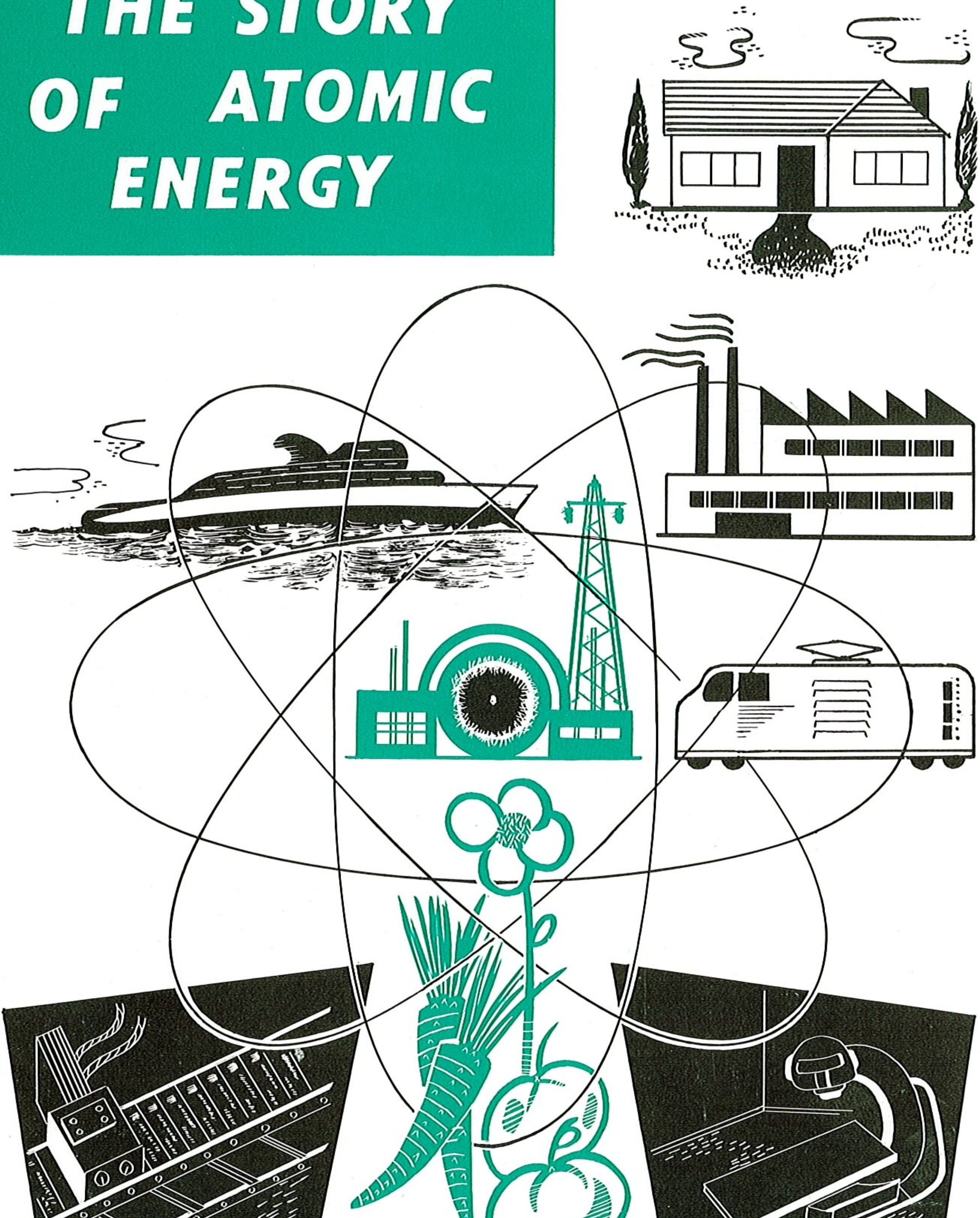
THE STORY OF ATOMIC ENERGY



What is atomic energy? How do we know what is inside an atom? What is an isotope? These questions are frequently asked as we enter the Atomic Age, and the text of a lecture given by Professor Sir Mark Oliphant, while Director of the Research School of Physical Sciences at the Australian National University, gives the answers in this easy to read and understand

STORY OF ATOMIC ENERGY

I want to tell you the story of the way in which we have come to understand something about the structure of the matter of which this world is made and, in particular, the structure of the little atoms which we believe to be the bricks from which it is built.

You are all familiar with the fact that to-day the world faces a very difficult situation. We have the probability that the work of the scientist may lead very rapidly to the elimination of disease and of want, of starvation and drudgery, throughout the whole world. Side by side with this there is the possibility that mankind, through foolishness, may use this knowledge for the wrong purpose and do very great harm to the human race as a result.

