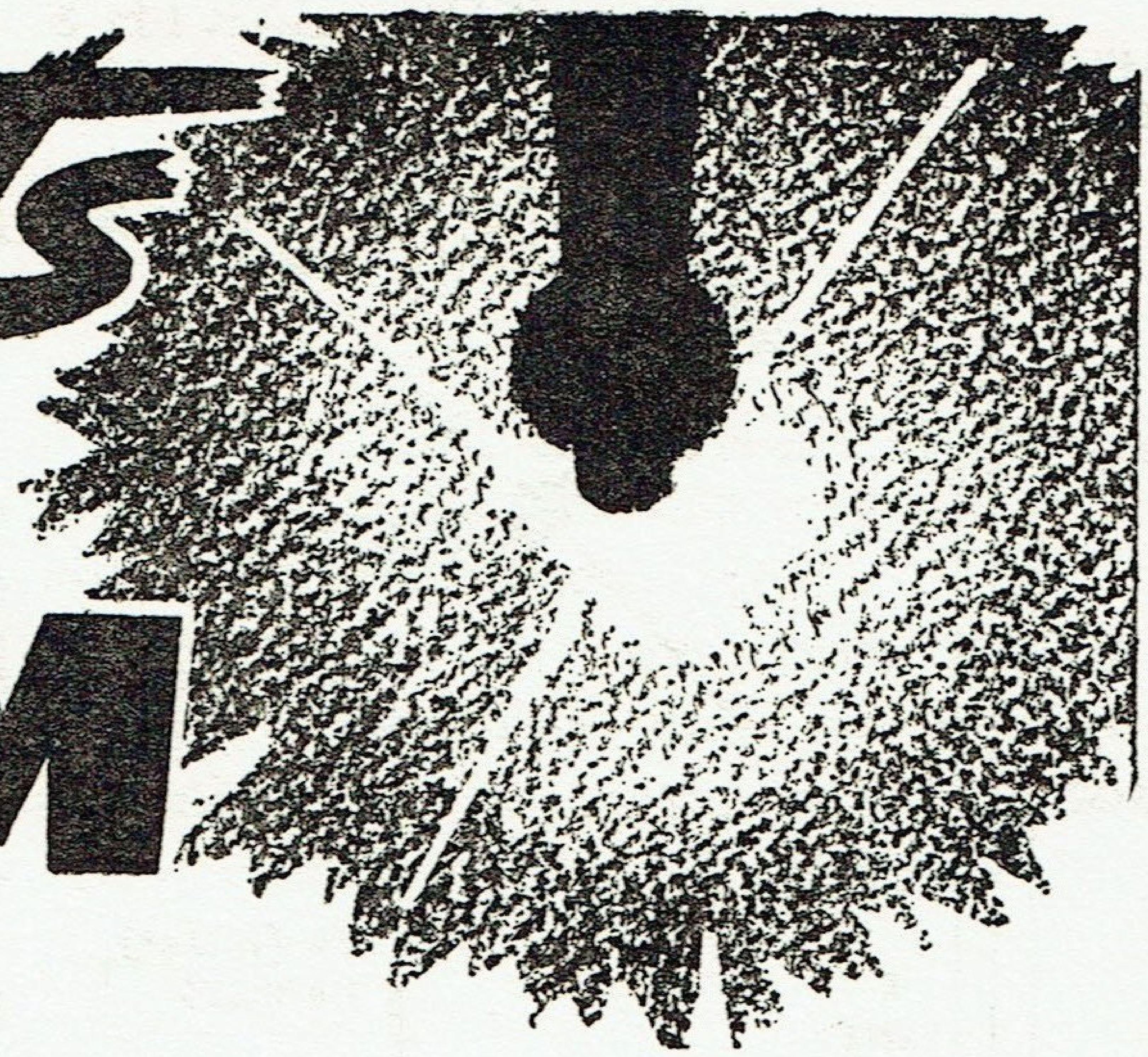
Secrets OF THE ATOM



SCIENTISTS say that the secrets of the atom are going to become more and more important to us during the course of the next few years.

They do not refer to the atom and hydrogen bombs which, after all, are purely weapons of destruction and which will have to be done away with if at all possible.

There is a clue to their real meaning in our chapters on space travel. If only some means can be found of driving rocket ships by means of atomic energy, voyages to Mars and Venus and perhaps to more distant planets will become an early possibility.

More will be said about this and other uses of atomic energy later.

But before we can really understand this kind of energy, we must take a closer look at the atom to find out just what it is and how it works.

What the World is Made of

If you have done chemistry at school you will already have heard something about the elements—things like oxygen, potassium, sulphur, and iron.

You will probably have heard also that there are about 100 of such elements and that everything in the world is made up of them.

You may also have heard that each element is different from all the rest, and that one element cannot be changed into another.

The last two statements are now known to be only partly true. As you will see in a moment, the atoms of all the elements are made up of the same kinds of " particles " ; further, the atom of one element *can* be changed into that of another.

What is an Atom ?

Let us have a look at an atom to see just what it is.

Imagine taking a piece of gold—only a small piece weighing about an ounce. We start dividing it, first into halves, then into quarters, then into eighths, and so on. We go on dividing it until any one piece is so small that it is invisible to the naked eye.

We do not stop there. With the aid

of powerful microscopes we go on dividing ; and when the microscopes are no longer of any use to us we still go on dividing—until we can divide no longer.

We have now produced pieces of gold which are the tiniest that can exist. If we divide any further, the pieces which result will cease to be gold ; they will become something else.

What we have is a heap of gold atoms.

Each single atom is very small indeed. It is somewhere about one forty-millionth of an inch across ; that is, if we took 40 million of them and laid them out in a single line, that line would measure no more than one inch from end to end. The number of atoms which could be placed in a single line across the top of a pin-head would be about two million, and if you tried to count this number you would be counting day and night for about eight days without stopping.

What an Atom is Made of

The meaning of the word *atom* is *indivisible*, and that was how earlier scientists thought of it—as being indivisible.

But we must be careful these days not to take that word *indivisible* too literally. It is true that we could not take one of our atoms of gold and divide it any further if we still wanted to keep it as gold ; but we *can* divide an atom and thereby produce something else.

To see how this can be done, let us see what an atom is made of.

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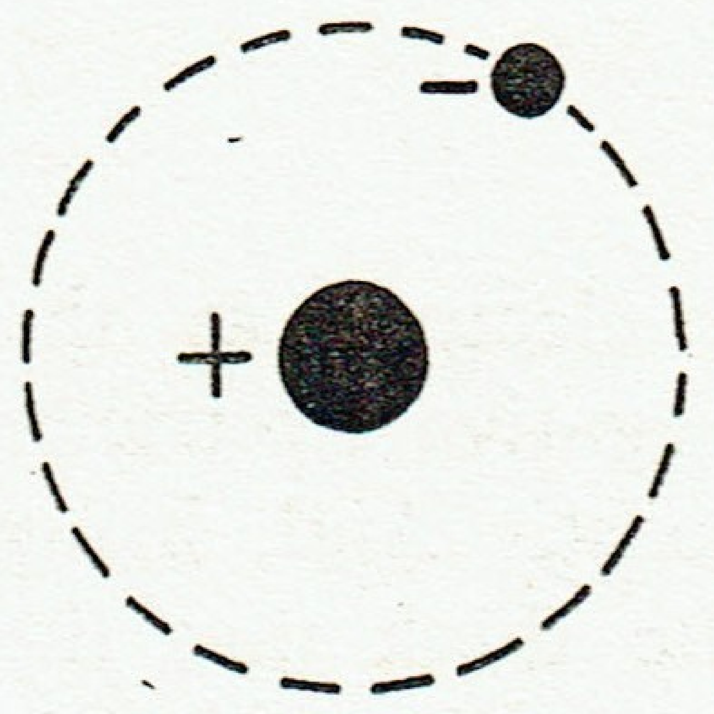
Starting with the simplest kind of atom—that of hydrogen—we can represent it, as in the drawing below, rather like a world with a moon revolving round it.



