VIII
FOUNDATIONS OF THE UNIVERSE

THE WORLD OF ATOMS

MOST people have heard of the oriental race which puzzled over the foundations of the universe, and decided that it must be supported on the back of a giant elephant. But the elephant ? They put it on the back of a monstrous tortoise, and there they let the matter end. If every animal in nature had been called upon, they would have been no nearer a foundation. Most ancient peoples, indeed, made no effort to find a foundation. The universe was a very compact little structure, mainly composed of the earth and the great canopy over the earth which they called the sky. They left it, as a whole, floating in nothing. And in this the ancients were wiser than they knew. Things do not fall down unless they are pulled down by that mysterious force which we call gravitation. The earth, it is true, is pulled by the sun, and would fall into it ; but the earth escapes this fiery fate by circulating at great speed round the sun. The stars pull each other ; but it has already been explained that they meet this by travelling rapidly in gigantic orbits. Yet we do, in a new sense of the word, need foundations of the universe. Our mind craves for some explanation of the matter out of which the universe is made. For this explanation we turn to modern Physics and Chemistry. Both these sciences study, under different aspects, matter and energy ; and between them they have put together a conception of the fundamental nature of things which marks an epoch in the history of human thought.

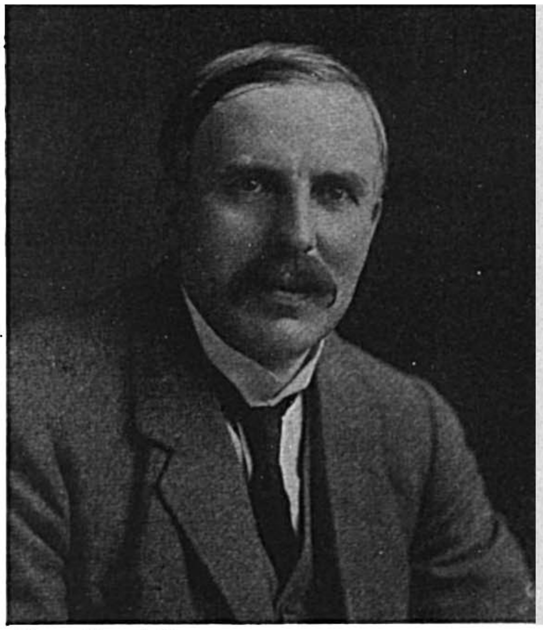


Photo : Elliott & Fry.

SIR ERNEST RUTHERFORD.

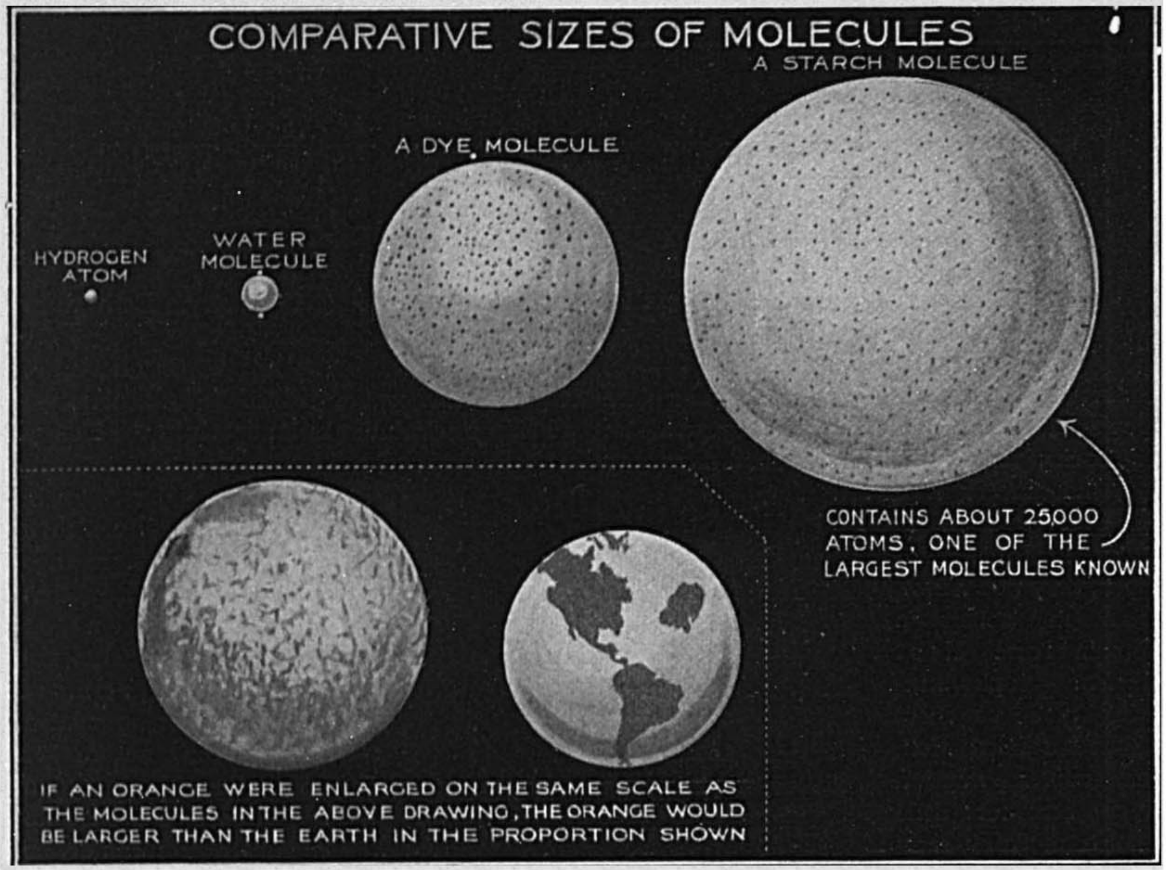
One of our most eminent physicists, who has succeeded Sir J. J. Thomson as Cavendish Professor of Physics at the University of Cambridge. The modern theory of the structure of the atom is largely due to him.

§ 1

The Bricks of the Cosmos.

More than two thousand years ago the first men of science, the Greeks of the cities of Asia Minor, speculated on the nature of matter. You can grind a piece of stone into dust. You can divide a spoonful of water into as many drops as you like. Apparently you can go on dividing as long as you have got apparatus fine enough for the work. But there must be a limit, these Greeks said, and so they supposed that all matter was ultimately composed of minute particles which were indivisible. That is the meaning of the Greek word " atom."

Like so many other ideas of these brilliant early Greek thinkers, the atom was a sound conception. We know to-day that matter is composed of atoms. But science was then so young that the way in which the Greeks applied the idea was not very profound. A liquid or a gas, they said, consisted of round, smooth atoms, which would not cling together. Then



An atom is the smallest particle of a chemical element. Two or more atoms come together to form a molecule: thus molecules form the mass of matter. A molecule of water is made up of two atoms of hydrogen and one atom of oxygen. Molecules of different substances, therefore, are of different sizes according to the number and kind of the particular atoms of which they are composed. A starch molecule contains no less than 25,000 atoms.

Molecules, of course, are invisible. The above diagram illustrates the *comparative* sizes of molecules.

there were atoms with rough surfaces, "hooky" surfaces, and these stuck together and formed solids. The atoms of iron or marble, for instance, were so very hooky that, once they got together, a strong man could not tear them apart. The Greeks thought that the explanation of the universe was that an infinite number of these atoms had been moving and mixing in an infinite space during an infinite time, and had at last hit by chance on the particular combination which is our universe.

This was too simple and superficial. The idea of atoms was cast aside, only to be advanced again in various ways. It was the famous Manchester chemist, John Dalton, who restored it in the early years of the nineteenth century. He first definitely formulated the atomic theory as a scientific hypothesis. The whole physical and chemical science of that century was now based upon the atom, and it is quite a mistake to suppose that recent discoveries have discredited "atomism." An atom is the smallest particle of a chemical element. No one has ever seen an atom. Even the wonderful new microscope which has just been invented cannot possibly show us particles of matter which are a million times smaller than the breadth of a hair; for that is the size of atoms. We can weigh them and measure them, though they are invisible, and we know that all matter is composed of them. It is a new discovery that atoms are not indivisible. They consist themselves of still smaller particles, as we shall see. But the atoms exist all the same, and we may still say that they are the bricks of which the material universe is built.

But if we had some magical glass by means of which we could see into the structure of material things, we should not see the atoms put evenly together as bricks are in a wall. As a rule, two or more atoms first come together to form a larger particle, which we call a "molecule." Single atoms do not, as a rule, exist apart from other atoms; if a molecule is broken up, the individual atoms seek to unite with other atoms of another kind or amongst themselves. For example, three atoms of oxygen form what we call ozone; two atoms of hydrogen uniting with one atom of oxygen form water. It is molecules that form the mass of matter; a molecule, as it has been expressed, is a little building of which atoms are the bricks.

In this way we get a useful first view of the material things we handle. In a liquid the molecules of the liquid cling together loosely. They remain together as a body, but they roll over and away from each other. There is "cohesion" between them, but it is less powerful than in a solid. Put some water in a kettle over the lighted gas, and presently the tiny molecules of water will rush through the spout in a cloud of steam and scatter over the kitchen. The heat has broken their bond of association and turned the water into something like a gas; though we know that the particles will come together again, as they cool, and form once more drops of water.

In a gas the molecules have full individual liberty. They are in a state of violent movement, and they form no union with each other. If we want to force them to enter into the loose sort of association which molecules have in a liquid, we have to slow down their individual movements by applying severe cold. That is how a modern man of science liquefies gases. No power that we have will liquefy air at its ordinary temperature. In *very* severe cold, on the other hand, the air will spontaneously become liquid. Some day, when the fires of the sun have sunk very low, the temperature of the earth will be less than −200° C.: that is to say, more than two hundred degrees Centigrade below freezing-point. It will sink to the temperature of the moon. Our atmosphere will then be an ocean of liquid air, 35 feet deep, lying upon the solidly frozen masses of our water-oceans.

In a solid the molecules cling firmly to each other. We need a force equal to twenty-five tons to tear asunder the molecules in a bar of iron an inch thick. Yet the structure is not "solid" in the popular sense of the word. If you put a piece of solid gold in a little pool of mercury, the gold will take in the mercury *between* its molecules, as if it were porous like a sponge. The hardest solid is more like a lattice-work than what we usually mean by "solid"; though the molecules are not fixed, like the bars of a lattice-work, but are in violent motion; they vibrate about equilibrium positions. If we could see right into the heart of a bit of the hardest steel, we should see billions of separate molecules, at some distance from each other, all moving rapidly to and fro.

This molecular movement can, in a measure, be made visible. It was noticed by a microscopist named Brown that, in a solution containing very fine suspended particles,

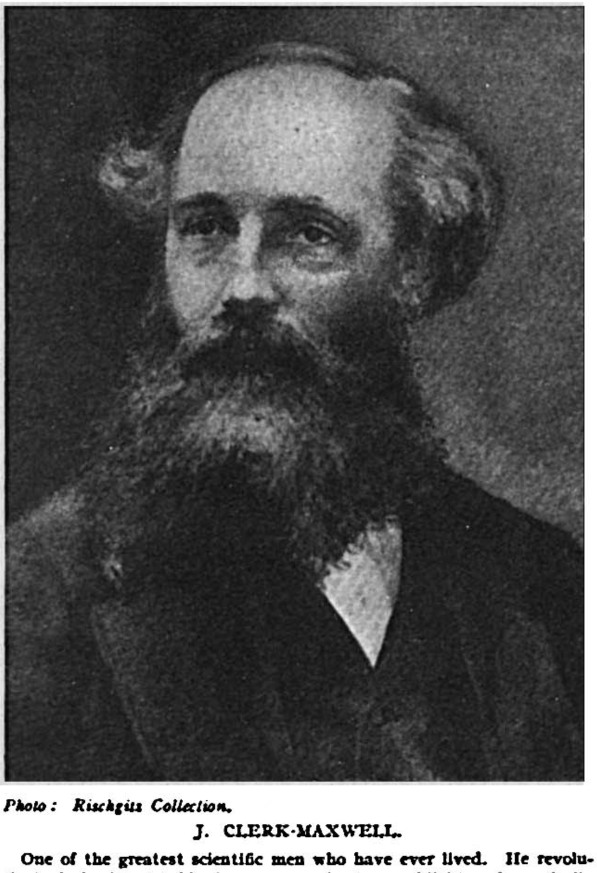
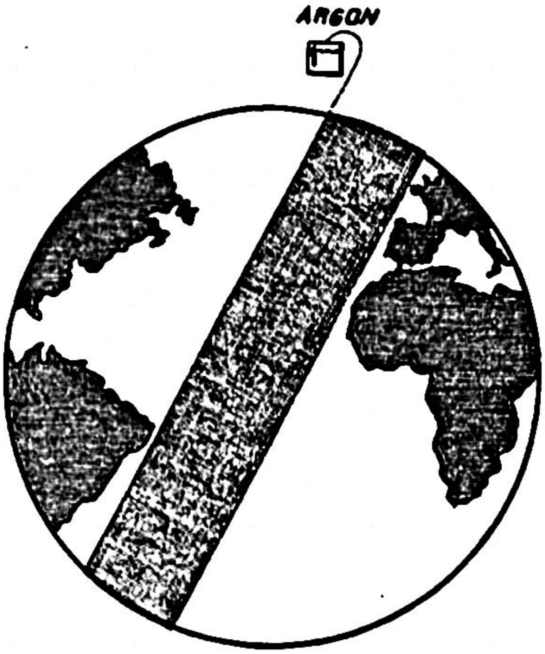


Photo: Rischgitz Collection.