If we look at the story of the development of nuclear physics and atomic energy, we see that this great result has not been brought about by wicked men bent upon the destruction of humanity, nor even by men who had the foresight to look ahead and see what great benefits could be conferred upon mankind if they could bring about such a development. It has been brought about through a very fundamental and simple instinct of mankind, his curiosity—the desire he has to understand something more of the world in which he lives, and to find for himself the same satisfaction in the exploration of the world of science that the explorers of old, experienced in the exploration and discovery of new continents and new peoples.

The story of the development of atomic energy from nuclear physics, the basic science on which it is founded, goes back to the last century, when for the first time men began to prove to their own satisfaction that the matter which to us appears to be so solid, so continuous, is in fact built up entirely of miscroscopic objects which we call atoms and these atoms themselves are built up from still tinier fundamental particles which we call protons and neutrons.

The Victorian scientists had satisfied themselves by a variety of ways that matter was atomic, for instance by developing the kinetic theory of gases which assumed that a gas was atomic and showed that if it were atomic it would have the properties that it does possess. In other words, they proved their thesis by a roundabout method.

Today, physical science has developed methods for showing quite unambiguously that matter is made out of atoms. When a radioactive substance, like uranium, disintegrates in a way that we will talk about a little later on, it throws out with high energy little bits of itself which are atoms of simpler kinds.

These little atoms, called alpha particles, are sent out with such high velocity that as they pass through matter they tear electric charges off it. When this happens in a gas like air, for instance, loose electric charges accumulate in it and will conduct electricity, momentarily, after one of these alpha particles has travelled through it.

By using modern techniques of eectronics, by amplifying the very small electric current that each particle produces in a little volume of gas, we can actually hear these single particles of matter entering the chamber; we can count them and collect them. Having collected them, we can show that they are atoms of helium, because the gas that we will collect

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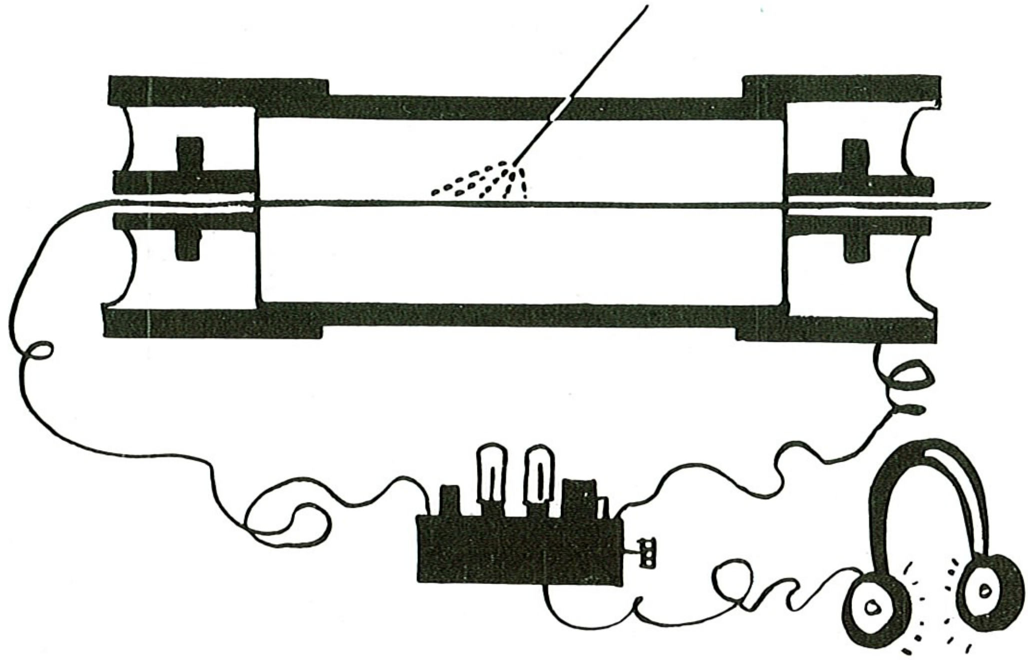
Our cover illustration shows in symbol some of the benefits the peaceful atom can bring to mankind. From the heart of the atom we can draw the power that drives turbines to supply electricity to our homes and factories, and drive electric trains. We can harness this power to drive ships across the oceans. Radioisotopes, "by-products" of atomic reactors, can help us in factories, laboratories and hospitals.



. . . We can use a simple electronic amplifier, and a small chamber through which we can make alpha particles pass. The alpha particles will register as a series of clicks.

will behave just like helium gas, give out the same light—that is to say, the same spectrum—as does helium gas.

To convince you, we can carry out simple experiments of counting and detecting the alpha particles which are shot out from a radioactive substance. We can use a simple electronic amplifier and a small chamber through which we can make alpha particles pass.

A radioactive source of alpha particles is placed on the table and covered with a sheet of white paper and the counting chamber. If that piece of white paper is pulled away, the alpha particles, which could not previously penetrate through the paper, will be able to make their way to the little ionisation chamber, as we call it, and will register as a series of clicks in the loudspeaker.