HYDROGEN ATOM

A HYDROGEN ATOM can be imagined as a sort of Earth with its Moon, the Earth being called a "nucleus" and the Moon an "electron". Atoms of other elements have larger nuclei and numbers of electrons, as shown later.

In atom language, the "world" is called a *nucleus*, and the "moon" is called an *electron*.

You will notice in the diagram that the nucleus is marked with + and the electron with a —. These signs represent charges of electricity, the + being *positive* and the — *negative*.

Now there is something you should know about electrical charges, and it is this : a positive and a negative charge will always attract one another, but two positives or two negatives will repel each other. Or, as our physics teachers put it, *unlike charges attract ; like charges repel*.

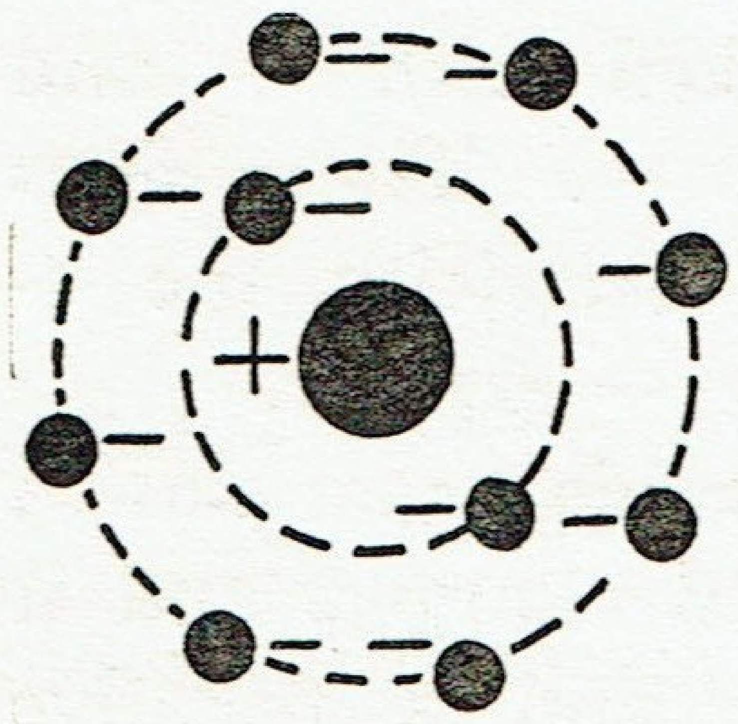
Going back to the earth-and-moon idea for a moment, you know that the moon revolves round the earth, and that if it did not do so it would fall on the earth because of the attraction of gravity. The force which keeps it from falling on us is known as centrifugal force.

Exactly the same kind of thing is thought to happen within the atom. The electron moves around the nucleus with sufficient speed to prevent it from " falling into " the nucleus ; with sufficient speed, in fact, exactly to counteract the attraction which exists between the positive and negative charges of electricity.

Inside the Nucleus

We think of the electron as the smallest particle of negative electricity which can possibly exist. And, being logical, we might also think that the nucleus is therefore the smallest particle of positive electricity which can possibly exist.

Would we be right ? Well, look at the next diagram of an atom.



NEON ATOM

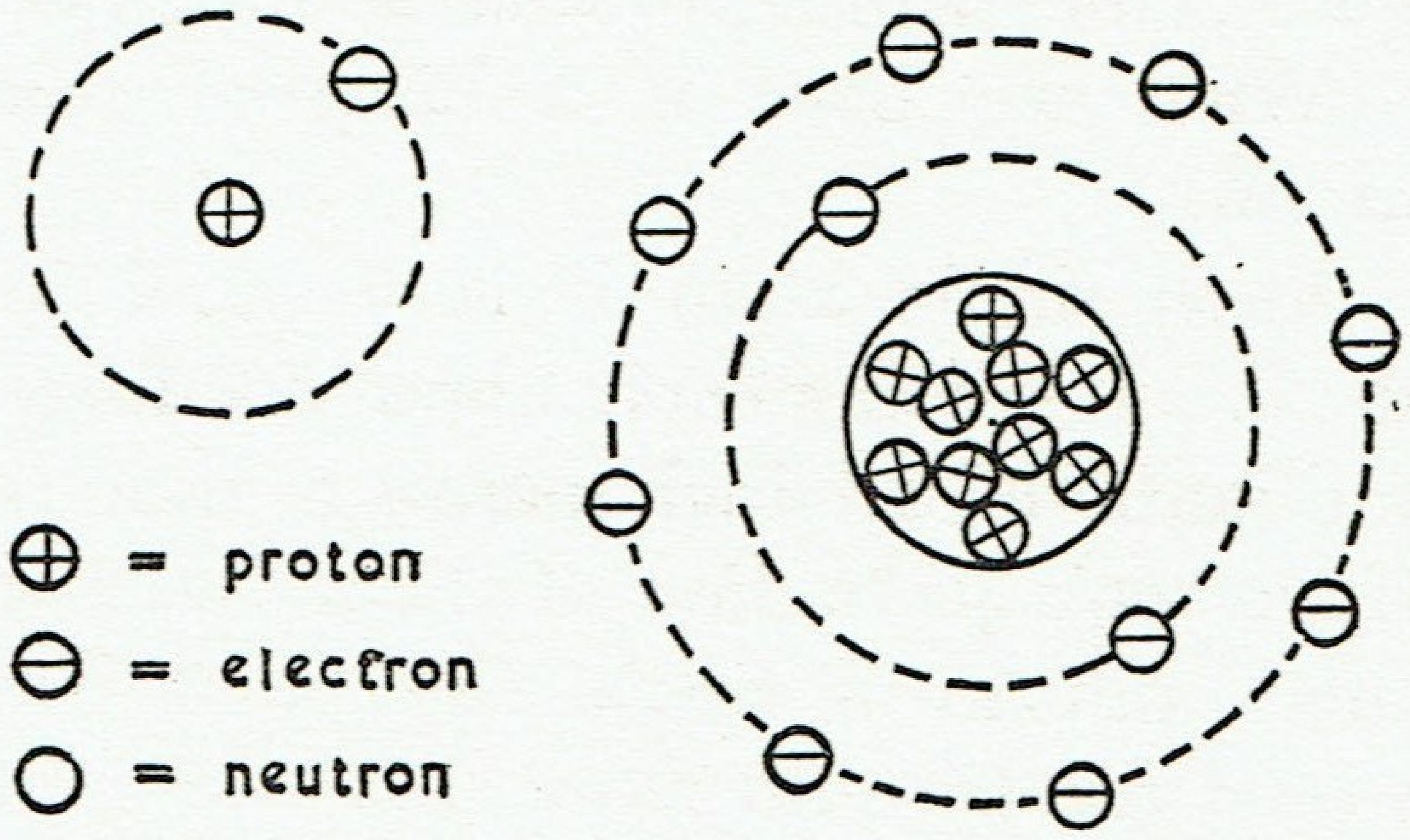
A NEON ATOM has 10 electrons revolving in two orbits, as shown here. Neon is the element which is put into electric-tube advertising signs to make them glow vivid red. It is a rare gas.