J. CLERK-MAXWELL.

One of the greatest scientific men who have ever lived. He revolutionised physics with his electro-magnetic theory of light, and practically all modern researches have had their origin, direct or indirect, in his work. Together with Faraday he constitutes one of the main scientific glories of the nineteenth century.

the particles were in constant movement. Under a powerful microscope these particles are seen to be violently agitated; they are each independently darting hither and thither somewhat like a lot of billiard balls on a billiard table, colliding and bounding about in all directions. Thousands of times a second these encounters occur, and this lively commotion is always going on, this incessant colliding of one molecule with another is the normal condition of affairs; not one of them is at rest. The reason for this has been worked out, and it is now known



INCONCEIVABLE NUMBERS AND INCONCEIVABLY SMALL PARTICLES.

The molecules, which are inconceivably small, are, on the other hand, so numerous that if one was able to place, end to end, all those which are contained in, for example, a cubic centimetre of gas (less than half a cubic inch), one would obtain a line capable of passing two hundred times round the earth.

that these particles move about because they are being incessantly bombarded by the molecules of the liquid. The molecules cannot, of course, be seen, but the fact of their incessant movement is revealed to the eye by the behaviour of the visible suspended particles. This incessant movement in the world of molecules is called the Brownian movement, and is a striking proof of the reality of molecular motions.

§ 2

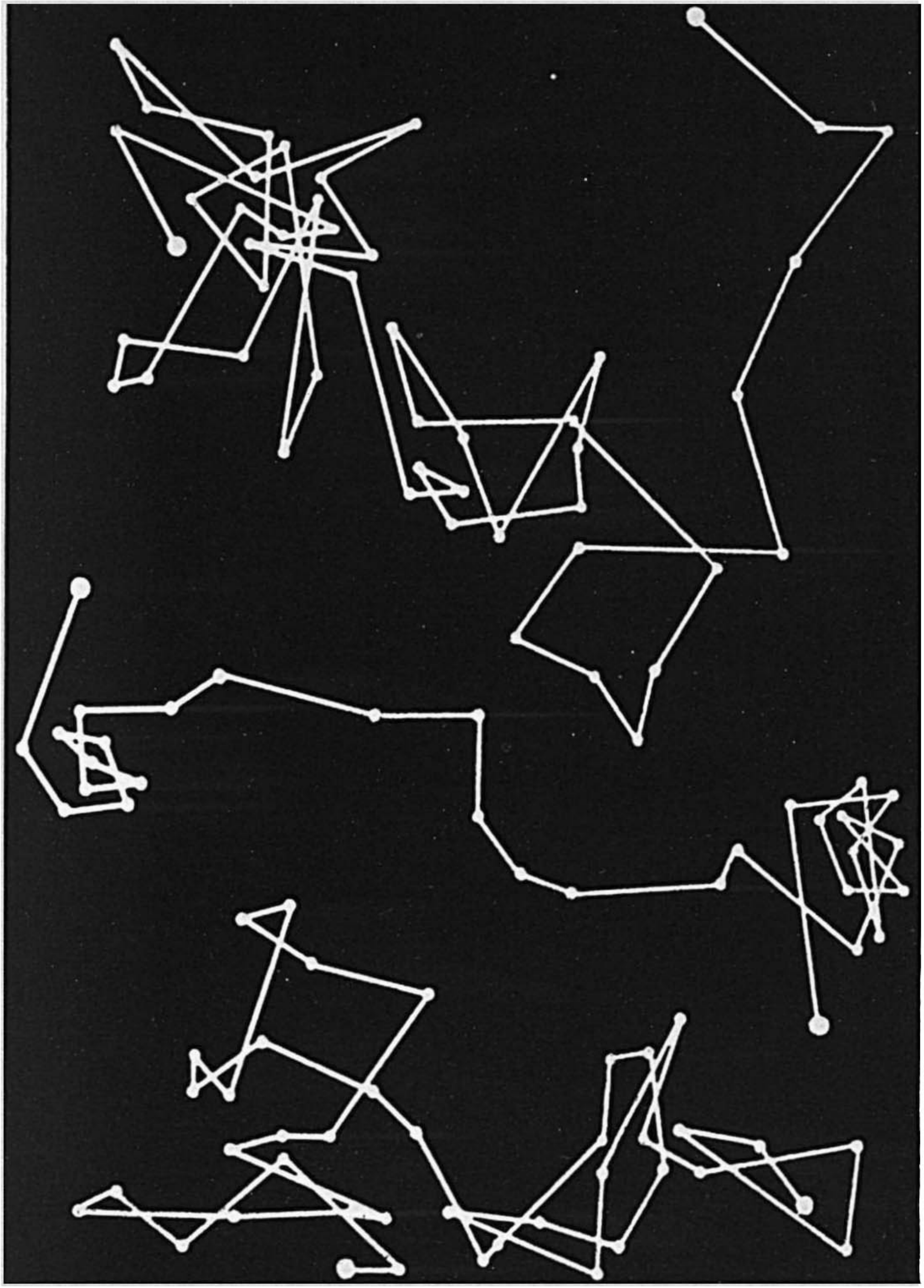
The exploration of this wonder-world of atoms and molecules by the physicists and chemists of to-day is one of the most impressive triumphs of modern science. Quite apart from radium and electrons and other sensational discoveries of recent years, the study of ordinary matter is hardly inferior, either in interest or audacity, to the work of the astronomer. And there is the same foundation in both cases—marvellous apparatus, and trains of mathematical reasoning that would have astonished Euclid or Archimedes. Extraordinary, therefore, as are some of the facts and figures we are now going to give in connection with the minuteness of atoms and molecules, let us bear in mind that we owe them to the most solid and severe processes of human thought.

The Wonder-World of Atoms.

Yet the principle can in most cases be made so clear that the reader will not be asked to take much on trust. It is, for instance, a matter of common knowledge that gold is soft enough to be beaten into gold leaf. It is a matter of common sense, one hopes, that if you beat a measured cube of gold into a leaf six inches square, the mathematician can tell the thickness of that leaf without measuring it. As a matter of fact, a single grain of gold has been beaten into a leaf seventy-five inches square. Now the mathematician can easily find that when a single grain of gold is beaten out to that size, the leaf must be $\frac{1}{367,000}$ of an inch thick, or about a thousand times thinner than the paper on which these words are printed; yet the leaf must be several molecules thick.

The finest gold leaf is, in fact, too thick for our purpose, and we turn with a new interest to that toy of our boyhood, the soap-bubble. If you carefully examine one of these delicate films of soapy water, you notice certain dark spots or patches on them. These are their thinnest parts, and by two quite independent methods—one using electricity and the other light—we have found that at these spots the bubble is less than the three-millionth of an inch thick! But the molecules in the film cling together so firmly that they must be at least twenty or thirty deep in the thinnest part. A molecule, therefore, must be far less than the three-millionth of an inch thick.

We found next that a film of oil on the surface of water may be even thinner than a soap-bubble. Professor Perrin, the great French

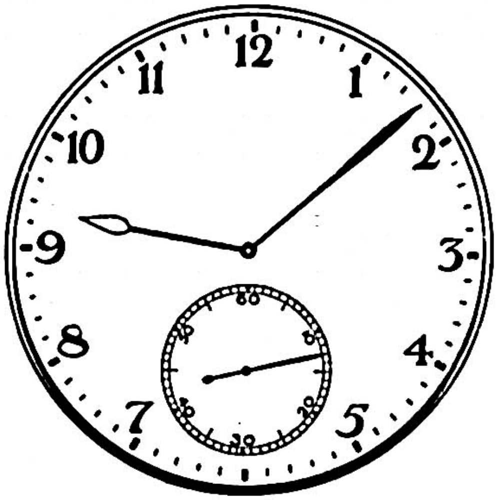


THE BROWNIAN MOVEMENT.

A diagram, constructed from actual observations, showing the erratic paths pursued by very fine particles suspended in a liquid, when bombarded by the molecules of the liquid. This movement is called the Brownian movement, and it furnishes a striking illustration of the truth of the theory that the molecules of a body are in a state of continual motion.

authority on atoms, got films of oil down to the fifty-millionth of an inch in thickness! He poured a measured drop of oil upon water. Then he found the exact limits of the area of the oil-sheet by blowing upon the water a fine powder which spread to the edge of the film and clearly outlined it. The rest is safe and simple calculation, as in the case of the beaten grain of gold. Now this film of oil must have been at least two molecules deep, so a single molecule of oil is considerably less than a hundred-millionth of an inch in diameter.

Innumerable methods have been tried, and



WHAT IS A MILLION?

In dealing with the infinitely small, it is difficult to apprehend the vast figures with which scientists confront us. A million is one thousand thousand. We may realise what this implies if we consider that a clock beating seconds takes approximately 278 hours (i.e. one week four days fourteen hours) to tick one million times. A billion is one million million. To tick a billion the clock would tick for over 31,733 years.

(In France and America a thousand millions is called a billion.)

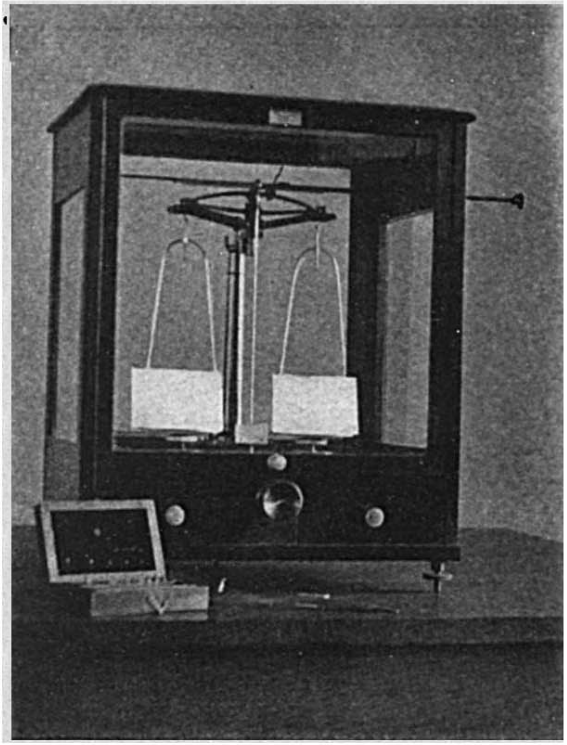
the result is always the same. A single grain of indigo, for instance, will colour a ton of water. This obviously means that the grain contains billions of molecules which spread through the water. A grain of musk will scent a room—pour molecules into every part of it—for several years, yet not lose one-millionth of its mass in a year. There are a hundred ways of showing the minuteness of the ultimate particles of matter, and some of these enable us to give definite figures. On a careful comparison of the best methods we can say that the average molecule of matter is less than the $\frac{1}{125,000,000}$ of an inch in diameter. In a single cubic centimetre of air—a globule about the size of a small marble—there are thirty million billion molecules. And since the molecule is, as we saw, a group or cluster of atoms, the atom itself is smaller. Atoms, for reasons which we shall see later, differ very greatly from each other in size and weight. It is enough to say that some of them are so small that it would take 400,000,000 of them, in a line, to cover an inch of space; and that it takes at least a trillion atoms of gold to weigh a single gramme. Five million atoms of helium could be placed in a line across the diameter of a full stop.

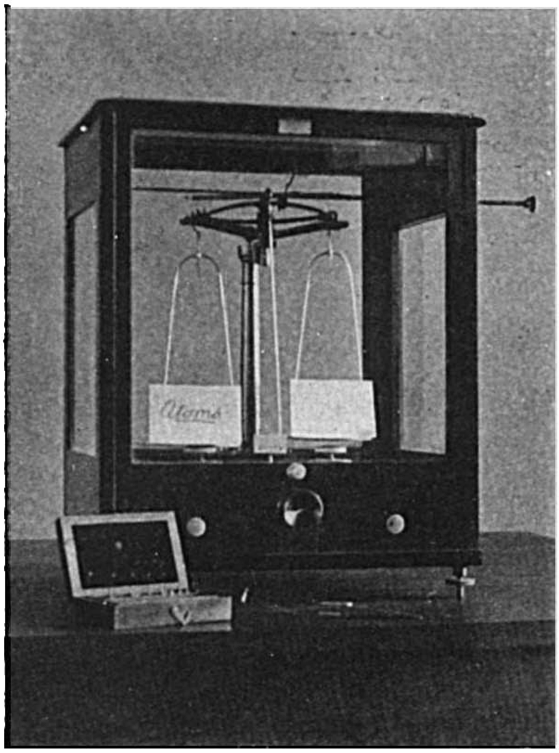
And this is only the beginning of the wonders that were done with "ordinary matter," quite apart from radium and its revelations, to which we will come presently.

