized each week in laboratories all over the world.

The "arsenal" of inorganic chemistry is much poorer: approximately 200,000 compounds, although it is based on more than 80 elements. But usually inorganic compounds are more difficult to synthesize than organic ones. There are more opportunities for organic synthesis.

Inogranic chemistry is essentially the oldest branch of chemistry. Long ago it was called mineral chemistry because the objects of its study were primarily minerals. In the process of research many chemical elements were discovered and techniques and methods were developed.

Organic chemistry actually formed in the first

quarter of the 19th century. Of course, many organic substances were known before, but they were isolated from plant and animal products. Many scientists were sure that such substances could not be synthesized in the laboratory but were formed in living organisms due to some vital force. In 1828 the German chemist Friedrich Wöhler put an end to the notorious force, having synthesized urea out of inorganic substances. This event gave an impetus to the development of organic chemistry. By the middle of the last century it had noticeably surpassed its "elder sister" in its scope and results of research. In many aspects it has retained its leadership up to now, primarily in the numbers of synthesized compounds. A distinct boundary between the two chemistries has never really existed. For instance, is the long known hydrocyanic acid, HCN, an organic or inorganic compound? On the one hand, it fully consists of the elements-organogenes, on the other, its salts, cyanides, were once within the realm of mineral chemistry. The number of such "controversial" compounds was rather large.

Today this number is more than impressive: several tens of thousands. These are the compounds of two vast classes: the complex compounds, which have organic "fragments" incorporated in the structure of their molecules, and organometallic compounds. Such compounds have become the subject of great interest of chemists only in our century. No one will take the responsibility of classifying them as either organic or inorganic.

This makes the border between the two chem-

istries even more vague. And there is no doubt
that new interests common to both organic and
inorganic chemistry will be found in the future.
And it should also be born in mind that both of
them use one and the same theoretical methods
of calculation.

Historians of science, especially those who spe-
cialize in the history of chemistry, affirm that
the consolidation of the union of organic and in-
organic chemistry is one of the principal features
of modern chemical science.

How Many Chemistries Are There?

The cooperation of different sciences and the emer-
gence of new hybrid ones as a result is denoted by
a rather dull word—"integration". Simultaneous-
ly the opposite process occurs: the sciences branch,
break into fragments to give rise to new trends of
research, which at times acquire the status of
independent sciences. This process bears the no
less tedious name of "differentiation". But this
word contains quite a lot. This is the result of
many years of development of chemical science.

Today even the most capable person cannot
be an expert in all fields of chemistry. For exam-
ple, the specialist in inorganic chemistry can-
not remember all the peculiarities of behaviour of
all chemical elements. He will have to look
through many encyclopaedia and reference books
in order to obtain the necessary information. Of
course, every chemist should known the basic
facts and techniques of his science, but the spe-
cialist will be qualified only in some particular
field.

Nor even the most detailed textbook on chemistry can reflect the whole bulk of knowledge accumulated by this science. The one published today will inevitably be out of date after several years because it will not contain the most recent achievements and discoveries. It is believed that any specialist in any field must undergo a course of additional training, if not study anew, every five years otherwise he will find himself lagging behind.

We beg the reader's pardon for being somewhat instructive, but all that was said above is necessary to make one thing clear, namely, that the rapid increase in chemical information makes the differentiation of the science inevitable.

The two "main chemistries"—organic and inorganic—are no exception. They are differentiated according to their subject matter.

Here is the "register" of branches of inorganic chemistry. It includes "chemistries" of single elements, e.g., of fluorine, silicon, phosphorus, or of groups of elements, say, of noble gases, of rare-earth, or of transuranium elements. There are also chemistries of light elements, of heavy elements, of radioactive elements.

Certain elements which are of practical importance are being studied very rapidly. The whole amount of plutonium obtained in 1942 could be seen only with the aid of the microscope. Four decades later the monographs dedicated to the chemistry of this element could hardly be placed on a bookshelf of medium size, and this is to say nothing of the noble gases. Then come the classes of different inorganic compounds. We find chemistries of hydrides, carbides, peroxides, in-

termetallic compounds, semiconductors, etc. We assume we have made our point.

No less impressive is the list of "organic chemistries". It comprises chemistries of certain chemical compounds, e.g., of methane, ethylene, acetylene, benzene, and chemistries of classes of compounds like alicyclic, unsaturated, aromatic hydrocarbons. We can also see in the list petrochemistry, the chemistry of natural compounds, as are scores of other names which testify to the differentiation in organic chemistry.

Philosophers have long since regarded the problem of the classification of sciences. But they haven't attended yet to the matter of differentiation in chemistry. And they are not likely to cope without the most active help from chemists, since who knows the "soul" of his science better than the one who has dedicated his life to it

At the Crossroads
of Chemistry and Physics

So, the main difference between inorganic and organic chemistries lies in the subject of investigation.

Rich with innovations, the 19th century brought to life a new chemical science which was called "physical chemistry". The exact material object is not important for this science, i.e., it does not matter whether it is organic or inorganic substance.