It is of the element called " neon "—the rare gas which is put into those neon tubes which glow so brightly as advertising signs. Here you see that there are 10 electrons revolving around the nucleus. In fact, the nucleus is holding 10 negative electrical charges to it. Quite clearly, therefore, the nucleus of neon must have 10 positive charges, whereas the nucleus of hydrogen has only one.

And so, while all electrons may be considered alike, the same cannot be said of all nuclei.

If we opened up a nucleus of neon, we would find that within it were 10 positively-charged particles, and the scientists call these particles *protons*.

We are now able to redraw the atoms of hydrogen and of neon showing not only the numbers of electrons each have, but also the numbers of protons which go to make up their nuclei. They would appear as follows :



THE NUCLEUS of hydrogen has only one proton ; the nucleus of neon has 10. The signs shown left are those used in later drawings of atoms.

Notice from these drawings that while the hydrogen nucleus has only one proton, the neon nucleus has 10 protons.

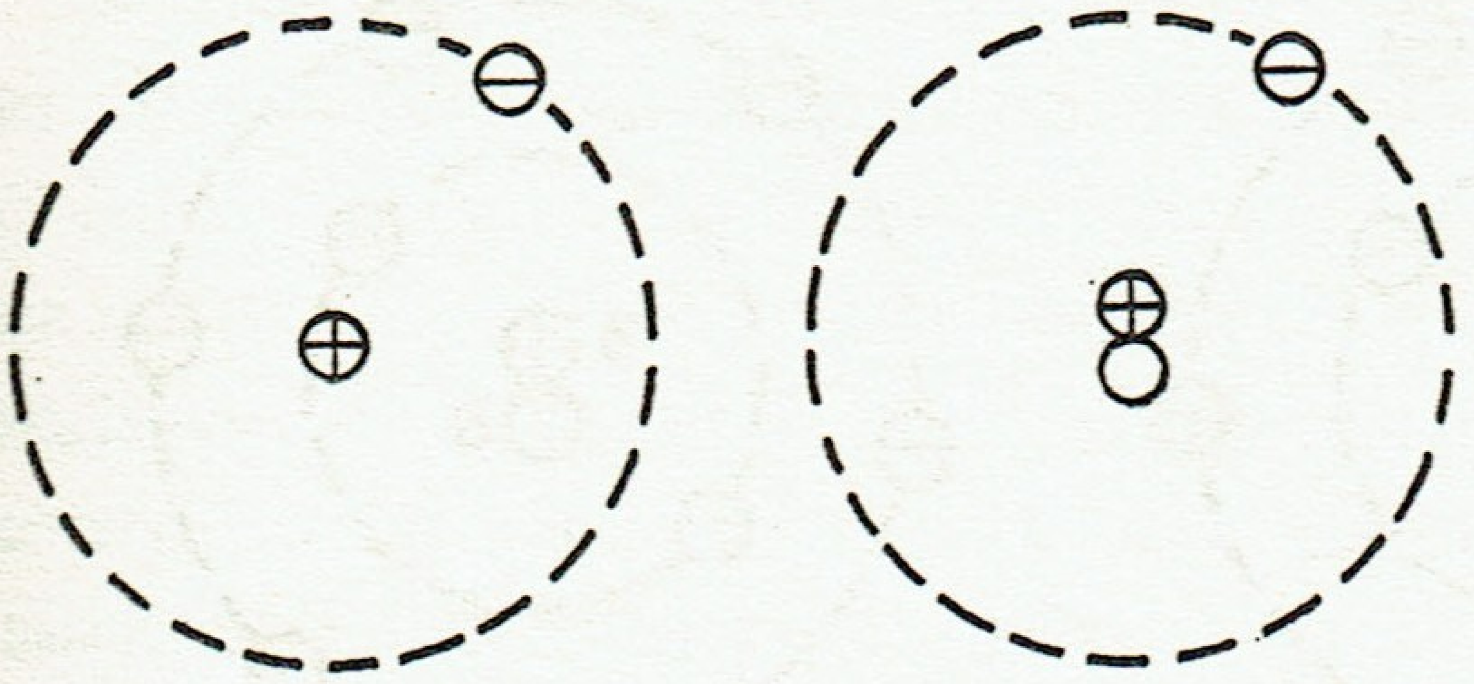
Atom " Particles "

So far, the atom seems to be made up of two kinds of " particles " (they are called particles for convenience), but this is not the end of the story by any means. There is a third particle which is of great importance to us—and to the nucleus.

This particle is a sort of neutral, for it has neither a positive nor a negative electrical charge. In other words, it can be added to an atom without being either attracted or repelled.

It is called the *neutron*.

To see something of the importance of neutrons, let us take a look at the next two drawings of atoms. They are both of hydrogen. One we already recognise ; it is the simple atom of hydrogen we saw earlier, and consists of one proton and one electron.



HYDROGEN HEAVY HYDROGEN

An atom of hydrogen is turned into one of heavy hydrogen (deuterium) by adding a neutron to the proton in the nucleus.

But look at the nucleus of the next one. Here the proton is in company with a neutron ; but the two together still make up only one positive charge of electricity, so the atom still has only one electron.

The second atom is known as *heavy hydrogen*. Scientists call it *deuterium*, and the nucleus itself they call a *deuteron*.

Now as you know, ordinary water is made up of two parts of ordinary hydrogen with one part of oxygen (written H_2O as a chemical formula). By using dueterium, which is a heavier form of hydrogen, we can make heavy water (written D_2O), and this heavy water is of considerable importance in atomic physics, as you will see later.

The thing to remember now is that when you change the contents of a nucleus by adding or taking away neutrons, you get what scientists call an *isotope*—that is, a slightly different form of the same element.

But—and this is very important to note—if you force an extra neutron into some nuclei, they simply will not stand for it. Instead they fly to pieces. A case in point is the nucleus of uranium 235.

This breaking up of a nucleus is known as *nuclear fission*.

But getting back to our atom particles, we find now that we have protons, neutrons, and electrons. There are also some other particles scientists talk about, and these are—

Positrons, which are single positive charges of electricity, and which scientists know to exist in nuclei.

Neutrinos, which are negative charges of electricity that are thought to live inside the nucleus. The scientists have not succeeded in isolating any yet, but they say that they must exist because, since protons and electrons in any atom must have equal electrical charges, some particle must be present to counterbalance the positrons which they have discovered.

Mesitrons or *Mesons*, which are particles which are something of a mystery but they are believed to be necessary inside a nucleus in order to hold protons and neutrons together. One might think of them as a sort of nuclear " glue ".

We need not bother too much about these last three particles—positrons, neutrinos and mesons—but keep our minds firmly fixed upon protons, neutrons and electrons.

One rather startling thing occurs to

us from all this—that the elements are simply made up of about six kinds of atomic particles. In fact you can say that everything in the world is made up from these particles, *and these alone*.