The Energy of Atoms.

Most people have heard of "atomic energy," and the extraordinary things that might be accomplished if we could harness this energy and turn it to human use. A deeper and more wonderful source of this energy has been discovered in the last twenty years, but it is well to realise that the atoms themselves have stupendous energy. The atoms of matter are vibrating or gyrating with extraordinary vigour. The piece of cold iron you hold in your hand, the bit of brick you pick up, or the penny you take from your pocket is a colossal reservoir of energy, since it consists of billions of moving atoms. To realise the total energy, of course, we should have to witness a transformation such as we do in atoms of radio-active elements, about which we shall have something to say presently.

If we put a grain of indigo in a glass of water, or a grain of musk in a perfectly still room, we soon realise that molecules travel. Similarly, the fact that gases spread until they fill every "empty" available space shows definitely that they consist of small particles travelling at great speed. The physicist brings his refined methods to bear on these things, and he measures the energy and velocity of these infinitely minute molecules. He tells us that molecules of oxygen, at the temperature of melting ice, travel at the rate of about 500 yards a second—more than a quarter of a mile a second. Molecules of hydrogen travel at four times that speed, or three times the speed with which a bullet leaves a rifle. Each





From "Scientific Ideas of To-day."

DETECTING A SMALL QUANTITY OF MATTER.

In the left-hand photograph the two pieces of paper exactly balance. The balance used is very sensitive, and when the single word "atoms" has been written with a lead pencil upon one of the papers the additional weight is sufficient to depress one of the pans, as shown in the second photograph. The spectroscope will detect less than one-millionth of the matter contained in the word pencilled above.

molecule of the air, which seems so still in the house on a summer's day, is really travelling faster than a rifle bullet does at the beginning of its journey. It collides with another molecule every twenty-thousandth of an inch of its journey. It is turned from its course 5,000,000,000 times in every second by collisions. If we could stop the molecules of hydrogen gas, and utilise their energy, as we utilise the energy of steam or the energy of the water at Niagara, we should find enough in every gramme of gas (about two-thousandths of a pound) to raise a third of a ton to a height of forty inches.

I have used for comparison the speed of a rifle bullet, and in an earlier generation people would have thought it impossible even to estimate this. If is, of course, easy. We put two screens in the path of the bullet, one near the rifle and the other some distance away. We connect them electrically and use a fine time-recording machine, and the bullet itself registers the time it takes to travel from the first to the second screen.

Now this is very simple and superficial work in comparison with the system of exact and minute measurements which the physicist and chemist use. In one of his interesting works Mr. Charles R. Gibson gives a photograph of two exactly equal pieces of paper in the opposite pans of a fine balance. A single word has been written in pencil on one of these papers, and that little scraping of lead has been enough to bring down the scale! The spectroscope will detect a quantity of matter four million times smaller even than this; and the electroscope is a million times still more sensitive than the spectroscope. We have a heat-measuring instrument, the bolometer, which makes the best thermometer seem Early Victorian. It records the millionth of a degree of temperature. It is such instruments, multiplied by the score, which enable us to do the fine work recorded in these pages.

§ 3
THE DISCOVERY OF X-RAYS AND RADIUM

The Discovery of Sir Wm. Crookes.

But these wonders of the atom are only a prelude to the more romantic and far-reaching discoveries of the new physics—the wonders of the electron. Another and the most important phase of our exploration of the material universe opened with the discovery of radium in 1898.

In the discovery of radio-active elements, a new property of matter was discovered. What followed on the discovery of radium and of the X-rays we shall see.

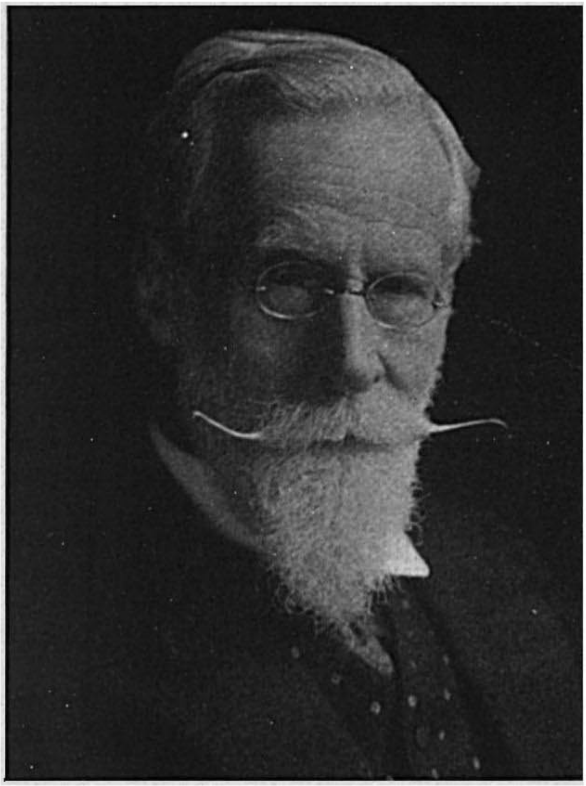


Photo: Ernest H. Mills.

SIR WILLIAM CROOKES.

Sir William Crookes experimented on the electric discharge in vacuum tubes and described the phenomena as a "fourth state of matter." He was actually observing the flight of electrons, but he did not fully appreciate the nature of his experiments.

As Sir Ernest Rutherford, one of our greatest authorities, recently said, the new physics has dissipated the last doubt about the reality of atoms and molecules. The closer examination of matter which we have been able to make shows positively that it is composed of atoms. But we must not take the word now in its original Greek meaning (an "indivisible" thing). The atoms are not indivisible. They can be broken up. They are composed of still smaller particles.

The discovery that the atom was composed of smaller particles was the welcome realisation of a dream that had haunted the imagination of the nineteenth century. Chemists said that there were about eighty different kinds of atoms—different kinds of matter—but no one was satisfied with the multiplicity. Science is always aiming at simplicity and unity. It may be that science has now taken a long step in the direction of explaining the fundamental unity of all matter. The chemist was unable to break up these "elements" into something simpler, so he called their atoms "indivisible" in that sense. But one man of science after another expressed the hope that we would yet discover some fundamental matter of which the various atoms were composed—*one primordial substance from which all the varying forms of matter have been evolved or built up.* Prout suggested this at the very beginning of the century, when atoms were rediscovered by Dalton. Father Secchi, the famous Jesuit astronomer, said that all the atoms were probably evolved from ether; and this was a very favoured speculation. Sir William Crookes talked of "prothyl" as the fundamental substance. Others thought hydrogen was the stuff out of which all the other atoms were composed.

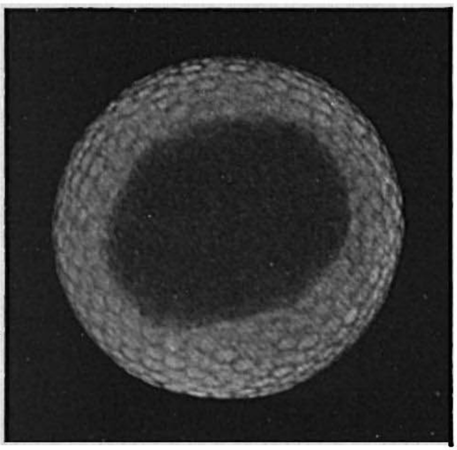


Photo: National Physical Laboratory.

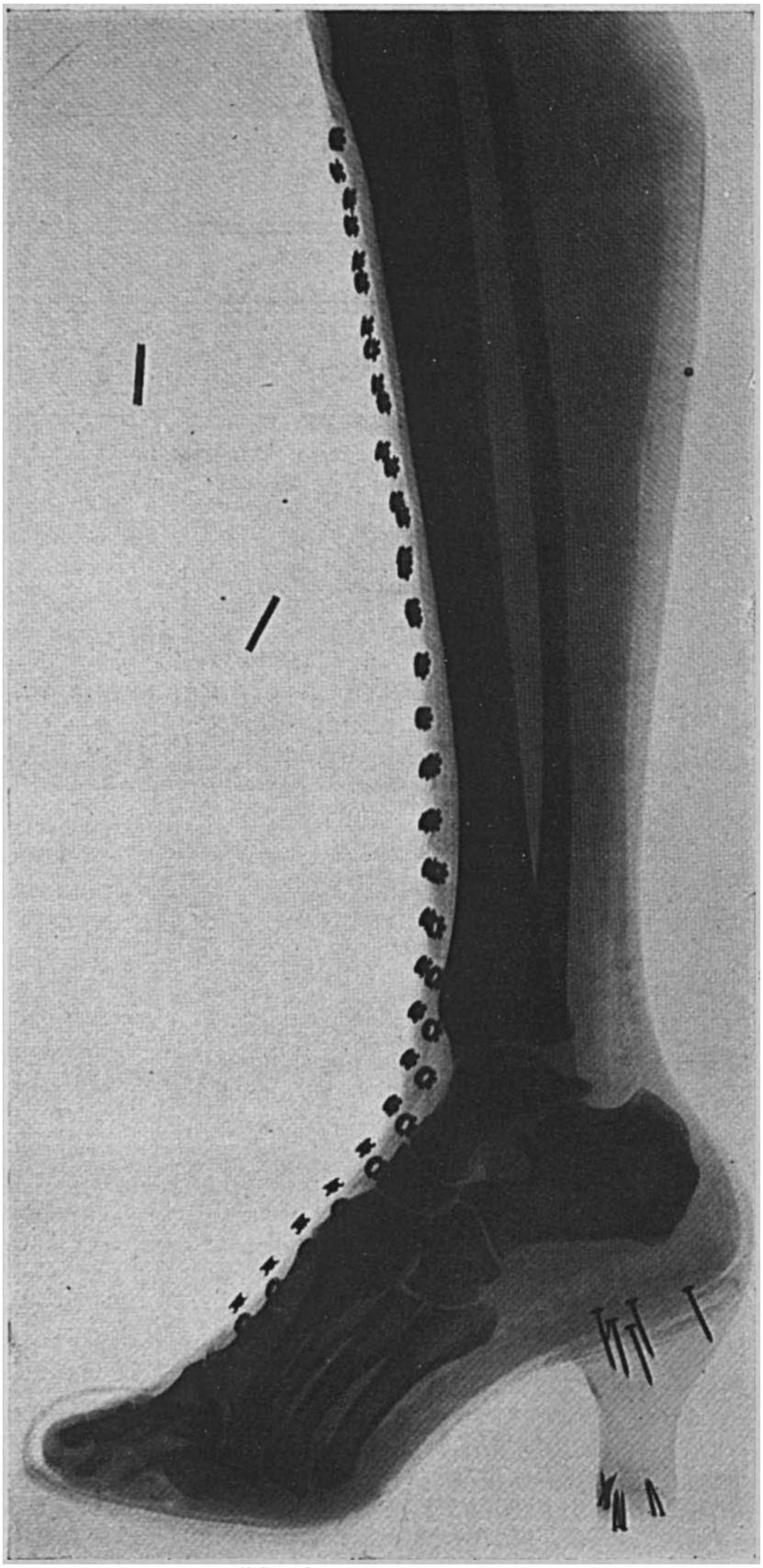
AN X-RAY PHOTOGRAPH OF A GOLF BALL, REVEALING AN IMPERFECT CORE.

The work which finally resulted in the discovery of radium began with some beautiful experiments of

Professor (later Sir William) Crookes in the eighties.

It had been noticed in 1869 that a strange colouring was caused when an electric charge was sent through a vacuum tube—the walls of the glass tube began to glow with a greenish phosphorescence. A vacuum tube is one from which nearly all the air has been pumped, although we can never completely empty the tube. Crookes used such ingenious methods that he reduced the gas in his tubes until it was twenty million times thinner than the atmosphere. He then sent an electric discharge through, and got very remarkable results. The negative pole of the electric current (the "cathode") *gave off rays which faintly lit the molecules of the thin gas in the tube*, and caused a pretty fluorescence on the glass walls of the tube. What were these rays? Crookes at first thought they corresponded to a "new or fourth state of matter." Hitherto we had only been familiar with matter in the three conditions of solid, liquid, and gaseous.

Now Crookes really had the great secret under his eyes. But about twenty years elapsed before the true nature of these rays was finally and independently established by various experiments. The experiments proved "that the rays consisted of a stream of negatively charged particles travelling with enormous velocities from 10,000 to 100,000 miles a second. In addition, it was found that the mass of each particle was exceedingly small, about $\frac{1}{1800}$ of the mass of a hydrogen atom,



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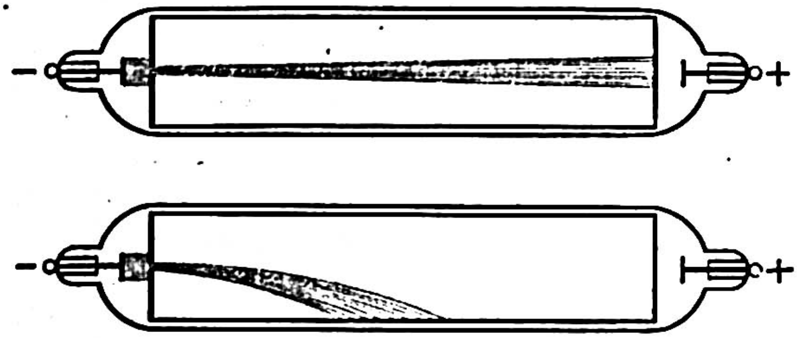
A WONDERFUL X-RAY PHOTOGRAPH.