So what is this science about? Modern encyclopaedias present it as the science which strives to account for chemical phenomena and transformations and to detect regularities in them, on the

basis of the general laws and principles of physics.

Hence, is it a kind of hybrid of two main natural sciences, chemistry and physics? The product of their close cooperation? Many scientists characterize physical chemistry in this way. But this is too much of a one-sided view of it.

Let's make a short digression.

Another important feature of modern chemistry is its contact with other natural sciences, primarily with biology and geology, which resulted in the emergence of two branches of natural science, biochemistry and geochemistry, which are rapidly developing now.

But are the expressions biochemistry = biology + chemistry, and geochemistry = geology + chemistry correct? Only in the rough approximation. The interaction of two different sciences gives rise to a new field of knowledge with its own objectives, concepts and methods. In fact, a new science is born. Such investigations often lead to the most extraordinary discoveries, which force one to take a fresh look at the surrounding world.

Physical chemistry is something different because its concepts and methods are absolutely indispensable for biochemical and geochemical research.

The historical development of physical chemistry was gradual. The investigations of the effect of the electric current on the course of chemical reactions gave birth to electrochemistry. As far back as in the 18th century, it was noticed that chemical reactions are accompanied by the evolution or absorption of heat. Numerous observa-

tions made it possible to establish important regularities and the emergence of thermochemistry was the result. The latter became the foundation of thermodynamics, which is one of the most difficult subjects for students. But it is essential not only for the accounting of certain chemical processes, it also enables us to predict whether a given chemical reaction will take place.

It turned out that the speed of chemical reactions could be noticeably increased if special compounds—catalysts were used. Thus physical chemistry gained another support in the teaching of catalysis.

For a long time, researchers could speak of the speed of chemical reactions using only the following formulas: "this chemical reaction proceeds quickly and that one slowly". How fast or how slowly can tell chemical kinetics, for it is the science of the speeds of chemical reactions. Now the magnitude of time entered into the strict mathematical formulas. And this was another great contribution to the formation of physical chemistry.

Photochemistry started research on the influence of light on the course of chemical reactions. Later it was followed by radiation chemistry.

All these scientific disciplines constitute the flexible framework of physical chemistry, but do not exhaust its contents. Numerous physical methods of analysis are also a part of it. The first of them, spectrum analysis, was introduced into practice in the middle of the last century. Now there are several dozen of such methods. We shall just name some of them without going into detail: X-ray spectral analysis, X-ray diffraction

analysis, ultraviolet-, infrared-, and radio-
spectroscopies, mass-spectrometry, methods of
electron paramagnetic and nuclear magnetic reso-
nance, tracer technique and radioactivation
analysis. All of them are powerful instruments in
the hands of researchers. All of them, as well as oth-
ers not included in the list, enabled chemists to
penetrate into the most intricate details of the
structure of molecules and chemical transforma-
tions.

This is, perhaps, the main list of issues that
the science of physical chemistry deals with. May-
be it deserves some other, more precise name. In
any case, thanks to it, chemistry was given oppor-
tunity to look at itself through the eyes of
physics.

Does the Science
of Chemistry Exist at All?

This question sounds incredible, doesn't it?
It seems to belong to the category of questions
which, according to the legend, cannot be answered
by a hundred wise men. In other words, is it
not a foolish question?

By no means. For many years scientists, es-
pecially those who tend toward philosophical gene-
ralizations, have been discussing on the pages of
respectable scientific journals the issue of whether
modern chemistry can be regarded as part of
physics.

Let's follow their reasoning. Their main argu-
ment sounds as follows: any chemical transfor-
mation is backed by strict physical principles
according to which the electron configurations

of the interacting atoms are rearranged. The conditions under which the chemical reactions occur, in the end, are nothing but various combinations of different "purely physical" factors.

And all this is quite true. Paradoxical as it may seem, physics, by its nature, turned out to be "deeper" than chemistry.

Four fundamental physical interactions govern the universe: electromagnetic, strong, weak, and gravitational. We shall have to apologize to the reader again for not giving any details. The world of tremendous energies, unheard-of temperatures and pressures, absolute zero temperatures and ultrahigh vacuum form the arena for the action of those physical forces.

Those transformations which are commonly called "chemical" preserve their "own nature" only under much milder conditions, i.e., until the atomic structure of the matter remains unchanged. Such expressions are commonly used: "chemistry of the Sun" or "chemistry of the stars". But this has nothing to do with chemistry! These objects fall within the absolute reign of nuclear physics.

Obviously, "deep" regularities must underlie those which are more "superficial". Many purely chemical regularities are interpreted in "electronic" language. Thus, the advocates of the bringing chemistry to physics are right in this issue as well. But, of course, those who claim chemistry and physics to be one and the same thing are too categorical. Chemistry simply can't be deprived of the right to an independent existence!