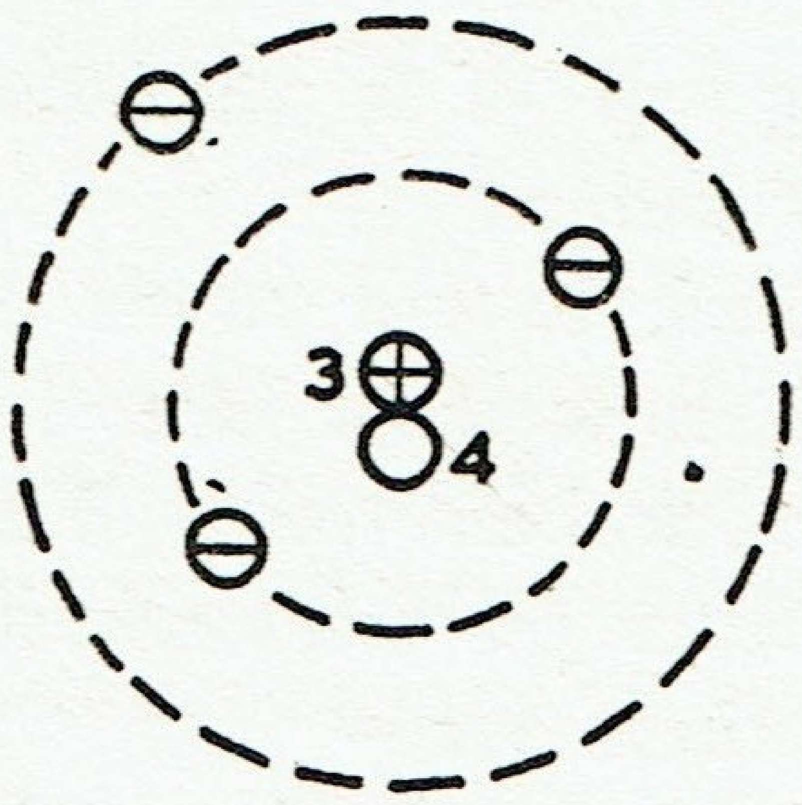
Very little thought will give us the clue to why one element differs from another. The reason is the different possible quantities and arrangements of the particles within the atom, and in particular within the nuclei.

Here are one or two elements illustrated to show the differences.

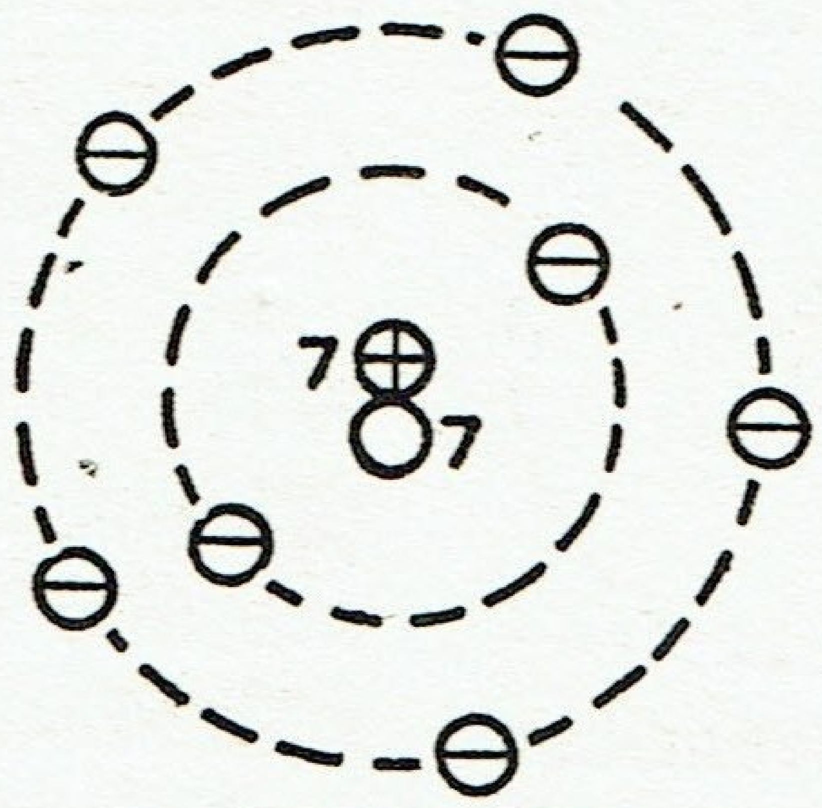
You can get a very good idea of the contents of other atoms by turning to the table of elements on page 87. In that table you will find a heading " Atomic Number ". The number given under it for any particular element gives the number of protons and the number of electrons in that element.

There are other numbers under the heading " Atomic Weight ", and these give a clue to the number of neutrons present in the nuclei of the elements. Simply subtract the atomic number from the atomic weight, and the answer is the number of neutrons.

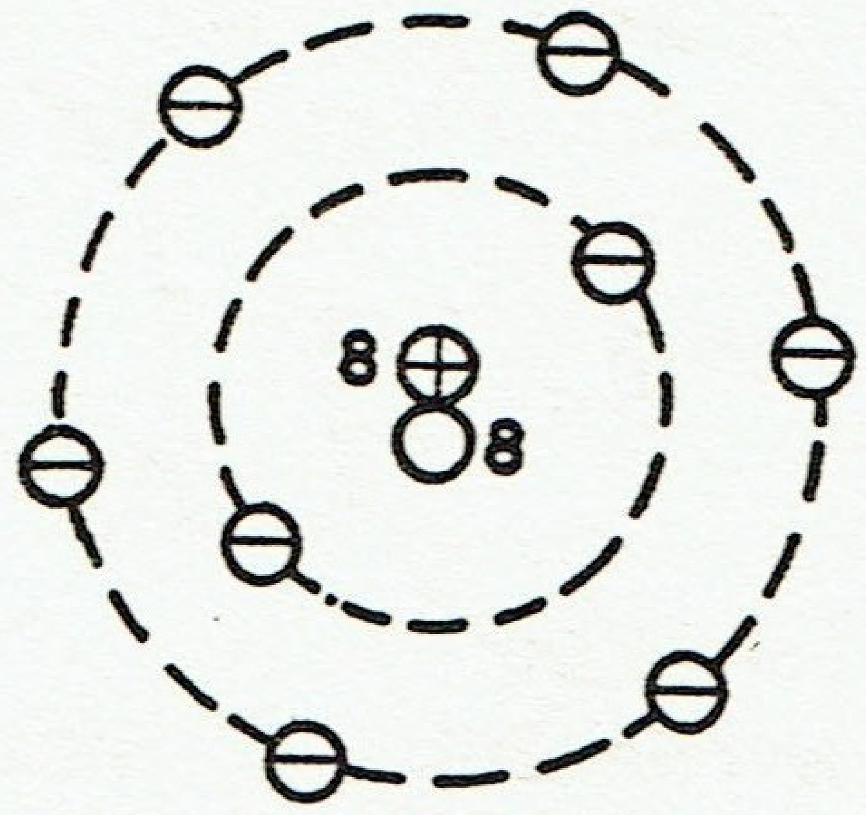
Take oxygen as a simple example. The atomic number is 8 (meaning 8 protons and 8 electrons), and the atomic weight is 16 (so neutrons = 16−8=8). Oxygen, then, has 8 protons and 8 neutrons in its nucleus, and 8 electrons circling around it to make up the complete atom.