If this is continued to something like a count of a million million million particles, we will have accumulated in that little chamber one cubic centimetre of helium gas and its properties can be detected. It takes about one million million million atoms to make one cubic centimetre—about one-sixteenth of a cubic inch—of helium gas at ordinary temperature and pressure.

Now, if we put back the piece of paper, the alpha particles are prevented from entering the chamber. The same things happens if we take the chamber away so that the alpha particles cannot penetrate into the chamber. As we bring it closer, the particles enter again.

This very simple experiment convinces us, in a way that was impossible in the past, that matter does indeed consist of atoms. Tiny invisible particles which you can't see as they come off the radioactive material collectively give the matter all its properties.

These atoms are held together in solids or liquids by what we call chemical forces and these chemical forces arise from the hooking together, as it were, of the outermost parts of the atom.

The outermost parts of atoms consist of electrons—little electrically charged particles, with negative charges of electricity on them—which are individually about 1/2,000th of the mass (or weight) of the hydrogen atom

They are extremely light, extremely small particles of matter, which seem to consist wholly of a negative charge of electricity. What they consist of ultimately is one of the great puzzles that scientists have yet to unravel, but we know their mass, we know their diameter, and we know the electric charge with extreme accuracy.

These little electrons were discovered towards the end of last century by Sir J. J. Thompson, in Great Britain. He showed that when you pass a charge of electricity through a gas, no matter what sort of gas you put inside the chamber, you set free little electrons which have identically the same properties. It doesn't matter what sort of electrode materials you use, what sort of materials you use in the glass envelopes, or what sort of gas you put there. You will always find that you are able to knock little particles off the atoms. These particles have exactly the same charge and exactly the same mass. In other words, the electrons are universal constituents of all kinds of matter.

This was the first of the great discoveries significant in breaking up the conception of the atom, held in the last century, as being like a hard billiard ball and which no efforts could change into any other kind of billiard ball. An atom of copper, say, was assumed to be something that had been created at the beginning of time, and would go on forever. And the idea of changing one kind of atom into another was thought to be nonsense.

We know better today. We know that we can change one kind of substance into another, provided we are prepared to pay the price. And we will see that the production of atomic energy—the release of energy from atoms—takes place as a result of our great understanding of the way in which the atom is designed.

Sir J. J. Thompson showed that every kind of atom contained electrons. If we take electrons out of the atom, we must leave behind an atom which has a positive charge of electricity, because we know that the atom as a whole carries no electrical charge. A charged piece of matter is an abnormal piece. Ordinary matter carries no electric charge.

So, if we take negative electrons out of matter we must leave behind an equalising positive charge. At once, one may ask of what do these positive charges consist?

The answer to this came from experiments which were carried out by the late Lord Rutherford. He used a very simple method of discovering what was inside an atom.

Special techniques developed in the earlier part of this century for measuring accurately the sizes of atoms have shown us that it would take about 100 million atoms placed side by side and touching one another, to make up one inch in length. That is to say, an atom has a size of about 1/100-millionth of an inch.

You know very well that we cannot see anything with the naked eye that is much smaller than about 1/1,000th of an inch. How on earth can we see or understand anything about particles which are less than a millionth of an inch in diameter? Well, the answer is really quite simple. And we can illustrate it very well by a little story which was first used by the late Sir William Bragg, and which is a very apt way of describing what the physicist does.

He supposed that you were in a little rowing boat, rowing across the surface of the sea, and you were well out of sight of land when you came across a little island. Disappointingly, your efforts to explore this island were frustrated by the fact that when you got close to it you discovered that it was surrounded by a high, smooth wall which you couldn't look over, and which was impossible to climb.

How could you discover whether there were any inhabitants on the island and, if so, what sort of people they were—were they tall or short, were they strong or weak, intelligent or otherwise?

You could answer all these questions with out being able to look over the wall.

The way to go about it would be this. You could pick up some stones from the beach, and throw them over the wall. You could repeatedly do this until the inhabitants were irritated. Then perhaps they would pick up the stones and throw them back again.

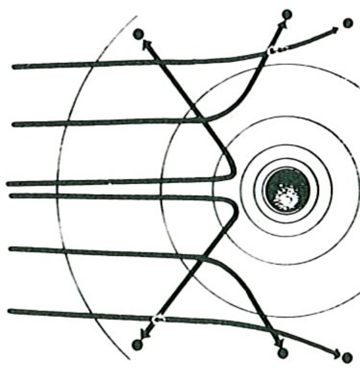
Their intelligence would be shown by whether or not they threw them back in the direction from which they had come. From the speed with which they came out one could gather a great deal about the strength of the inhabitants.

Perhaps instead of picking up the stones which you had thrown in, they would pick up other objects and throw them out. They may be cups, or teaspoons, or other objects, so that one could then learn a great deal about the nature of the civilisation which existed on that island.