Note the fine details revealed, down to the metal tags of the bootlace and the nails in the heel of the boot.

the lightest atom known to science." *These particles or electrons, as they are now called,*



ELECTRIC DISCHARGE IN A VACUUM TUBE.

The two ends, marked + and —, of a tube from which nearly all air has been exhausted are connected to electric terminals, thus producing an electric discharge in the vacuum tube. This discharge travels straight along the tube, as in the upper diagram. When a magnetic field is applied, however, the rays are deflected, as shown in the lower diagram. The similarity of the behaviour of the electric discharge with the radium rays (see illustration on page 191) shows that the two phenomena may be identified. It was by this means that the characteristics of electrons were first discovered.

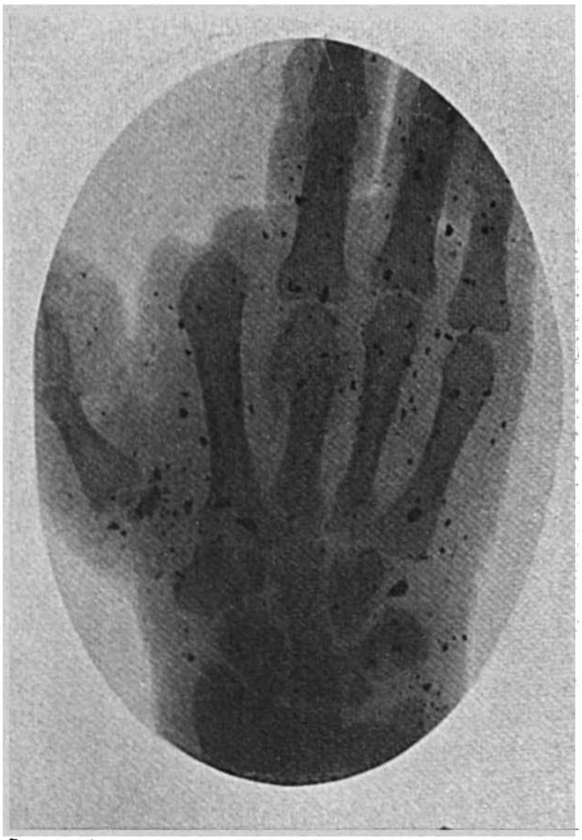
were being liberated from the atom. The atoms of matter were breaking down in Crookes tubes. At that time, however, it was premature to think of such a thing, and Crookes preferred to say that the particles of the gas were electrified and hurled against the walls of the tube. He said that it was ordinary matter in a new state—" radiant matter." Another distinguished man of science, Lenard, found that, when he fitted a little plate of aluminium in the glass wall of the tube, the mysterious rays passed through this as if it were a window. They must be waves in the ether, he said.

§ 4

So the story went on from year to year. We shall see in a moment to what it led.

The Discovery of X-rays.

Meanwhile the next great step was when, in 1895, Röntgen discovered the X-rays, which are now known to everybody. He was following up the work of Lenard, and he one day covered a " Crookes tube " with some black stuff. To his astonishment a prepared chemical screen which was near the tube began to glow. *The rays had gone through the black stuff; and on further experiment he found that they would go through stone, living flesh, and all sorts of " opaque " substances.* In a short time the world was astonished to learn that we could photograph the skeleton in a living man's body, locate a penny in the interior of a child that had



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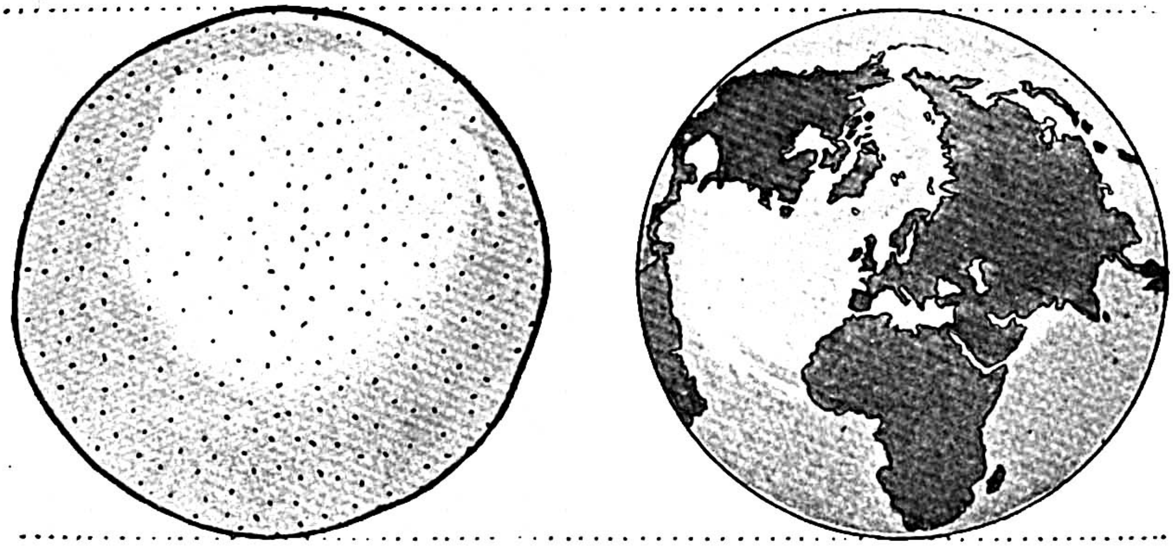
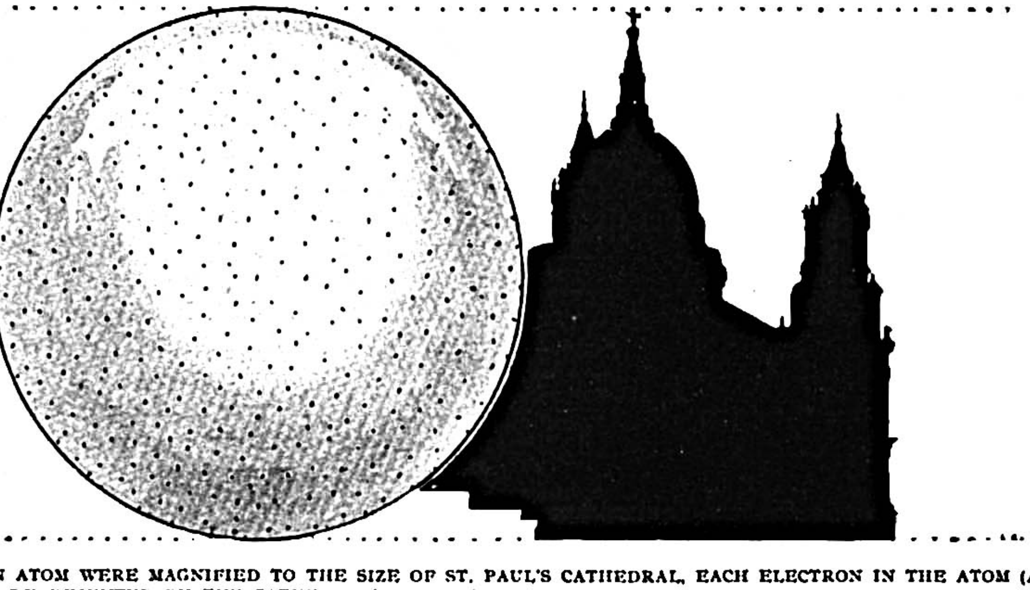
THIS X-RAY PHOTOGRAPH IS THAT OF A HAND OF A SOLDIER WOUNDED IN THE GREAT WAR.

Note the pieces of shrapnel which are revealed.



THE RELATIVE SIZES OF ATOMS AND ELECTRONS.

An atom is far too small to be seen. In a bubble of hydrogen gas no larger than the letter "O" there are billions of atoms, whilst an electron is more than a thousand times smaller than the smallest atom. How their size is ascertained is described in the text. In this diagram a bubble of gas is magnified to the size of the world. Adopting this scale, *each atom* in the bubble would then be as large as a tennis ball.



IF AN ATOM WERE MAGNIFIED TO THE SIZE OF ST. PAUL'S CATHEDRAL, EACH ELECTRON IN THE ATOM (AS REPRESENTED BY THE CATHEDRAL) WOULD THEN BE ABOUT THE SIZE OF A SMALL BULLET.

swallowed one, or take an impression of a coin through a slab of stone.

And what are these X-rays? They are not a form of matter; they are not material particles. X-rays were found to be a new variety of *light* with a remarkable power of penetration. We have seen what the spectroscope reveals about the varying nature of light wave-lengths. Light-waves are set up by vibrations in ether,[1] and, as we shall see,

[1] We refer throughout to the "ether" because, although modern theories dispense largely with this conception, the theories of physics are so inextricably interwoven with it that it is necessary, in an elementary exposition, to assume its existence. The modern view will be explained later in the article on Einstein's Theory.

these ether disturbances are all of the same kind; they only differ as regards wave-lengths. The X-rays which Röntgen discovered, then, are light, but a variety of light previously unknown to us; they are ether waves of very short length. X-rays have proved of great value in many directions, as all the world knows, but that we need not discuss at this point. Let us see what followed Röntgen's discovery.

While the world wondered at these marvels, the men of science were eagerly following up the new clue to the mystery of matter which was exercising the mind of Crookes and other investigators. In 1896 Becquerel brought us to the threshold of the great discovery.

Certain substances are phosphorescent--they become luminous after they have been exposed to sunlight for some time, and Becquerel was trying to find if any of these substances give rise to X-rays. One day he chose a salt of the metal uranium. He was going to see if, after exposing it to sunlight, he could photograph a cross with it through an opaque substance. He wrapped it up and laid it aside, to wait for the sun, but he found the uranium salt did not wait for the sun. Some strong radiation from it went through the opaque covering and made an impression of the cross upon the plate underneath. Light or darkness was immaterial. The mysterious rays streamed night and day from the salt. This was something new. Here was a substance which appeared to be producing X-rays; the rays emitted by uranium would penetrate the same opaque substances as the X-rays discovered by Röntgen.

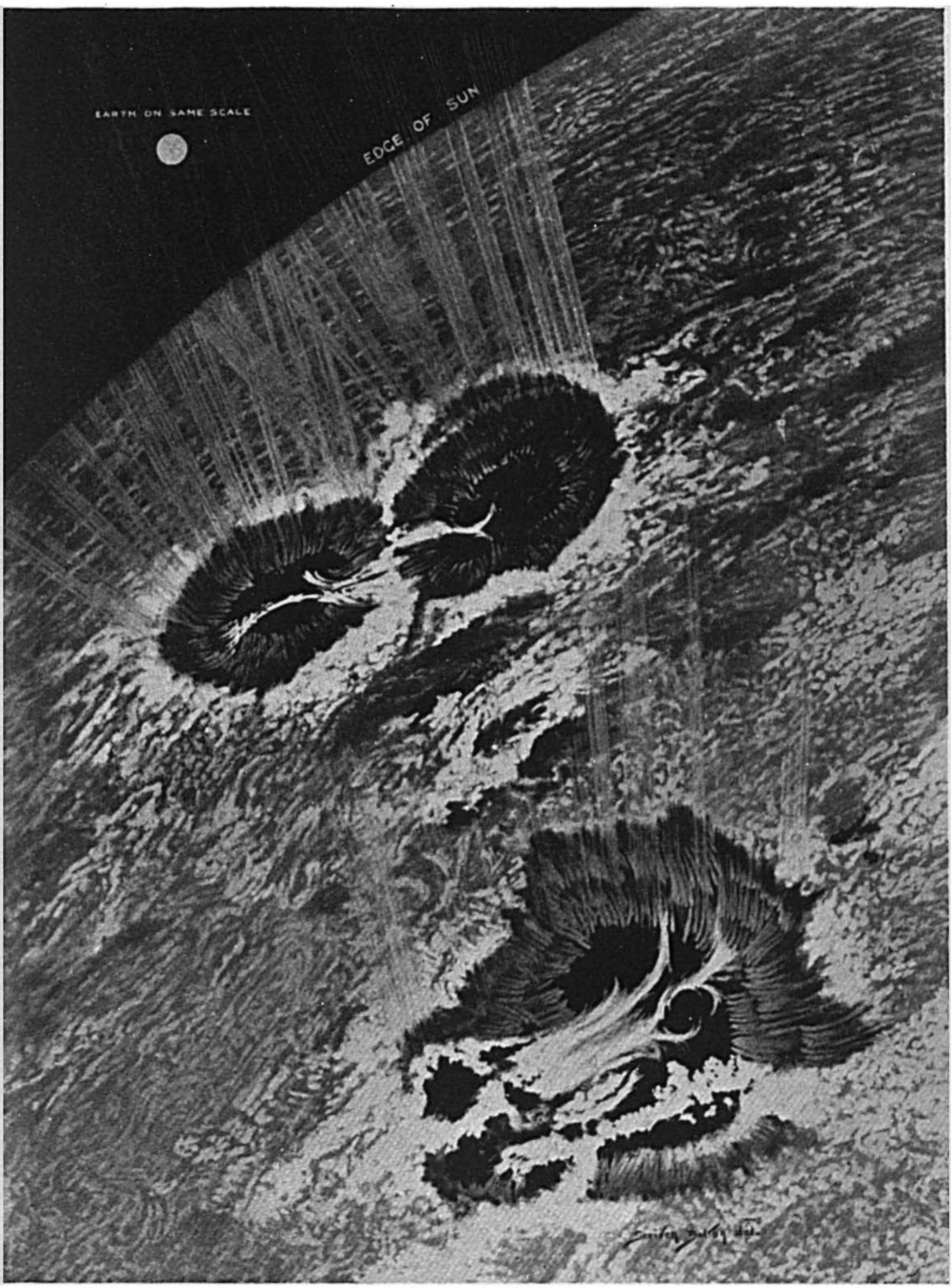
Discovery of Radium.