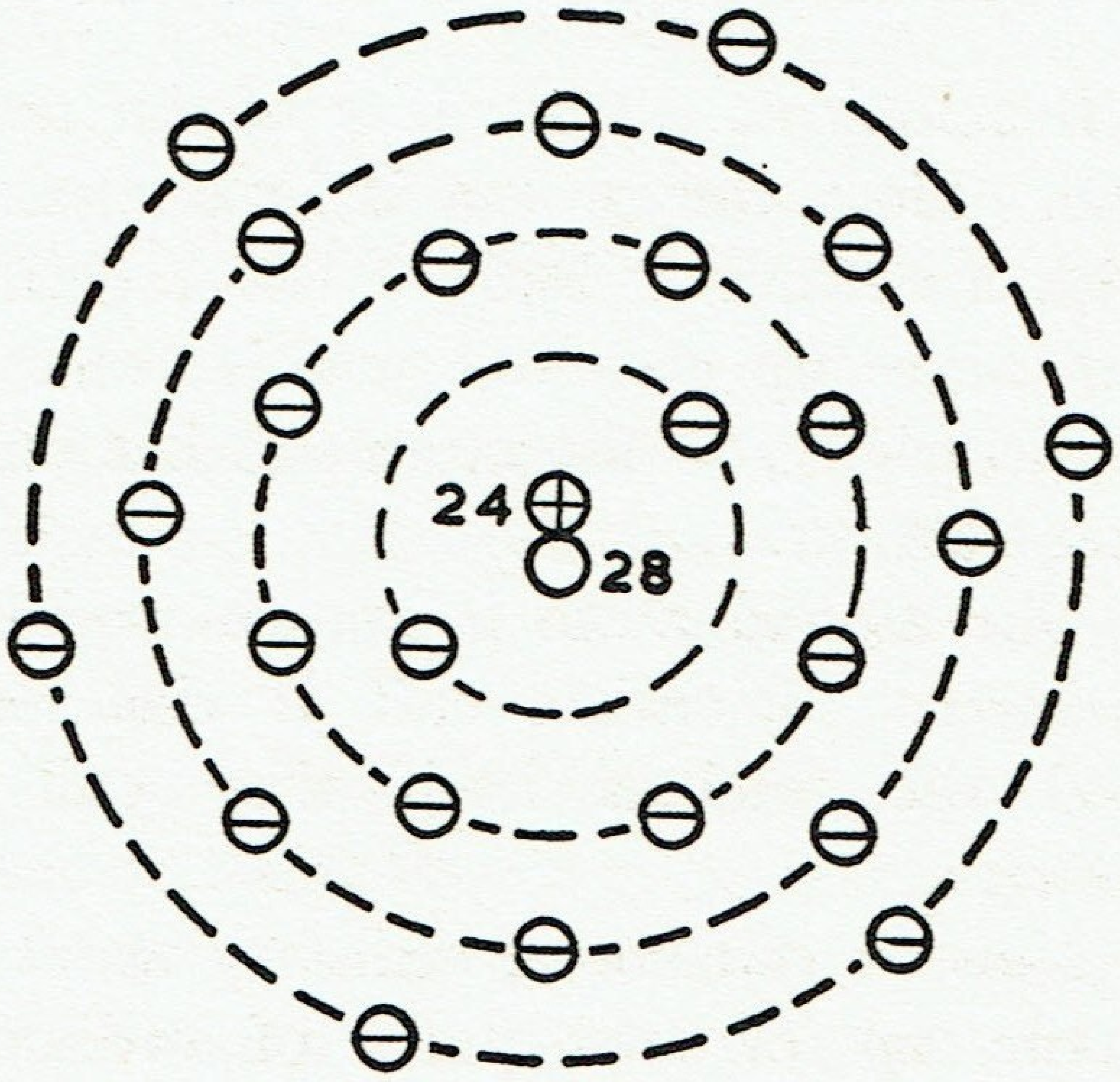
LITHIUM



NITROGEN



OXYGEN



CHROMIUM

But you will notice from the table that not all atomic weight are simple numbers like 16. For lead, for example, you have atomic number 82 and atomic weight 207·21.

The reason is the presence of isotopes. All lead has 82 protons in its nucleus, but some kinds have 124 neutrons, some 125, and some 126. The mixture of atoms having varying numbers of neutrons accounts for the fractions in atomic weights—a piece of lead as we are likely to find it is simply a mixture of its isotopes in varying proportions.

" The Philosopher's Stone "

In olden times certain people who set themselves up as learned men tried to find a way of becoming rich. They searched for what they called " the philosopher's stone ", by which they hoped to be able to turn a base metal (such as lead) into pure gold.

They never succeeded, of course. In fact they never got anywhere near succeeding because they did not have any knowledge of the structure of the atom.

But you, if you have read this chapter carefully so far, have that knowledge—theoretically, at any rate. You know that what makes the main characteristics of any element is the number of protons in its nucleus.

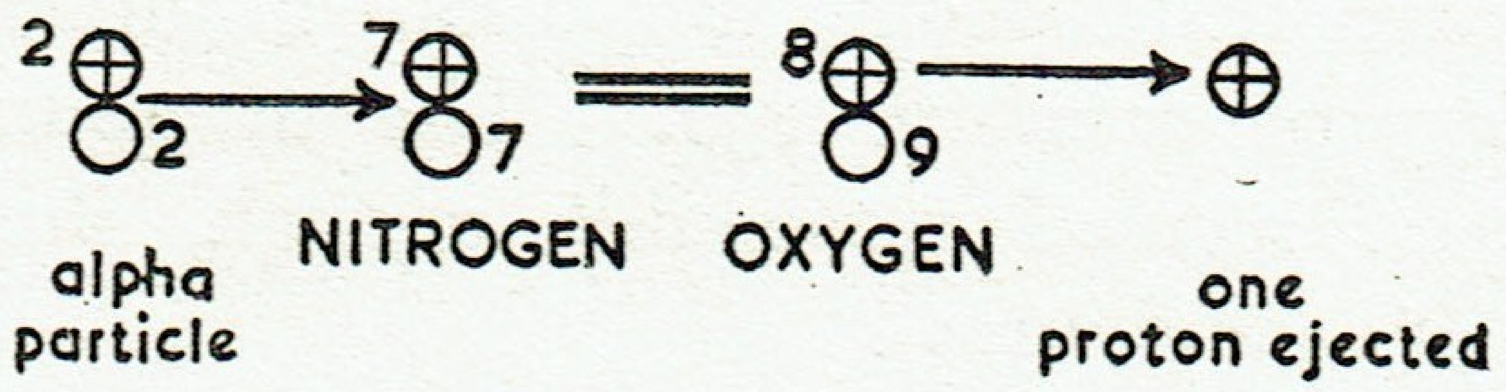
So, if you look up the table of elements again, you find in that dull mass of figures something really exciting—that lead has 82 protons and gold has 79 protons.

If only you knew the way of getting some lead and shooting out of each of the nuclei of its atoms just 3 protons. You would be left with gold !

Startling, isn't it ? But there is one difficulty : the apparatus needed to do the shooting would be so expensive, and the power to operate it would have to be so vast, that any gold you got would be of small value compared with the money you would have spent to make it.