Now this is exactly what the physicist has done to explore his tiny little world of the atom, which he cannot see, because it is beyond the limit of any microscope, and yet which he wants to explore as thoroughly as he can. The methods developed, largely by Lord Rutherford, are singularly powerful, and have given us more information about the inside of the atom than we know about the outside of many atoms.

What Lord Rutherford did, and what is done today by the physicist, is to fire into the inside of atoms little particles of matter. They might be electrons, they might be charged alpha particles, which we spoke about earlier. They might be artificially accelerated particles which come from accelerators like betatrons, cosmotrons, bevatrons, cyclotrons and all the rest of the "trons" you read about which are in use all over the world, and which produce particles moving at speeds comparable with the speed of light. You remember that light travels at 186,000 miles a second, so you have to fire these particles at very much higher speeds than you could ever fire a rifle bullet, or even a rocket or a satellite.

These particles are fired, with the atomic



. . .Occasionally one of these exploring particles hits something inside the atom. It is deflected from its original direction, and makes off in some new direction, sometimes even back at the sender.

"guns" which the physicist has developed, into the inside of bits of matter to see what happens.

One can show that most of the bullets that you fire into an atom go straight through. They don't hit anything, so that inside an atom must be mostly empty space. That's the first thing that one learns.

The second thing one learns is that occasionally the bullet hits one of the electrons on the outside of the atom and knocks it off.

Far less frequently, but just occasionally, one of these exploring particles hits something inside the atom. It is deflected from its original direction, and makes off in some new direction, sometimes even back at the sender.

One should realise that the forces required to make an atomic bullet turn around and come back are extremely large. Lord Rutherford said that it was as surprising to him as if he had fired a 16-inch gun at a sheet of tissue paper, and the 16-inch shell bounced back. You can appreciate the effective force that would be required to push the 16-inch shell back again along its original track.

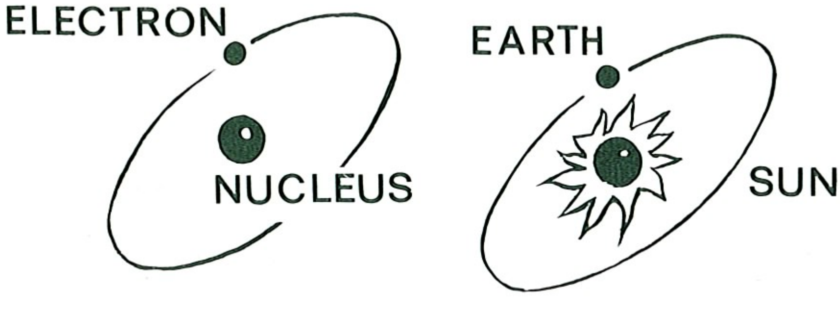
The forces involved in deflecting the particles fired at an atom are believed to be electrical forces. If they are electrical forces, we can calculate just how close together charges have come in order that these particles should be turned back.

We know that like charges of electricity repel one another. If a positively charged electrical particle like the alpha particle penetrates inside the atom, and is repelled back again by electrical forces, immediately we know that the particles must approach very close together to experience forces which are big enough.

Rutherford calculated that the size of the positive charge inside the atom which repelled the alpha particle must be less than 1/10,000th of the diameter of the atom.

When you remember that the atom is very small—a hundred million atoms have to be placed in line to measure an inch in length—these little partices at the centre of the atom, which Rutherford called the nucleus, are so small that a million million have to be placed in line to equal an inch.

We can think of the size perhaps a little more realistically if we think of this 1/8th



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inch ball-bearing on the tip of my finger, as representing the tiny core or nucleus of an atom. Then the first electron which would be rotating round that central nucleus, just like the planets rotate around the sun, would be about 50 feet away.

So we see that an atom is mostly empty space, and the little core or nucleus is just like a sun in the solar system. You know the sun is the centre of the solar system. The gravitational force that it exerts on the earth and the other planets keeps them moving in circles round its centre. So the little nucleus of the atom, through the attractive force that its positive charge has upon the negative charge on the electrons, keeps them moving around in orbits.

These little negative electrons on the outside of the atom account for all the ordinary chemical properties of the atom. They are the little hooks that I spoke about earlier, and which hold together atoms in a piece of solid material and in a chemical compound. When the outer electrons of atoms get tangled up together, the atoms stick together in various ways.

The nucleus of the atom, this little sun at the core of the atom, is what determines what kind of atom it is. Whether it is hydrogen or copper or gold or uranium is determined entirely by the mass and the electric charge of the little nucleus at the centre.

But Rutherford wasn't satisfied with this picture of the atom, which explained so well all the ordinary properties of matter. He set to work to fire particles with still more energy into the inside of the nucleus to see what was inside.

To his surprise he discovered that if he fired one of these alpha particles into the inside of the nucleus of nitrogen, the alpha particles never came out again, but instead there came out hydrogen atoms. He had changed an alpha particle (which is a helium atom) and a nitrogen atom into an oxygen atom and a hydrogen atom. For the first time, in the year 1919, Rutherford was able artificially to change one kind of atom into another.