Now, at the same time as many other investigators, Professor Curie and his Polish wife took up the search. They decided to find out whether the emission came from the uranium itself or *from something associated with it*, and for this purpose they made a chemical analysis of great quantities of minerals. They found a certain kind of pitchblende which was very active, and they analysed tons of it, concentrating always on the radiant element in it. After a time, as they successively worked out the non-radiant matter, the stuff began to glow. In the end they extracted from eight tons of pitchblende about half a teaspoonful of something *that was a million times more radiant than uranium*. There was only one name for it—Radium.

That was the starting-point of the new development of physics and chemistry. From every laboratory in the world came a cry for radium salts (as pure radium was too precious), and hundreds of brilliant workers fastened on the new element. The inquiry was broadened, and, as year followed year, one substance after another was found to possess the power of emitting rays, that is to be radio-active. We know to-day that nearly every form of matter can be stimulated to radio-activity; which, as we shall see, means that *its atoms break up into smaller and wonderfully energetic particles which we call "electrons."* This discovery of electrons has brought about a complete change in our ideas in many directions.

So, instead of atoms being indivisible, they are actually dividing themselves, spontaneously, and giving off throughout the universe tiny fragments of their substance. We shall explain presently what was later discovered about the electron; meanwhile we can say that every glowing metal is pouring out a stream of these electrons. Every arc-lamp is discharging them. Every clap of thunder means a shower of them. Every star is flooding space with them. We are witnessing the spontaneous breaking up of atoms, atoms which had been thought to be indivisible. The sun not only pours out streams of electrons from its own atoms, but the ultra-violet light which it sends to the earth is one of the most powerful agencies for releasing electrons from the surface-atoms of matter on the earth. It is fortunate for us that our atmosphere absorbs most of this ultra-violet or invisible light of the sun—a kind of light which will be explained presently. It has been suggested that, if we received the full flood of it from the sun, our metals would disintegrate under its influence and this "steel civilisation" of ours would be impossible!

But we are here anticipating, we are going beyond radium to the wonderful discoveries which were made by the chemists and physicists of the world who concentrated upon it. The



ELECTRONS STREAMING FROM THE SUN TO THE EARTH.

There are strong reasons for supposing that sun-spots are huge electronic cyclones. The sun is constantly pouring out vast streams of electrons into space. Many of these streams encounter the earth, giving rise to various electrical phenomena.

work of Professor and Mme. Curie was merely the final clue to guide the great search. How it was followed up, how we penetrated into the very heart of the minute atom and discovered new and portentous mines of energy, and how we were able to understand, not only matter, but electricity and light, will be told in the next chapter.

THE DISCOVERY OF THE ELECTRON AND HOW IT EFFECTED A REVOLUTION IN IDEAS

What the discovery of radium implied was only gradually realised. Radium captivated the imagination of the world; it was a boon to medicine, but to the man of science it was at first a most puzzling and most attractive phenomenon. It was felt that some great secret of nature was dimly unveiled in its wonderful manifestations, and there now concentrated upon it as gifted a body of men—conspicuous amongst them Sir J. J. Thomson, Sir Ernest Rutherford, Sir W. Ramsay, and Professor Soddy—as any age could boast, with an apparatus of research as far beyond that of any other age as the *Aquitania* is beyond a Roman galley. Within five years the secret was fairly mastered. Not only were all kinds of matter reduced to a common basis, but the forces of the universe were brought into a unity and understood as they had never been understood before.

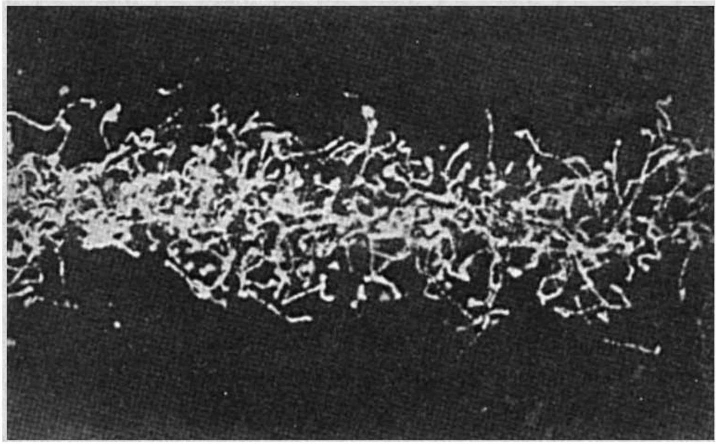
§ 5

The Discovery of the Electron.

Physicists did not take long to discover that the radiation from radium was very like the radiation in a "Crookes tube." It was quickly recognised, moreover, that both in the tube and in radium

PROFESSOR SIR J. J. THOMSON.

Experimental discoverer of the electronic constitution of matter, in the Cavendish Physical Laboratory, Cambridge. A great investigator, noted for the imaginative range of his hypotheses and his fertility in experimental devices.



From the Smithsonian Report, 1915.

ELECTRONS PRODUCED BY PASSAGE OF X-RAYS THROUGH AIR.

A photograph clearly showing that electrons are definite entities. As electrons leave atoms they may traverse matter or pass through the air in a straight path. The illustration shows the tortuous path of electrons resulting from collision with atoms.

(and other metals) the atoms of matter were somehow breaking down.

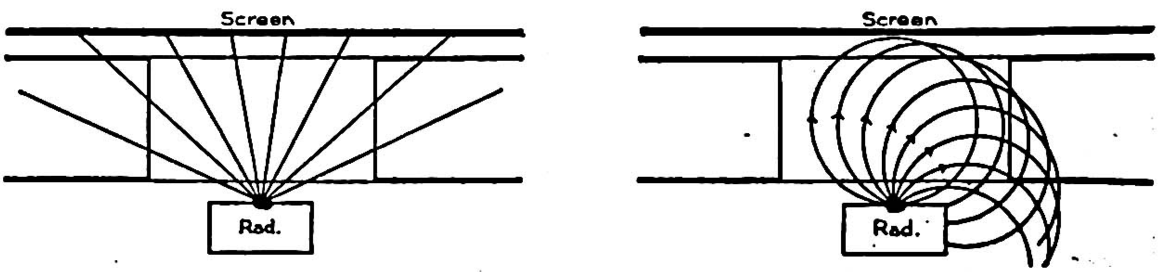
However, the first step was to recognise that there were three distinct and different rays that were given off by such metals as radium and uranium. Sir Ernest Rutherford christened them, after the first three letters of the Greek alphabet, the Alpha, the Beta, and Gamma rays. We are concerned chiefly with the second group and propose here to deal with that group only.[1]

The "Beta rays," as they were at first called, have proved to be one of the most interesting discoveries that science ever made. They proved what Crookes had surmised about the radiations he discovered in his vacuum tube. But it was *not* a fourth state of matter that had been found, but a new *property* of matter, a property common to all atoms of matter. The Beta rays were later christened Electrons. They are particles of disembodied electricity, here spontaneously liberated from the atoms of matter: only when the electron was isolated from the atom was it recognised for the first time as a separate entity. Electrons, therefore, are a constituent of the atoms of matter, and we have discovered that they can be released from the atom by a variety of agencies. Electrons are to be found everywhere, forming part of every atom.

"An electron," Sir William Bragg says, "can only maintain a separate existence if it is travelling at an immense rate, from one-three hundredth of the velocity of light upwards, that is to say, at least 600 *miles a second, or thereabouts*. Otherwise the electron sticks to the first atom it meets." These amazing particles may travel with the enormous velocity of from 10,000 to more than 100,000 miles a second. It was first learned that they are of an electrical nature, because they are bent out of their normal path if a magnet is brought near them. And this fact led to a further discovery: to one of those sensational estimates which the general public is apt to believe to be founded on the most

[1] The "Alpha rays" were presently recognised as atoms of helium gas, shot out at the rate of 12,000 miles a second.

The "Gamma rays" are *waves*, like the X-rays, not material particles. They appear to be a type of X-rays. They possess the remarkable power of penetrating opaque substances; they will pass through a foot of solid iron, for example.



MAGNETIC DEFLECTION OF RADIUM RAYS.

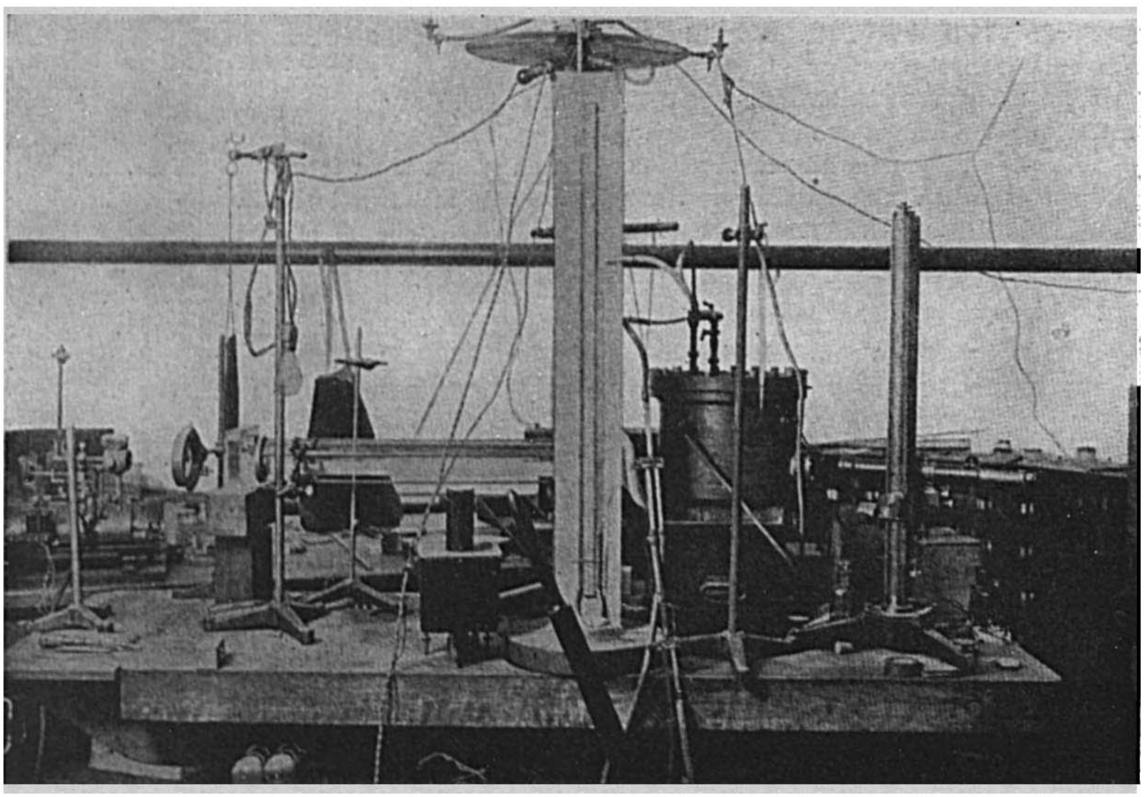
The radium rays are made to strike a screen, producing visible spots of light. When a magnetic field is applied the rays are seen to be deflected, as in the diagram. This can only happen if the rays carry an electric charge, and it was by experiments of this kind that we obtained our knowledge respecting the electric charges carried by radium rays.

abstruse speculations. The physicist set up a little chemical screen for the "Beta rays" to hit, and he so arranged his tube that only a narrow sheaf of the rays poured on to the screen. He then drew this sheaf of rays out of its course with a magnet, and he accurately measured the shift of the luminous spot on the screen where the rays impinged on it. But when he knows the exact intensity of his magnetic field—which he can control as he likes—and the amount of deviation it causes, and the mass of the moving particles, he can tell the speed of the moving particles which he thus diverts. These particles were being hurled out of the atoms of radium, or from the negative pole in a vacuum tube, at a speed which, in good conditions, reached nearly the velocity of light, i.e. nearly 186,000 miles a second.