But transmutation—that is, the changing of one element into another—*is* possible. It has been done.

Lord Rutherford is the scientist who first did it, and he changed an atom of nitrogen into an atom of oxygen. What he did was to shoot a helium nucleus (called an *alpha particle*) into a nitrogen nucleus, with the following result—



TRANSMUTATION—this diagram illustrates how an atom of nitrogen can be turned into one of oxygen.

You will see from this diagram that the helium nucleus (consisting of 2 protons and 2 neutrons) hit the nitrogen nucleus (consisting of 7 protons and 7 neutrons). The combined nucleus could not manage to keep all the protons and ejected one, leaving 8 protons and 9 neutrons.

Now, if we refer to our table of elements, we see that a nucleus having 8 protons is oxygen.

So Lord Rutherford became the first magician to discover " the philosopher's stone ".

Another transmutation which has been performed by scientists is to add 2 protons to aluminium (13 protons) to make phosphorus (15 protons), and then to knock 1 proton out of phosphorus to make silicon (14 protons).

And when neutrons are shot into uranium 235 (92 protons), there is considerable transmutation as a result of the atomic explosion which follows, the uranium 235 disappearing completely as it splits into such elements as barium, bromine, krypton, molybdenum, antimony, strontium, tellurium and xenon.

But we shall see more of what happens to uranium in the next two chapters.

Making the Nucleus Explode

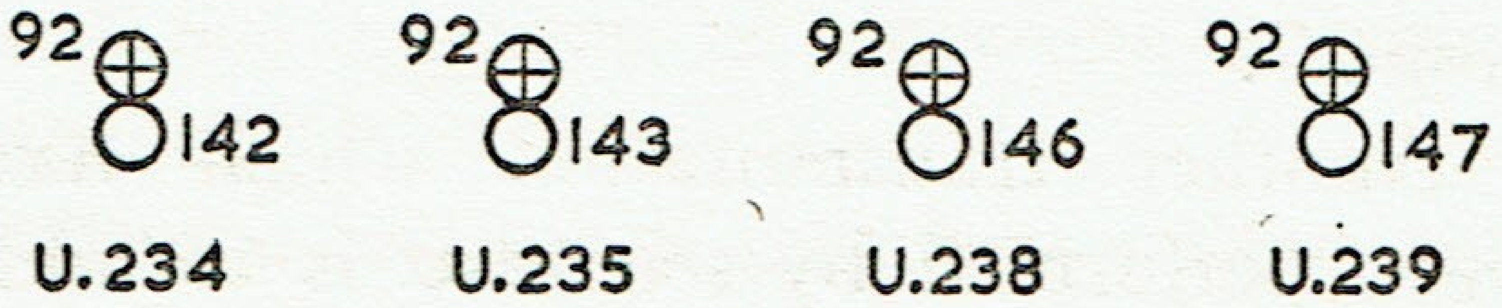
YOU HAVE probably been somewhat puzzled up to now when you have heard people talk about uranium 235 or uranium 238. The uranium part seemed reasonable enough, but why the figures ?

Well, if you have read the last chapter, you now know the answer. Uranium 235 has 235 particles in its nucleus, and uranium 238 has 238.

But, remembering our Table of Elements, we recall that uranium has the atomic number 92—which, we found, indicates the number of protons in its nucleus.

So, taking uranium 238, if the number of its protons is 92, then the number of neutrons it has is $238-92=146$.

We can easily show something of the uranium family in the form of a simple diagram.



THE URANIUM FAMILY

Here we see the nuclei of four isotopes of uranium, the first three of which are found in the ordinary kind of uranium metal which is mined. Most of this uranium metal is in the form of U.238 ; only 7 parts in 1,000 consists of U.235 ; and only about 1 part in 10,000 consists of U.234.

Scientists say that at present there does not seem to be any use for U.234, and so we will ignore it here.

U.238 and Plutonium

The problem of people who want to use uranium for various purposes is to separate the U.235 from the U.238.

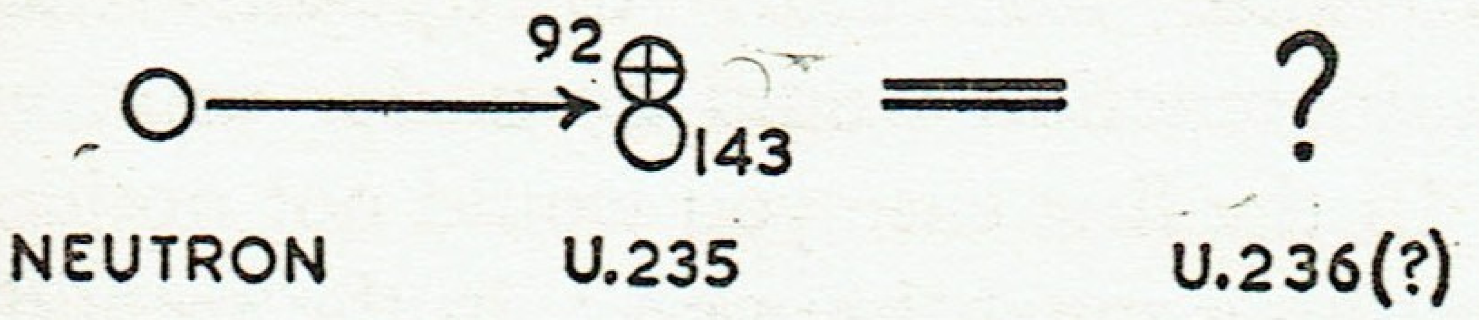
Almost everyone knows that it is the U.235 which can be used in atomic bombs ; and there is a tendency to think that this U.235 is the only really valuable isotope, and that U.238 is a waste product.

Nothing could be farther from the truth, for U.238 can be bombarded with neutrons with the startling result that it takes in one neutron and becomes U.239. This U.239 is very unstable, and quickly changes into neptunium (atomic number 93) and plutonium (atomic number 94).

This change from U.238 to plutonium by bombardment with neutrons can take place in an atom pile, a description of which is given on pages 69–72.

The two really explosive nuclei we know about so far are those of U.235 and plutonium. Let us see how the explosion is made to take place.

What we have to do is set up a nucleus of, say, U.235 and shoot a neutron into it—rather like setting up an apple and shooting into it a slug from an air-gun. Using one of our diagrams, we have—



THE BEGINNING OF FISSION

A neutron hits a nucleus of U.235, with the result described in the text immediately below.

You would think, from what we have just said, that the result of the shooting would be a nucleus of U.236. But there is no such thing as U.236, or if there is it can exist for less than a billionth part of a second, because the moment the neutron enters the nucleus of U.235, the U.235 finds life too much for it and blows apart.

Here is the sort of thing which happens—

The U.235 (in the centre) is hit by a neutron, and in a flash it breaks up into, say, xenon (left) and strontium (right), plus a lot of free neutrons.

Chain Reaction

The xenon and strontium are not important to us at the moment, so we will leave them. What are important are those free neutrons.

For supposing there were some more U.235 nuclei knocking around, and supposing that some of the free neutrons could hit them? You know what would happen, because it has happened already. There would be more explosions—and there would be a further release of free neutrons.