By continuing this process of firing particles of different kinds into the interior of the nucleus of atoms, physicists came gradually to understand a little of how the nucleus is built up. They discovered that the nucleus was made of two kinds of particles which are very closely related to one another.

The first of these is the little particle that forms the nucleus of an atom of hydrogen, which Rutherford called the proton. He called it the proton because it is extremely probable that all matter has been built up over a period of time by the gradual sticking together of hydrogen atoms, or of the protons which are their nuclei. A proton is the primordial substance of all, and it is, when we look out into space, the most plentiful material that exists in the universe.

These nuclei of hydrogen, called protons, are found to be one of the constituents of the nucleus of every atom. The number of protons in the nucleus determines its positive electric charge because the proton is the unit of positive electricity.

As we add more protons to the nucleus, the nucleus gets heavier and heavier, and we build what the chemists call the periodic table of the elements.

An atom with one proton in its nucleus is an atom of hydrogen. No matter how much it weighs, if it only has one proton in its nucleus, then it is an atom of hydrogen. If it has two protons in its nucleus, then it is an atom of helium. If it has 92 protons in its nucleus, it is an atom of uranium.

But we know that an atom of uranium is 238 times as heavy as an atom of hydrogen. It has only 92 protons in its nucleus, so what about the remainder of the atom which is 146 times as heavy as an atom of hydrogen? This must be matter in some form other than positively charged matter, because there are only 92 charges on the nucleus.

The answer was discovered in 1932, in the Cavendish Laboratory, when Sir James Chadwick discovered a particle which had been predicted 11 years before by Rutherford, and which Rutherford had given the name of neutron. It is actually a particle with the same mass as a hydrogen atom, but with no electric charge.

The nuclei of all atoms of matter are built up of protons and neutrons, and the atom of hydrogen contains one solitary proton in its nucleus. An atom of heavy hydrogen, or deuterium (which is very important in this atomic physics world) has one proton in its nucleus, which makes it hydrogen, plus one neutron, which makes it twice as heavy as ordinary hydrogen.

An atom of triple-heavy hydrogen, or tritium, has two neutrons in its nucleus and one proton. It is three times as heavy as ordinary hydrogen, has one electric charge on its nucleus, therefore it is hydrogen. It has all the chemical properties of hydrogen, because it has only one electron rotating about the nucleus to make it neutral.

So one can go right through the periodic table. We find that every kind of nucleus can exist in several forms, with different masses—different isotopes—of the substances, which have exactly the same chemical properties because they have the same positive charge on the nucleus and the same number of electrons rotating around it.

Now this is the picture which we have of the structure of the nuclei. The neutrons which exist inside the nucleus, and which Chadwick discovered, can be set free sometimes by hitting the nucleus with an alpha particle or by putting enough energy into the nucleus.

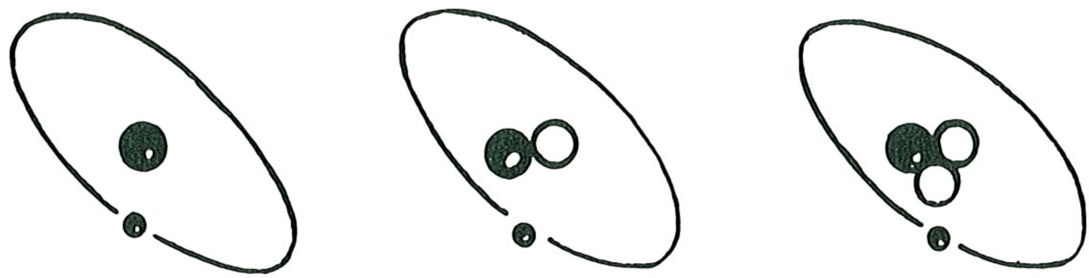
When they are set free they have very strange properties. We find that they are radioactive—that is to say, quite spontaneously, on the average after about half an hour, a neutron disappears, and in its place we have a proton, the nucleus of a hydrogen atom, and one negative electron. These together, of course, make a hydrogen bomb.

So the proton is changed into a neutron if we can stick an electron to it, and a neutron can throw out a negative electron, which is equivalent to gaining a positive charge, and will itself change into a proton.

The neutrons, in other words, when they are not inside the nucleus, are not permanent inhabitants of this world of ours, so we don't find neutrons in the atmosphere around us to any appreciable extent. Just a few are being produced by cosmic radiation all the time.

We find we can change one kind of atom to another by putting into it these little particles.

Of course, the neutron has no "handle" by which you can get hold of it. If a particle carries a positive charge of electricity, the positive charge is attracted towards a negative charge of electricity. A negatively charged



. . . An atom of hydrogen has one proton in its nucleus, an atom of deuterium has one proton and one neutron, and an atom or tritium has one proton and two neutrons.

electrode or plate will attract all the positive charges in the neighbourhood, and repel the negative charges. In other words, we can control, accelerate, deflect, and do what we like with charged particles because they carry an electrical charge.