Their speed has, of course, been confirmed by numbers of experiments; and another series of experiments enabled physicists to determine the size of the particles. Only one of these need be described, to give the reader an idea how men of science arrive at their more startling results.

Fog, as most people know, is thick in our great cities because the water-vapour gathers on the particles of dust and smoke that are in the atmosphere. This fact was used as the basis of some beautiful experiments. Artificial fogs were created in little glass tubes, by introducing dust, in various proportions, for supersaturated vapour to gather on. In the end it was possible to cause tiny drops of rain, each with a particle of dust at its core, to fall upon a silver mirror and be counted. It was a method of counting the quite invisible particles of dust in the tube; and the method was now successfully applied to the new rays. Yet another method was to direct a slender stream of the particles upon a chemical screen. The screen glowed under the cannonade of particles, and a powerful lens resolved the glow into distinct sparks, which could be counted.

In short, a series of the most remarkable and beautiful experiments, checked in all the great



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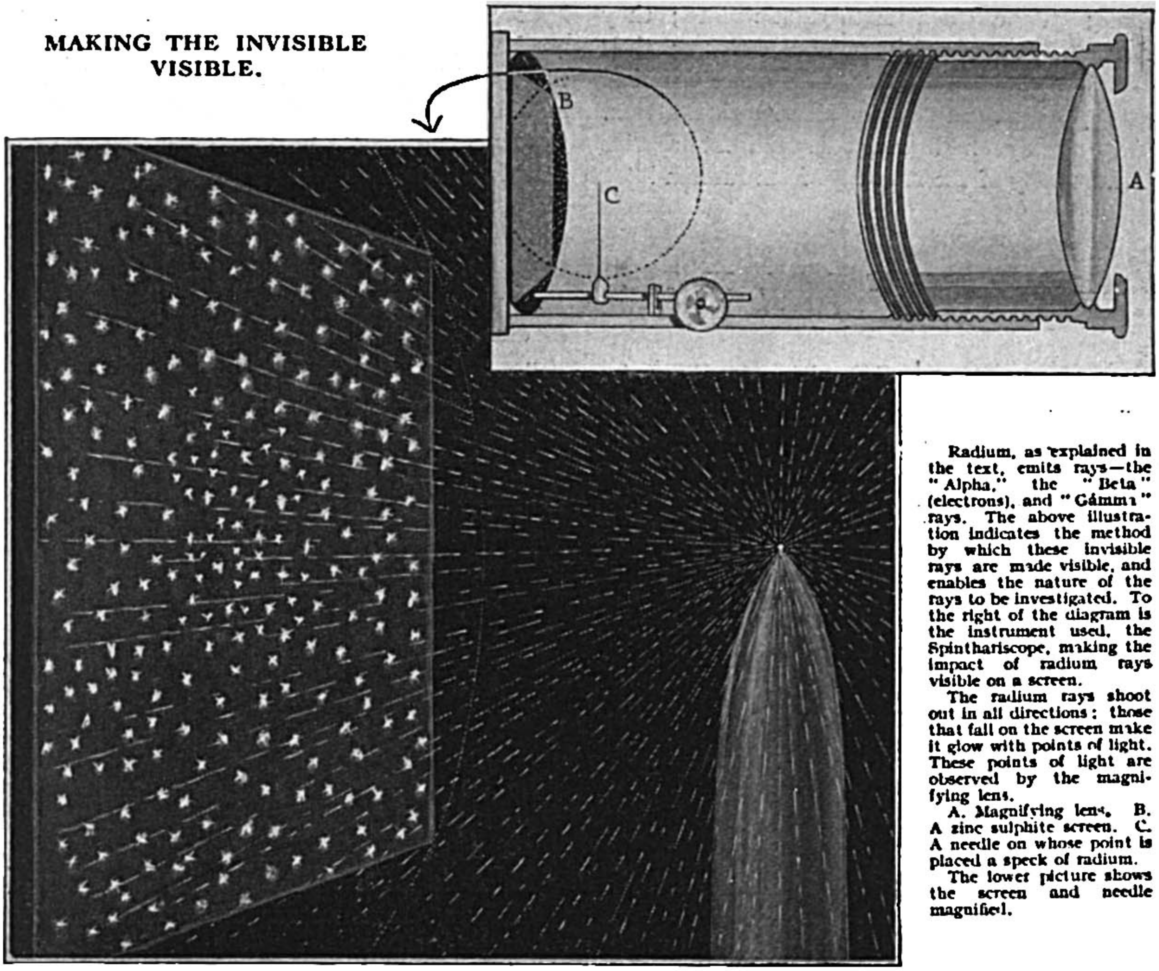
PROFESSOR R. A. MILLIKAN'S APPARATUS FOR COUNTING ELECTRONS.

MAKING THE INVISIBLE VISIBLE.



Radium, as explained in the text, emits rays—the "Alpha," the "Beta" (electrons), and "Gamma" rays. The above illustration indicates the method by which these invisible rays are made visible, and enables the nature of the rays to be investigated. To the right of the diagram is the instrument used, the Spinthariscope, making the impact of radium rays visible on a screen.

The radium rays shoot out in all directions: those that fall on the screen make it glow with points of light. These points of light are observed by the magnifying lens.

A. Magnifying lens. B. A zinc sulphite screen. C. A needle on whose point is placed a speck of radium.

The lower picture shows the screen and needle magnified.

laboratories of the world, settled the nature of these so-called rays. They were streams of particles more than a thousand times smaller than the smallest known atom. The mass of each particle is, according to the latest and finest measurements, $\frac{1}{1843}$ of that of an atom of hydrogen. The physicist has not been able to find any character except electricity in them, and the name "electrons" has been generally adopted.

The Key to many Mysteries.

The Electron is an atom, of disembodied electricity; it occupies an exceedingly small volume, and its "mass" is entirely electrical. These electrons are the key to half the mysteries of matter. Electrons in rapid motion, as we shall see, explain what we mean by an "electric current," not so long ago regarded as one of the most mysterious manifestations in nature.

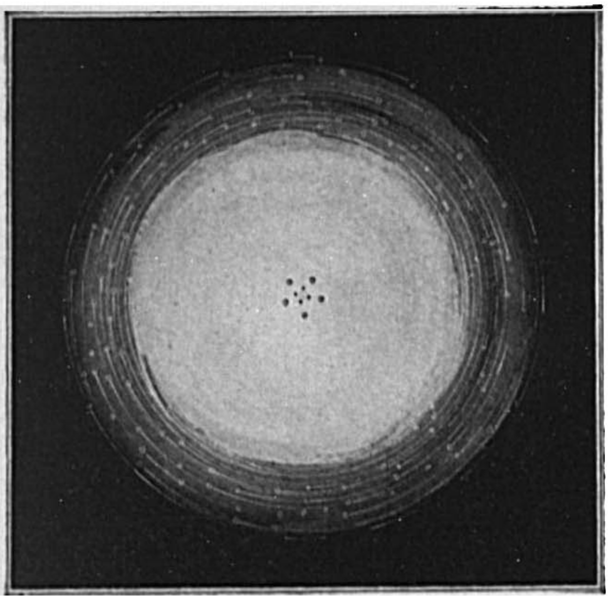
"What a wonder, then, have we here!" says Professor R. K. Duncan. "An innocent-looking little pinch of salt and yet possessed of special properties utterly beyond even the fanciful imaginings of men of past time; for nowhere do we find in the records of thought even the hint of the possibility of things which we now regard as established fact. This pinch of salt projects from its surface bodies [i.e. electrons] possessing the inconceivable velocity of over 100,000 miles a second, a velocity sufficient to carry them, if unimpeded, five times around the earth in a second, and possessing with this velocity, masses a thousand times smaller than the smallest atom known to science. Furthermore, they are charged with negative electricity; they pass straight through bodies considered opaque with a sublime indifference to the properties of the body, with the exception of its mere density; they cause bodies which they strike to shine out in the dark; they affect a photographic plate; they render the air a conductor of electricity; they cause clouds in moist air; they cause chemical action and have a peculiar physiological action. Who, to-day, shall predict the ultimate service to humanity of the beta-rays from radium!"

§ 6

THE ELECTRON THEORY, OR THE NEW VIEW OF MATTER

There is general agreement amongst all chemists, physicists, and mathematicians upon the conclusions which we have so far given. We know that the atoms of matter are constantly—either spontaneously or under stimulation—giving off electrons, or breaking up into electrons; and they therefore contain electrons. Thus we have now complete proof of the independent existence of atoms and also of electrons.

The Structure of the Atom.



THE THEORY OF ELECTRONS.

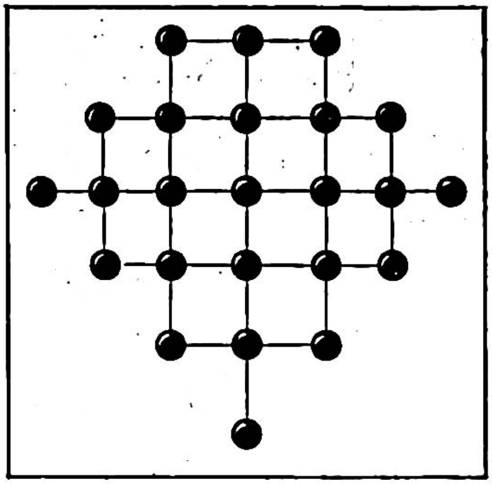
An atom of matter is composed of electrons. We picture an atom as a sort of miniature solar system, the electrons (particles of negative electricity) rotating round a central nucleus of positive electricity, as described in the text. In the above pictorial representation of an atom the whirling electrons are indicated in the outer ring. Electrons move with incredible speed as they pass from one atom to another.

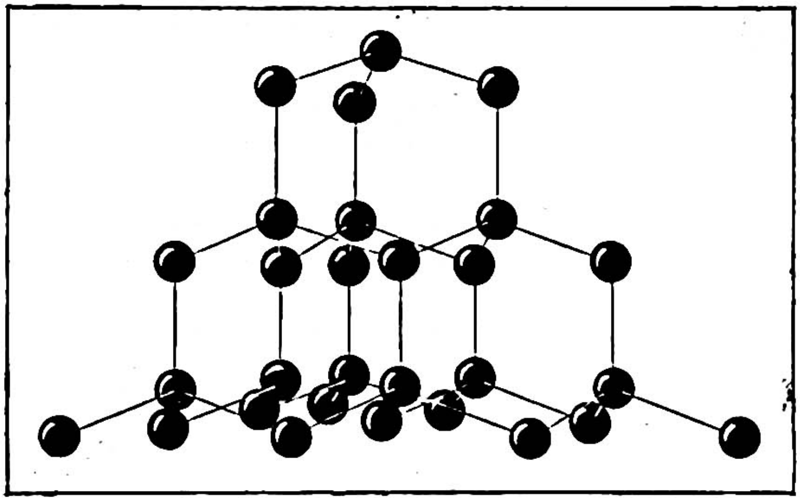
When, however, the man of science tries to tell us *how* electrons compose atoms, he passes from facts to speculation, and very difficult speculation. Take the letter "o" as it is printed on this page. In a little bubble of hydrogen gas no larger than that letter there are *billions* of atoms; and they are not packed together, but are circulating as freely as dancers in a ball-room. We are asking the physicist to take one of these minute atoms and tell us how the still smaller electrons are arranged in it. Naturally he can only make mental pictures, guesses or hypotheses, which he tries to fit to the facts, and discards when they will *not* fit.

At present, after nearly twenty years of critical discussion, there are two chief theories of the structure of the atom. At first Sir J. J. Thomson imagined the electrons circulating in shells (like the layers of an onion) round the nucleus of the atom. This did not suit, and Sir E. Rutherford and others worked out a theory that the electrons circulated round a nucleus rather like the planets of our solar system revolving round the central sun. Is there a nucleus, then, round which the electrons revolve? The electron, as we saw, is a disembodied atom of electricity; we should say, of "negative" electricity. Let us picture these electrons all moving round in orbits with great velocity. Now it is suggested that there is a nucleus of "positive" electricity attracting or pulling the revolving electrons to it, and so forming an equilibrium, otherwise the electrons would fly off in all directions. This nucleus has been recently named the proton. We have thus two electricities in the atom: the positive = the nucleus; the negative = the electron. Of recent years Dr. Langmuir has put out a theory that the electrons do not *revolve round* the nucleus, but remain in a state of violent agitation of some sort at fixed distances from the nucleus.

But we will confine ourselves here to the facts, and leave the contending theories to scientific men. It is now pretty generally accepted that an atom of matter consists of a number of electrons, or charges of negative electricity, held together by a charge of positive electricity. It is not disputed that these electrons are in a state of violent motion or strain, and that therefore a vast energy is locked up in the atoms of matter. To that we will return later. Here, rather, we will notice another remarkable discovery which helps us to understand the nature of matter.