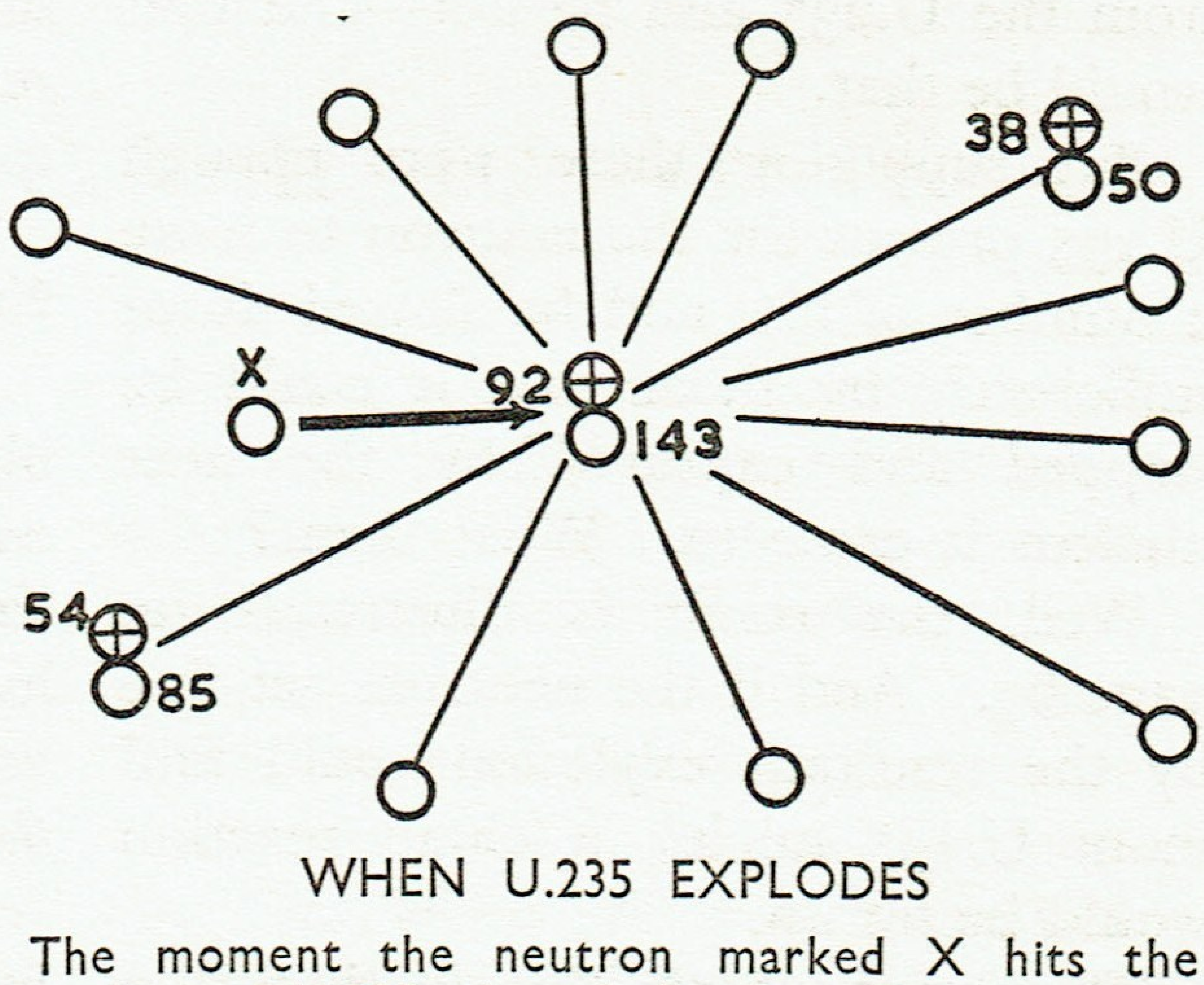
And if that further lot of free neutrons could find still more nuclei of U.235 to hit, there would be still more explosions, and still more free neutrons—and so on indefinitely.

The process is known as *chain reaction.*

Slowing Neutrons Down

Put like this it all sounds very simple, but there is a slight catch in it. The catch is this: a neutron has to be travelling at just the right speed before it can cause a U.235 to split. It must, in effect, be a slow neutron; a fast neutron will simply pass right through the U.235 nucleus and do no damage at all.

Now neutrons, when they first become free, are usually travelling at fairly high speeds—too high to be



WHEN U.235 EXPLODES

The moment the neutron marked X hits the nucleus of U.235, the whole thing flies apart. It "transmutes", in fact, the result here being the formation of xenon (left), strontium (right), and a number of free neutrons which are available to plunge into any more U.235 they can find.

stopped by U.235 nuclei anyway—and the problem is to slow them down. This can be done by giving them enough things to hit, each hit taking something away from their velocity.

They will find plenty of fairly harmless things to hit if they are made to pass through heavy water (see page 63), and this is the reason why heavy water is so valuable to the atomic scientist—he can control the speed of neutrons with it.

" Critical Size "

The neutrons can also be slowed down by giving them things to hit which are very far from harmless—the nuclei of U.235 itself, for example.

A neutron barging about in a small quantity of U.235 would hit perhaps two or three nuclei, but it would probably be going sufficiently fast that it would not be stopped by any one of them. In the end it would pass out from the U.235 and be lost—and that would be that.

But supposing there were enough U.235 present for the neutron to score a number of hits and be slowed down sufficiently by them that it could be stopped and captured by the next nucleus it came to. What then ?

Well, the result is illustrated on page 67. And if the neutrons set free by the resultant explosion could find more U.235 nuclei, a chain reaction would be set up.

The point of all this is that if a neutron is shot into a *small* piece of U.235, nothing much would happen—the neutron would simply pass out again, or perhaps it might cause trouble in just one nucleus of U.235.

But if the neutron were shot into a *larger* piece of U.235—a piece sufficiently large to enable it to disrupt one nucleus with the release of plenty of neutrons to cause lots more disruptions—the chain reaction would be under way.

In the first case you would not notice anything much happen ; in the second case the shock of the resulting explosion would be felt 10 or more miles away.

In other words, if the piece of U.235 is below a certain size (the scientists call it " critical size ") it is safe ; but if it is above that size it is dangerous.

Just what the critical size may be is a closely-guarded secret. A scientist did suggest some time ago that it may be about 120 lb. If this is so, the damaging part of a uranium bomb would be a ball measuring no more than about seven inches across ; and from such a ball can be released (by chain reaction) explosive energy equivalent to 20,000 tons of T.N.T. !

Nuclear Fusion

Great as is the energy released by blowing nuclei of U.235 apart with neutrons (*nuclear fission*) about seven times as much energy is released when hydrogen nuclei are made to combine into helium (*nuclear fusion*—also called *thermo-nuclear reaction*).

This nuclear fusion is the basis of the hydrogen bomb, but Sir John Cockcroft, Director of Research of the U.K. Atomic Energy Authority, predicted some time ago that the process may one day be so controlled that we can have all the useful energy we want from what is one of the most plentiful of elements.

You will see as you read on that his prediction was very accurate, and that power from nuclear fusion looks like becoming an accomplished fact in the not very distant future.

Making Nuclei Combine

The principle of nuclear fusion is not really difficult to understand. You will know from page 61 that nuclei have positive electric charges, and that when two nuclei come together they tend to repel one another.

So if you took two nuclei of hydrogen and tried to push them together in the ordinary way, you would not succeed —they would refuse to combine.