Here are some analogies from another field. Any musical composition can be expressed by

the complicated system of mathematical equations. It can be disintegrated into separate sounds which are the vibrations of the air perceived by the organs of hearing. And any vibrations can be expressed by mathematical formulas. Now imagine a thick volume stuffed with mathematical symbols instead of the notes of Tchaikovsky's "Barcarole". Instead of the charming music—abstruse mathematical balderdash.

Or take Pushkin's "I dream of our brief and wondrous meeting..."* and dismember it in accordance with the principles of structural linguistics. For theory it might be good and useful, but there would be nothing left of the "wondrous meeting"

All the diversity and splendour of chemical reactions is revealed in the experiment. Here the most abstract theories materialize, the most daring forecasts come true and receive their verdicts.

Experiment made the possibilities of chemistry inexhaustible. There is no end in sight to the synthesis of new chemical compounds, to the isolation of yet unknown substances from plant and animal organisms, to the obtaining of materials with remarkable properties which inventive nature was unable to create.

Not a single modern industry can do without the aid of chemistry. Its role in the development of civilization can be compared to that of electricity.

Any vital activity, in the end, is the result of

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* In translation by Eugene Mark Kayden, Sewanee Review, Oct.-Dec.,. No. 4, 1942.

many intricate chemical reactions. Chemistry became that "magic wand" which turned dead matter into live matter. The problem of the origin of life on Earth is primarily a "chemical problem".

Can all the splendour of chemical achievements, all the grandeur of the problems which have been solved and are still to be solved by chemistry be expressed by impassionate mathematical formulas which "model" the physical regularities of electron movement? Don't those who advocate the "absorption" of chemistry by physics liken themselve to pathologo-anatomists whose sphere of activity is limited to dead organisms?

It will always exist, this old and ever youthful science, and over the course of time the mighty crown of its tree will spread wide.

But this creates problems for scientists.

In the Boundless Ocean of Facts

Even one hundred and fifty years ago chemistry was developing rather rapidly. But then it was possible to keep abrest of all its advances, though it required a great deal of effort. The Swedish chemists Jöns Berzelius was publishing his "Annual Reports" during one and a half decades in which he endeavoured to reflect the results of chemical investigations carried out in different countries. These thick volumes were a kind of chemical encyclopaedia of that time.

But soon it became clear that there was no use in trying to keep in step with the progress in chemistry.

Any chemist that wanted to be aware of the

current events in his field had to read all periodical publications on chemistry. And this took time. And the numbers of such publications increased from year to year.

In search of a way out, scientists decided to issue special abstract journals which contained short annotations of the works scattered over thousands of pages of periodic publications.

Now before starting his research, the scientist needed to look through certain sections of the abstract journals, namely, those which had to do with his particular area of work. It was important to make sure that nobody did anything of the kind before. There is no sense in wasting time and effort on what has already been done.

The main advantage of abstract journals is their promptness. But still several months would pass before the communication of the synthesis of a new compound or of the determination of a new property was published. But during this time another investigator could have worked out another method of synthesizing the same compound or determined some new properties.

This is nothing but a vicious circle. It appears that it is impossible ·to keep abrest of impetuously increasing chemical information.

Maybe it would be better to carry out investigations without looking into the literature beforehand? A chemical experiment, even a complicated one, may require less time than the extremely tedious search through the literature.

Maybe we have drawn too gloomy picture? See for yourself. Today more than 700 special chemical journals are published in the world. Scores of other publications on other fields of

science often contain articles on chemistry, and these should be added to this list. It should also be remembered that each week several congresses, conferences, symposia and consultations are held in different countries around the world, where the most recent achievements in different fields of chemistry are reported. All of them must be made known to a wide circles of specialists.

One work in chemistry is published in the world every minute! This astounding fact dates back to 1975. Now one can speak of two works a minute... .

All the above suggests that the methods of obtaining information on what is happening in chemistry that were used by the investigators only several decades ago are not suitable now. Or, in any case, they are very ineffective.

A similar situation now exists in all the other fields of science and technology as well. "The information explosion"—that's how scientists define it.

The new methods of information search involve the extensive use of computers. Their "memory" is literally boundless. The main problem lies in finding the most rational ways of feeding information into them. Once this is done, the computer can produce the most recent and complete information on a given topic.

How all this is done in particular is the topic of a separate book. But one thing should always be borne in mind: no matter what advances the information service might make, the chemist cannot do without the diligent work with the literature. Neither can the theorist, nor the practical worker.

SCIENCE FOR EVERYONE

The authors of this book have endeavoured to touch upon the most important and interesting problems of chemistry. Their book describes and explains the structure of the Periodic System of elements; it guides you through a kind of chemical museum full of curious exhibits; it tells of the intricate substances chemists have produced and how they have learned to work even with single atoms of the elements;it acquaints you with the various chemical professionsand shows how chemistry has penetrated all spheresof human activity.

Reading these short but instructive stories about the exciting discoveries of chemistry will urge you to find out more about this fascinating science and to take up chemistry seriously.