But the neutrons having no electric charge cannot be controlled by electric or magnetic fields. The only thing we can do is to put lots of matter in the way, and to see if a neutron will collide with the nucleus of some atoms.

Most, of course, will go straight through, but occasionally one will hit a nucleus. Then what happens? It is found that the neutron is absorbed if it has a suitable, usually very low, energy.

Because it has no electric charge, it is not repelled away, as the alpha particle was, by the positive charge on the nucleus, and it just wanders inside the nucleus. There it stirs up the inside of the nucleus considerably because it carries with it a good deal of mass, which is equivalent to a good deal of energy. The nucleus becomes excited, and in general it throws out a part of itself, and an atomic transformation takes place.

Just as those nitrogen atoms were changed into oxygen atoms by Rutherford, in his first experiments, by bombarding with alpha particles, so a neutron will change one kind of atom into another. Among the most interesting reactions which the neutron can produce are those which take place in uranium when we expose it to neutrons.

Now we know there are about 92 chemical elements in this world. Some of them are rather difficult to observe, but in fact there are 92 elements and their chemical and physical properties are known. But the series of chemical elements ends abruptly at uranium, which is the heaviest and most complex of the atoms of matter which exist on this earth.

Uranium has two important isotopes, one of which is 235 times as heavy as an atom of hydrogen, and one which is 238 times as heavy as an atom of hydrogen. You've all heard the jargon of the physicist talking about U238 or U235; these are two kinds of uranium which exist in ordinary uranium.

Let's see what happens when we put neutrons into these two isotopes of uranium. The most plentiful isotope of uranium is U238, about 140 times as plentiful as U235 in ordinary uranium as we dig it out of the ground.

When a neutron enters the nucleus of the uranium isotope of mass 238, it increases the mass by one unit. Remember that uranium is element number 92, with 92 protons in the nucleus, and this uranium nucleus has 146 neutrons in it. Now we add another neutron to that nucleus.

A neutron has a mass of one — approximately the same mass as a hydrogen atom — but a zero electric charge. Because of that, we produce something that must still have 92 electric charges on it, and is therefore still uranium of charge 92, but the mass is increased now by one unit, so that it is uranium of mass 239.

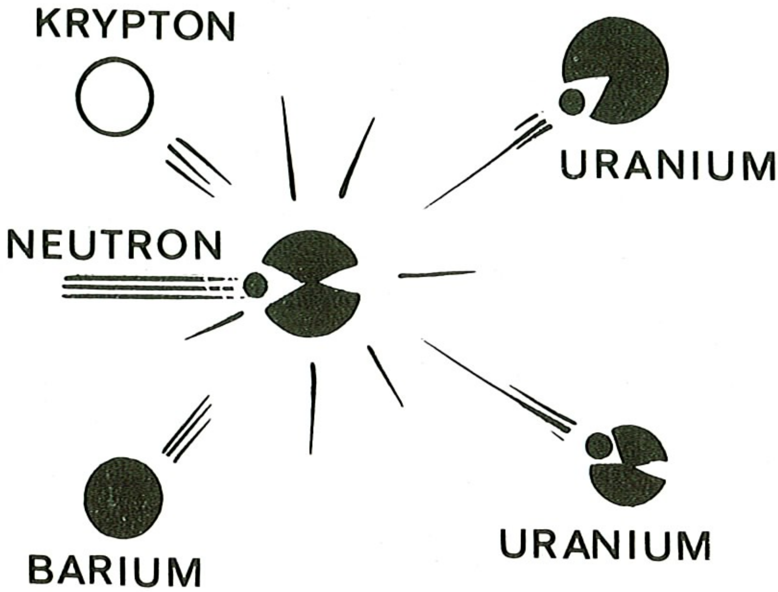
But the neutron in going into the nucleus has created a great deal of disturbance, like a small child adding the last brick to a tower of bricks. He has started building with one brick carefully on the ground — one neutron or one proton if you like — and then he adds others until he builds up an edifice which has got 92 protons in it and 146 neutrons. It is beginning to be a bit unstable.

If he now takes another brick — whether proton or neutron doesn't matter — and tries to put it on the top of this tower of bricks, the whole of the tower comes tumbling down.

This is what happens to the uranium atom. If we try to put one extra brick into the nucleus, the nucleus breaks up. It breaks up into several pieces—two large pieces which are called fission products, and also some little bits of dust, as it were, which turn out to be neutrons.

This only happens with the U238 nucleus when the neutron entering is a fast neutron. If the neutron doesn't dash in with high energy, but with very small energy, a different process takes place. This uranium of mass 239 is not so highly excited, and therefore after a few minutes, instead of falling to bits completely, just shakes off a little bit of itself —a negative electron.