One way of forcing them to combine is to subject them to terrific heat—something like 30-50 million° C., only obtainable at present during nuclear fission, but known to exist in the interior of the Sun.

Another way is to inject mesons (see page 63) into hydrogen gas. These mesons break down the repulsion between the nuclei and so make it possible for them to combine (hydrogen 1 proton ; helium 2 protons—see pages 61 and 87), with the release of energy.

This process has already been achieved on a minute scale in the California University laboratories, and work is still going on—with exciting possibilities.

And a third way—the one predicted by Sir John Cockcroft—is by the use of a remarkable development thought out and developed by British scientists at the Atomic Research Establishment, Harwell, and known as ZETA (Zero Energy Thermonuclear Assembly). You will find Zeta described on page 74.

Putting the Atom to Work

I—POWER FROM FISSION

URANIUM is rather like radium in one respect—it gives off radioactive particles all the time, and as it does so it very gradually changes into something else.

In fact, both uranium and radium (and two other substances, thorium and actinium) will, if left long enough, change into lead.

How long would the change take ? The answer is : thousands of millions of years. And during those years the substances would be giving off energy in tiny doses the whole time.

The Scientists' Problem

Let us imagine we have a lump of uranium which we want to turn into useful energy. How are we going to set about it ? That is the problem the scientists have been working on.

We know that the uranium, if just

these electrons, being electrically negative, fly at once to the positively charged wire. The remainder of the argon atoms (the *ionised* atoms), being electrically positive through having lost a bit of negative electricity, fly to the negatively charged walls of the copper cylinder.

For the reason for this, remember the rule : *Unlike charges attract; like charges repel* (see page 61).

Now you will remember that the electrical charge on the central wire inside the cylinder was 1,000 volts—which means that there was a difference of 1,000 volts between the wire and the walls of the cylinder.

That was so long as no gamma rays were causing trouble by knocking electrons off atoms. But once the atoms have been disturbed in this way, the electrical difference between the wire and the walls of the cylinder will be changed—by the mount of electricity contained in the free electron and in the ionised atom. This change will be measured by the meter on the geige counter, and so radioactivity will have been detected.

Of course, if there is very little radioactivitiy, then few of the argon atoms will have electrons knocked off them, and the reading on the meter will be small. But if there is a lot of radioactivity about, then a great number of electrons will be knocked off, and the reading on the meter will be high.

Thus radioactivity cannot only be detected by the geiger counter, it can be measured to a considerable degree of accuracy as well.

NEW ELEMENTS

As a result of the most recent studies in nuclear fission and the bombardment of existing elements with fast-moving particles in a cyclotron ("atom-smasher"), at least six new elements have been discovered—the last six in the table opposite.

These elements have been produced only in very small quantities, and data on them is not yet complete.

Elements nos. 98 and 100 were made by bombarding plutonium with neutrons, and no. 99 was made by bombarding uranium with the nuclei of nitrogen atoms. Nos. 97 and 101 (now the heaviest elements known) were produced during similar bombardments.

All the new elements are highly radioactive.

Making Nobelium

The last element in the table was discovered as recently as March 1958. It was made by bombarding curium (atomic number 96) with ions of carbon.

One of the scientists who made the discovery, Dr. J. Milsted of Harwell, said at the time that only 17 atoms of nobelium had been identified with certainty. It is not yet known whether the new element will prove of much use, for its effective "half life" is only about 10 minutes.

Table of Elements

In the list below are the names of elements which have so far been discovered—102 in all. The two marked * are known to exist, but up to now have not been isolated.

Element	*Symbol*	*Atomic Number*	*Atomic Weight*
Hydrogen	H	1	1·008
Helium	He	2	4·003
Lithium	Li	3	6·940
Beryllium	Be	4	9·013
Boron	B	5	10·820
Carbon	C	6	12·010
Nitrogen	N	7	14·008
Oxygen	O	8	16·000
Fluorine	F	9	19·000
Neon	Ne	10	20·183
Sodium	Na	11	22·997
Magnesium	Mg	12	24·320
Aluminium	Al	13	26·970
Silicon	Si	14	28·060
Phosphorus	P	15	30·980
Sulphur	S	16	32·066
Chlorine	Cl	17	35·457
Argon	A	18	39·944
Potassium	K	19	39·096
Calcium	Ca	20	40·080
Scandium	Sc	21	45·100
Titanium	Ti	22	47·900
Vanadium	V	23	50·950
Chromium	Cr	24	52·010
Manganese	Mn	25	54·930
Iron	Fe	26	55·850
Cobalt	Co	27	58·940
Nickel	Ni	28	58·690
Copper	Cu	29	63·540
Zinc	Zn	30	65·380
Gallium	Ga	31	69·720
Germanium	Ge	32	72·600
Arsenic	As	33	74·910
Selenium	Se	34	78·960
Bromine	Br	35	79·916
Krypton	Kr	36	83·780
Rubidium	Rb	37	85·480
Strontium	Sr	38	87·630
Yttrium	Y	39	88·920
Zirconium	Zr	40	91·220
Niobium (Columbium-Cb)	Nb	41	92·910
Molybdenum	Mo	42	95·950
Technetium	Tc	43	99·000
Ruthenium	Ru	44	101·700
Rhodium	Rh	45	102·910
Palladium	Pd	46	106·700
Silver	Ag	47	107·880
Cadmium	Cd	48	112·410
Indium	In	49	114·760
Tin	Sn	50	118·700
Antimony	Sb	51	121·760
Tellurium	Te	52	127·610
Iodine	T	53	126·910
Xenon	Xe	54	131·300
Caesium	Cs	55	132·910
Barium	Ba	56	137·360
Lanthanum	La	57	138·920
Cerium	Ce	58	140·130
Praseodymium	Pr	59	140·920
Neodymium	Nd	60	144·270
Illinium	Il	61	146·000
Samarium	Sa	62	150·430
Europium	Eu	63	152·000
Gadolinium	Gd	64	156·900
Terbium	Tb	65	159·200
Dysprosium	Dy	66	162·460
Holmium	Ho	67	164·940
Erbium	Er	68	167·200
Thulium	Tm	69	169·400
Ytterbium	Yb	70	173·040
Lutecium	Lu	71	174·990
Hafnium	Hf	72	178·600
Tantalum	Ta	73	180·880
Tungsten (Wolfram)	W	74	183·920
Rhenium	Re	75	186·310
Osmium	Os	76	190·200
Iridium	Ir	77	193·100
Platinum	Pt	78	195·230
Gold	Au	79	197·200
Mercury	Hg	80	200·610
Thallium	Tl	81	204·390
Lead	Pb	82	207·210
Bismuth	Bi	83	209·000
Polonium	Po	84	210·000
*Astatine	At	85	210·000
Radon (Niton)	Rn	86	222·000
*Francium	Fr	87	223·000
Radium	Ra	88	226·050
Actinium	Ac	89	227·000
Thorium	Th	90	232·120
Protoactinium	Pa	91	231·000
Uranium	U	92	238·070
Neptunium	Np	93	239·000
Plutonium	Pu	94	239·000
Americium	Am	95	241·000
Curium	Cm	96	242·000
Berkelium	Bk	97	243·000
Californium	Cf	98	244·000
Einsteinium		99	
Fermium		100	253·000
Mendelevium		101	
Nobelium		102	253·000