A brilliant young man of science who was killed in the war, Mr. Moseley, some years ago showed that, when the atoms of different substances are arranged in order of their weight, *they are also arranged in the order of increasing complexity of structure.* That is to say, the heavier the atom, the more electrons it contains. There is a gradual building up of atoms containing more and more electrons from the lightest atom to the heaviest. Here it is enough to say that, as he took element after element, from the lightest (hydrogen) to the heaviest (uranium), he found a strangely regular relation between them. If hydrogen were represented by the figure one, helium by two, lithium three, and so on up to uranium, then uranium should have the figure ninety-two. This makes it probable that there are in nature ninety-two elements—we have found eighty-seven—and that the number Mr. Moseley found is the number of electrons in the atom of each element; that is to say, the number is arranged in order of the atomic numbers of the various elements.





ARRANGEMENTS OF ATOMS IN A DIAMOND.

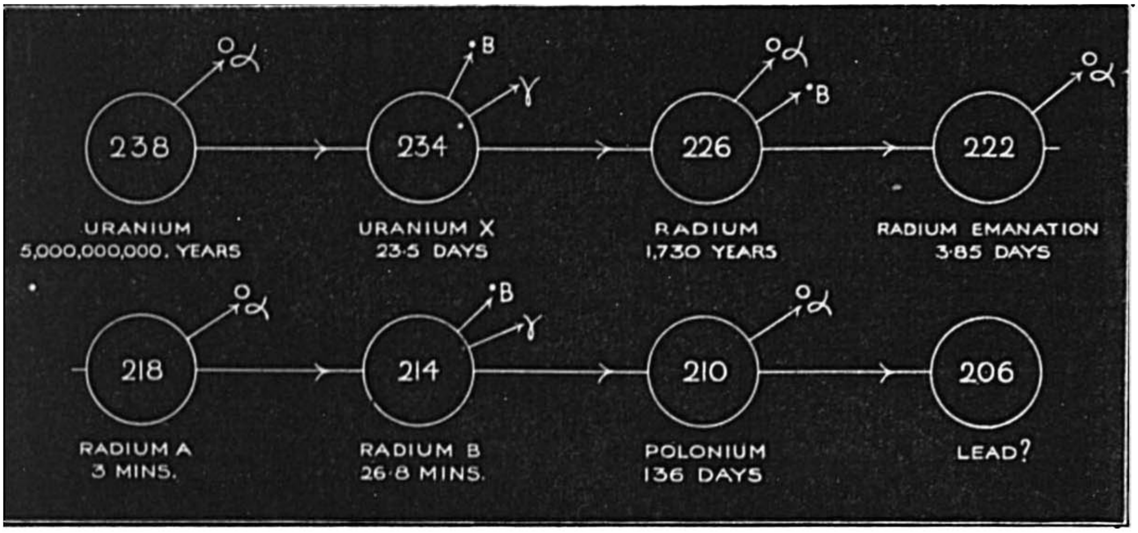
The above is a model (seen from two points of view) of the arrangement of the atoms in a diamond. The arrangement is found by studying the X-ray spectra of the diamond.

§ 7

Up to the point we have reached, then, we see what the new view of Matter is. Every atom of matter, of whatever kind throughout the whole universe, is built up of electrons in conjunction with a nucleus. From the smallest atom of all—the atom of hydrogen—which consists of one electron, rotating round a positively charged nucleus, to a heavy complicated atom, such as the atom of gold, constituted of many electrons and a complex nucleus, *we have only to do with positive and negative units of electricity.* The electron and its nucleus are particles of electricity. All Matter, therefore, is nothing but a manifestation of electricity. The atoms of matter, as we saw, combine and form molecules. Atoms and molecules are the bricks out of which nature has built up everything; we ourselves, the earth, the stars, the whole universe.

The New View of Matter.

But more than bricks are required to build a house. There are other fundamental existences, such as the various forms of energy, which give rise to several complex problems. And we have also to remember, that there are more than eighty distinct elements, each with its own definite type of atom. We shall deal with energy later. Meanwhile it remains to be said that, although we have discovered a great deal about the electron and the constitution of matter, and that while the physicists of our own day seem to see a possibility of explaining positive and negative electricity, the nature of



DISINTEGRATION OF ATOMS.

An atom of Uranium, by ejecting an Alpha particle, becomes Uranium X. This substance, by ejecting Beta and Gamma rays, becomes Radium. Radium passes through a number of further changes, as shown in the diagram, and finally becomes lead. Some radio-active substances disintegrate much faster than others. Thus Uranium changes very slowly, taking 5,000,000,000 years to reach the same stage of disintegration that Radium A reaches in 3 minutes. As the disintegration proceeds, the substances become of lighter and lighter atomic weights. Thus Uranium has an atomic weight of 238, whereas lead has an atomic weight of only 206. The breaking down of atoms is fully explained in the text.

them both is unknown. There exists the theory that the particles of positive and negative electricity, which make up the atoms of matter, are points or centres of disturbances of some kind in a universal ether, and that all the various forms of energy are, in some fundamental way, aspects of the same primary entity which constitutes matter itself.

But the discovery of the property of radio-activity has raised many other interesting questions, besides that which we have just dealt with. In radio-active elements, such as uranium for example, the element is breaking down; in what we call radio-activity we have a manifestation of the spontaneous change of elements. What is really taking place is a transmutation of one element into another, from a heavier to a lighter. The element uranium spontaneously becomes radium, and radium passes through a number of other stages until it, in turn, becomes lead. Each descending element is of lighter atomic weight than its predecessor. The changing process, of course, is a very slow one. It may be that all matter is radio-active, or can be made so. This raises the question whether all the matter in the universe may not undergo disintegration.

There is, however, another side of the question, which the discovery of radio-activity has brought to light, and which has effected a revolution in our views. We have seen that in radio-active substances the elements are breaking down. Is there a process of building up at work? If the more complicated atoms are breaking down into simpler forms, may there not be a converse process—a building up from simpler elements to more complicated elements? It is probably the case that both processes are at work.

There are some eighty-odd chemical elements on the earth to-day: are they all the outcome of an inorganic evolution, element giving rise to element, going back and back to some primeval stuff from which they were all originally derived infinitely long ago? Is there an evolution in the inorganic world which may be going on, parallel to that of the evolution of living things; or is organic evolution a continuation of inorganic evolution? We have seen what evidence there is of this inorganic evolution in the case of the stars. We cannot go deeply into the matter here, nor has the time come for any direct statement that can be based on the findings of modern investigation. Taking it altogether the evidence is steadily accumulating, and there are authorities who maintain that already the evidence of inorganic evolution is convincing enough. The heavier atoms would appear to behave as though they were evolved from the lighter. The more complex forms, it is supposed, have *evolved* from the simpler forms. Moseley's discovery, to which reference has been made, points to the conclusion that the elements are built up one from another.

§ 8

Other New Views.

We may here refer to another new conception to which the discovery of radio-activity has given rise. Lord Kelvin, who estimated the age of the earth at twenty million years, reached this estimate by considering the earth as a body which is gradually cooling down, "losing its primitive heat, like a loaf taken from the oven, at a rate which could be calculated, and that the heat radiated by the sun was due to contraction." Uranium and radio-activity were not known to Kelvin, and their discovery has upset both his arguments. Radio-active substances, which are perpetually giving out heat, introduce an entirely new factor. We cannot now assume that the earth is necessarily cooling down; it may even, for all we know, be getting hotter. At the 1921 meeting of the British Association, Professor Rayleigh stated that further knowledge had extended the probable period during which there had been life on this globe to about one thousand million years, and the total age of the earth to some small multiple of that. The earth, he considers, is not cooling, but "contains an internal source of heat from the disintegration of uranium in the outer crust." On the whole the estimate obtained would seem to be in agreement with the geological estimates. The question, of course, cannot, in the present state of our knowledge, be settled within fixed limits that meet with general agreement.

As we have said, there are other fundamental existences which give rise to more complex problems. The three great fundamental entities in the physical universe are matter, ether, and energy; so far as we know, outside these there is nothing. We have dealt with matter, there remain ether and energy. We shall see that just as no particle of matter, however small, may not be created or destroyed, and just as there is no such thing as empty space—ether pervades everything—so there is no such thing as *rest*. Every particle that goes to make up our solid earth is in a state of perpetual unremitting vibration; energy "is the universal commodity on which all life depends." Separate and distinct as these three fundamental entities—matter, ether, and energy—may appear, it may be that, after all, they are only different and mysterious phases of an essential "oneness" of the universe.

§ 9

The Future.

Let us, in concluding this chapter, give just one illustration of the way in which all this new knowledge may prove to be as valuable practically as it is wonderful intellectually. We saw that electrons are shot out of atoms at a speed that may approach 160,000 miles a second. Sir Oliver Lodge has written recently that a

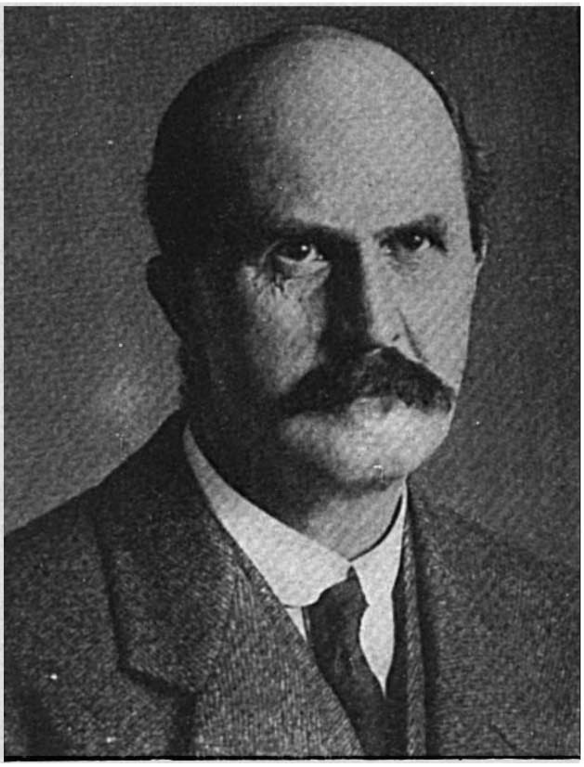


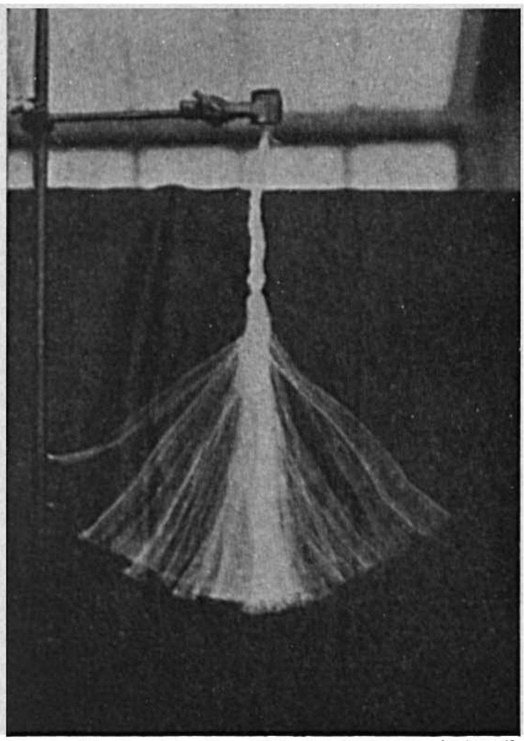
Photo: Photo Press.

PROFESSOR SIR W. H. BRAGG.

One of the most distinguished physicists of the present day.

seventieth of a grain of radium discharges, at a speed a thousand times that of a rifle bullet, thirty million electrons a second. Professor Le Bon has calculated that it would take 1,340,000 barrels of powder to give a bullet the speed of one of these electrons. He shows that the smallest French copper coin—smaller than a farthing—contains an energy equal to eighty million horse-power. A few pounds of matter contain more energy than we could extract from millions of tons of coal. Even in the atoms of hydrogen at a temperature which we could produce in an electric furnace the electrons spin round at a rate of nearly a hundred billion revolutions a second!

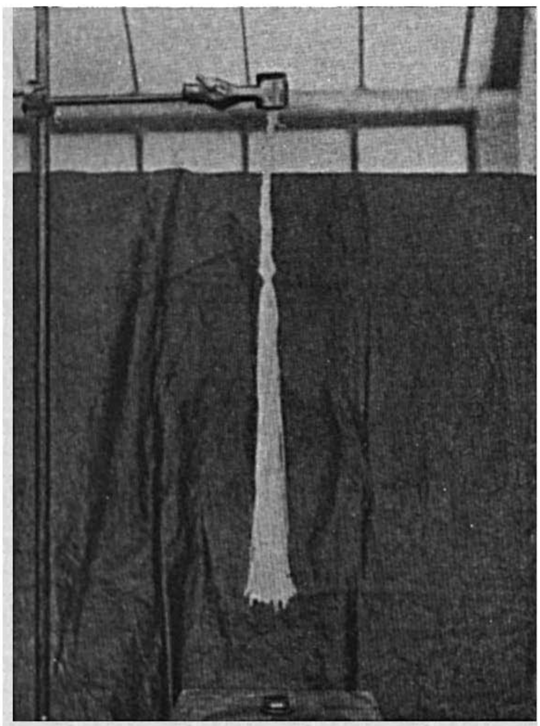
Every man asks at once: "Will science ever tap this energy?" If it does, no more smoke, no mining, no transit, no bulky fuel. The energy of an atom is of course only liberated when an atom passes from one state to another. The stored up energy is fortunately fast bound by the electrons being held together as has been described. If it were not so "the earth would explode and become a gaseous nebula"! It is believed that some day we shall be able to release, harness, and utilise atomic energy. "I am of opinion," says Sir William Bragg, "that atom energy will supply our future need. A thousand years may pass before we can harness the atom, or to-morrow might see us with the reins in our hands. That is the peculiarity of Physics—research and 'accidental' discovery go hand in hand." Half a brick contains as much energy as a small coal-field. The difficulties are tremendous, but, as Sir Oliver Lodge reminds us, there was just as much scepticism at one time about the utilisation of steam or electricity. "Is it to be supposed," he asks, "that there can be no fresh invention, that all the great discoveries have been made?" More than one man of science encourages us to hope. Here are some remarkable words written by Professor Soddy, one of the highest authorities on radio-active matter, in our chief scientific weekly (*Nature*, November 6, 1919):



Reproduced by permission from "The Interpretation of Radium" (John Murray).