As it throws out a negative electron, it must gain a positive charge. This means that one of the neutrons in that nucleus has changed into a proton, and an electron has been thrown



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out. So it has become a new chemical element — a chemical element with 93 protons in the nucleus, called neptunium, which has a charge of 93 and mass 239 because the mass of the electron which has disappeared is small.

This substance, neptunium, is still not quite happy, and does not live very long. It throws out another electron and changes into a substance, which we call plutonium, which also has a mass of 239, but has 94 protons in its nucleus.

This is the alternative process to fission, and happens in U238 when the neutrons are slow. Uranium 235 almost always splits into two pieces when a neutron is added, with the release of a large amount of energy — about three million times the energy released in a chemical action—and this energy appears as energy of motion of the fragments, which go out with high energy like bullets and which move in opposite directions.

Between two and three neutrons escape from these fragments as they move through space. The neutrons have an energy of about a million volts, which is a moderately high energy, but it is not a high enough energy to cause fission in U238.

Thus, if we have a mass of ordinary uranium, and the fission process takes place in one of the U235 atoms, the neutrons that are set free will wander out through the uranium. Most of them will be captured in U238, and the process will die away.

But suppose we have a mass of U235, which is big enough for the neutrons which are set free in fission near the centre of the mass to be absorbed on their way out through the mass of material. Such a mass of material needn't be very big — about as big as a grapefruit. When fission takes place near the middle, the neutrons set free in the fission will themselves go into other uranium nuclei and produce fission.

One neutron begins the fission in the first instance, producing two neutrons. They in turn will split two atoms, so producing four neutrons, which will split four atoms and so the process grows at catastrophic speed.

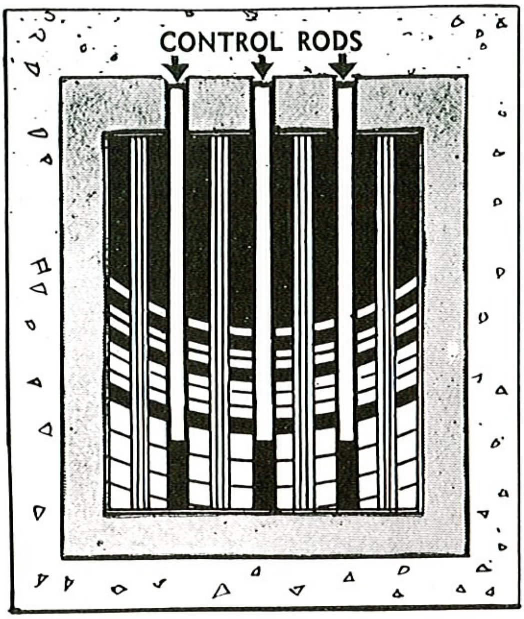
Because the neutrons are moving fast, the process of buildup takes only about one millionth of a second, and an enormous quantity of energy is set free in the process. This is the ordinary atomic bomb.

Alternatively, we could say to ourselves: "Let's trick the uranium 238, which would capture the neutrons which come out. Let's surround our piece of uranium with some material like water, particularly heavy water, or graphite (carbon)."

The neutrons coming into these materials will collide with the nuclei of the atoms of carbon, or with the deuterium nuclei. These particular nuclei will not readily absorb neutrons, and so they are bounced off. In the process of bouncing off, they lose some of their energy. The neutrons that go into this surrounding material, which we call the moderator, will be slowed down.

When they wander back into the uranium, they'll be slow neutrons, and will preferentially seek out the U235, producing the fission process. The very slow neutrons will ignore the U238, which can only absorb neutrons when they have particular velocities.

So in that way one may produce a nuclear reactor. Because the neutrons spend a considerable time wandering around in the water or the graphite, the process of buildup, instead of being an instantaneous chain reaction, will be slow. We can keep the whole process under control by inserting into the midst of the mass of uranium and graphite, or other moderator, some rods of material like boron and cadmium, or similar substances which



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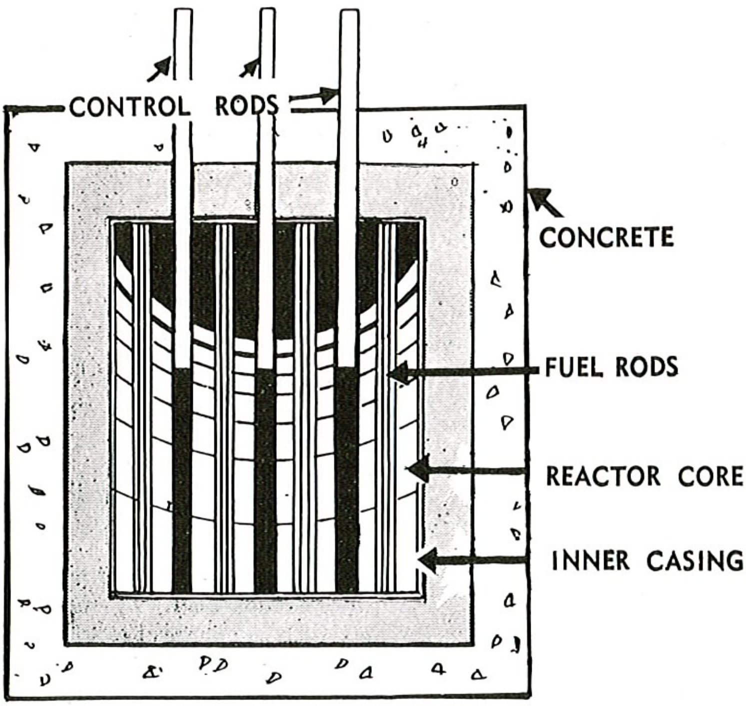

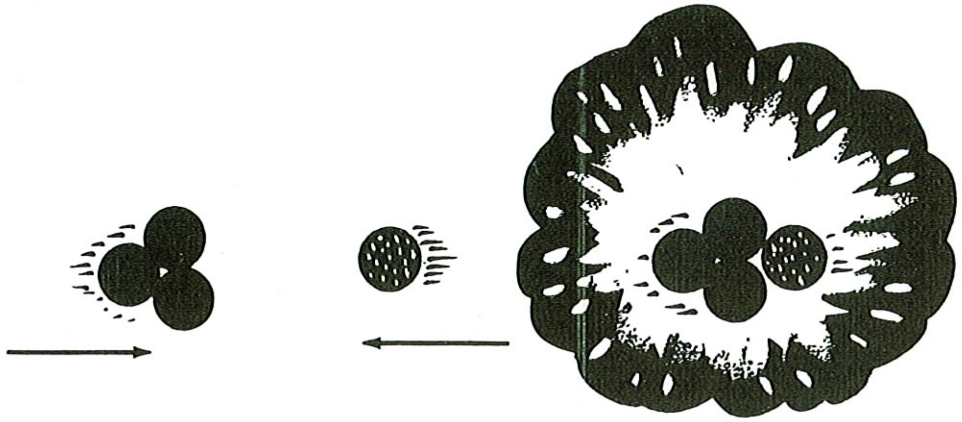

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readily absorb neutrons and take them out of circulation.

We thus have now two possibilities with our uranium. We can produce fission in an uncontrolled manner in atomic weapons, or in a controlled manner with the release of atomic energy for industrial purposes.

Lastly, we have just a few words to say about other ways in which we might hope in the future to produce atomic energy from matter.

We know that the sun keeps hot because it manufactures heavier substances out of very light elements like hydrogen. We believe that we should be able to get atomic energy on earth by combining hydrogen atoms together to make heavier atoms, but we don't quite know how to bring this process about. We know how to bring it about explosively in the hydrogen bomb, which I'm not going to discuss in detail, but we don't yet know how to bring it about in a controllable manner as a source of power for ourselves.

It is improbable that we shall ever be able to produce power by the fusion of ordinary hydrogen, as does the sun. However, it does seem possible that by passing very powerful electric discharges through deuterium, or heavy hydrogen, under the right conditions, the nuclei might combine to give helium, releasing large amounts of energy.

One pound of deuterium, undergoing fusion to helium, would release 10 times as much energy as one pound of uranium undergoing fission, or 30 million times as much energy as is released when one pound of coal is burned. This is the goal of research into thermonuclear reactions which is now pursued by men of science all over the world.

In the future, if we can find out how to bring about these thermonuclear or fusion reactions, we will have before us an inexhaustible source of power. The sea contains about 1 part in 6,000 of heavy hydrogen, which could provide every man, women and child in the world with more power than they could possibly need for ever—certainly for thousands of millions of years.

Finally, I would like to say something to you about the excitement of the great quest of exploration in which the scientists are engaged in an effort to understand nature.

We have seen how, slowly, over the years, knowledge of the atomic nucleus has accumulated. This has resulted in the release of atomic energy, which we can use for peaceful purposes, and which gives us unlimited power for the future — really unlimited power which will deprive mankind of all drudgery, of all need, of all want of every kind, if it is properly used with the other results of science.

On the other hand, we can see that if mankind chooses to take the wrong path, he could very easily use this great new knowledge which we possess to destroy himself. He could not only destroy by killing people, but he could destroy by so damaging the human race by radiations which are associated with atomic weapons, that humanity never recovers.

You who are young have before you the exciting prospect not only of solving this problem, which lies before us—it is largely a political problem—but you have before you also the exciting world of science.

Our real knowledge of matter, of nature, is only just beginning. You are those who are lucky enough to participate in the further exploration of the regions of knowledge of nature which mean so much for the future of mankind.

If you are at all interested in these things, if you feel at all attracted to the adventures of the mind, then I implore you to become scientists and follow the lead of men like Rutherford and Einstein, whose work has led to these great results which we have considered in this talk.

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