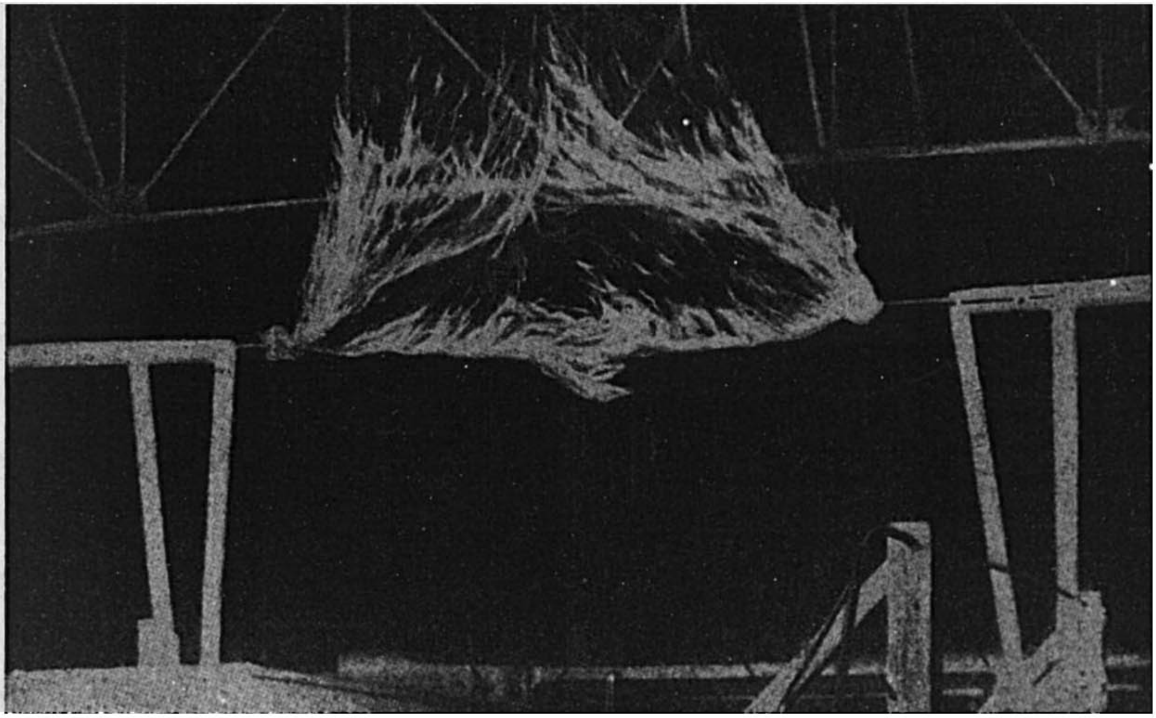
SILK TASSEL ELECTRIFIED.

The separate threads of the tassel, being each electrified with the same kind of electricity, repel one another, and thus the tassel branches out as in the photograph.



SILK TASSEL DISCHARGED BY THE RAYS FROM RADIUM.

When the radium rays, carrying an opposite electric charge to that on the tassel, strikes the threads, the threads are neutralised, and hence fall together again.



A HUGE ELECTRIC SPARK.

This is an actual photograph of an electric spark. It is leaping a distance of about 10 feet, and is the discharge of a million volts. It is a graphic illustration of the tremendous energy of electrons.

"The prospects of the successful accomplishment of artificial transmutation brighten almost daily. The ancients seem to have had something more than an inkling that the accomplishment of transmutation would confer upon men powers hitherto the prerogative of the gods. But now we know definitely that the material aspect of transmutation would be of small importance in comparison with the control over the inexhaustible stores of internal atomic energy to which its successful accomplishment would inevitably lead. It has become a problem, no longer redolent of the evil associations of the age of alchemy, but one big with the promise of a veritable physical renaissance of the whole world."

If that "promise" is ever realised, the economic and social face of the world will be transformed.

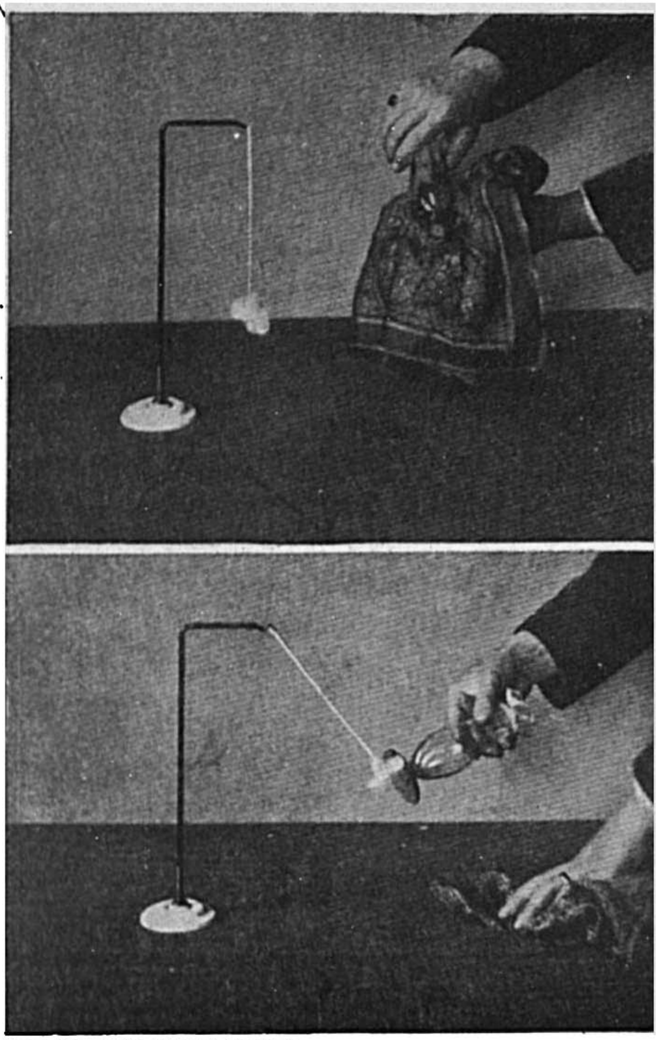
Before passing on to the consideration of ether, light, and energy, let us see what new light the discovery of the electron has thrown on the nature and manipulation of electricity.

WHAT IS ELECTRICITY?

The Nature of Electricity.

There is at least one manifestation in nature, and so late as twenty years ago it seemed to be one of the most mysterious manifestations of all, which has been in great measure explained by the new discoveries. Already, at the beginning of this century, we spoke of our "age of electricity," yet there were few things in nature about which we knew less. The "electric current" rang our bells, drove our trains, lit our rooms, but none knew what the current was. There was a vague idea that it was a sort of fluid that flowed along copper wires as water flows in a pipe. We now suppose that it is *a rapid movement of electrons from atom to atom* in the wire or wherever the current is.

Let us try to grasp the principle of the new view of electricity and see how it applies to all the varied electrical phenomena in the world about us. As we saw, the nucleus of an atom of matter consists of positive electricity which holds together a number of electrons, or charges of negative electricity.[1] This certainly tells us to some extent what electricity is, and how it is related to matter, but it leaves us with the usual difficulty about fundamental realities. But we now know that electricity, like matter, is atomic in structure; a charge of electricity is made up of a number of small units or charges of a definite, constant amount. It has been suggested that the two kinds of electricity, i.e. positive and negative, are right-handed and left-handed vortices or whirlpools in ether, or rings in ether, but there are very serious difficulties, and we leave this to the future.



From "Scientific Ideas of To-day."

ELECTRICAL ATTRACTION BETWEEN COMMON OBJECTS.

Take an ordinary flower-vase, well dried, and energetically rub it with a silk handkerchief. The vase, which thus becomes electrified, will attract any light body, such as a feather, as shown in the above illustration.

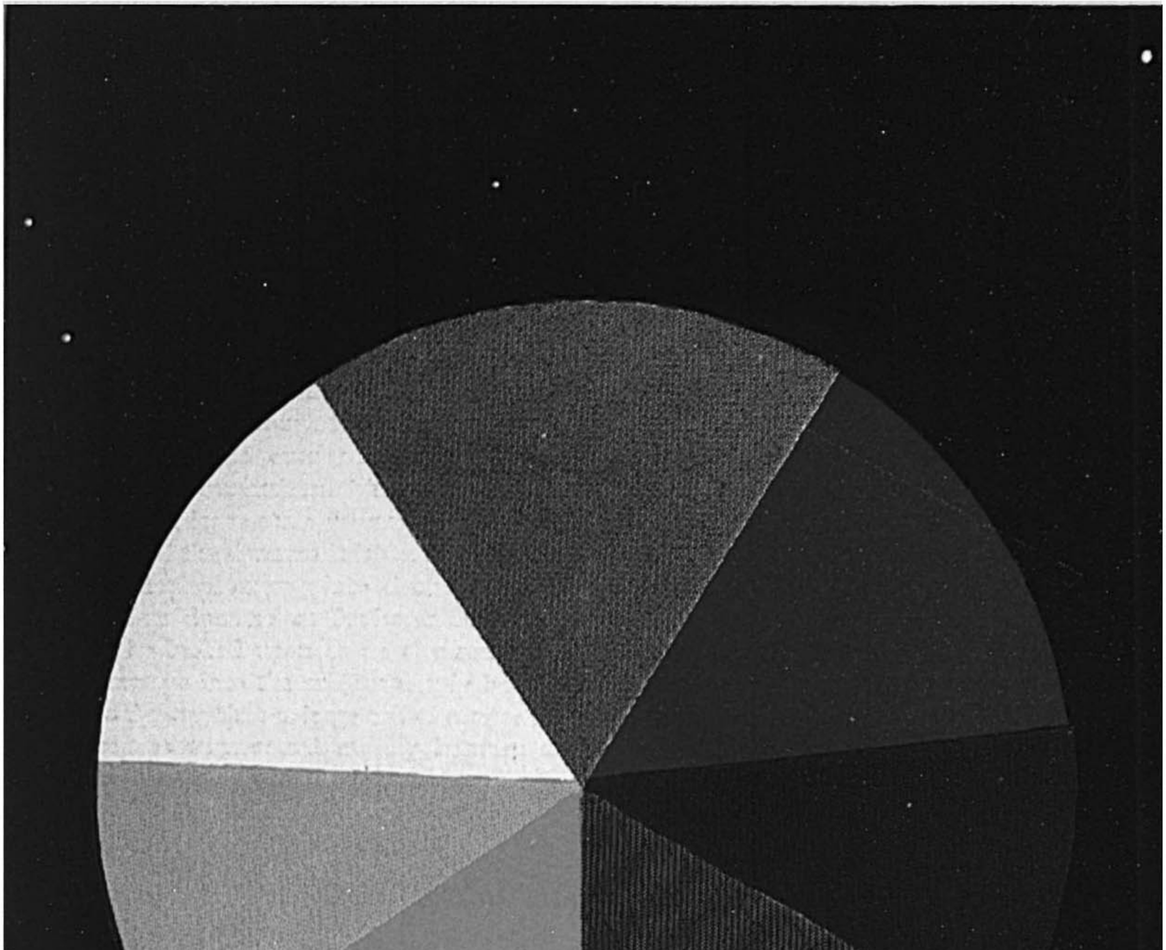
§ 10

What an Electric Current is.

The discovery of these two kinds of electricity has, however, enabled us to understand very fairly what goes on in electrical phenomena. The outlying electrons, as we saw, may pass from atom to atom, and this, on a large scale, is the meaning of the electric current. In other words, we believe an electric current to be a flow of electrons. Let us take, to begin with, a simple electrical "cell," in which a feeble current is generated: such a cell as there is in every house to serve its electric bells.

In the original form this simple sort of "battery" consisted of a plate of zinc and a plate of copper immersed in a chemical. Long before anything was known about electrons it was known that, if you put zinc and copper together, you produce a mild current of electricity. We know now what this means. Zinc is a metal the atoms of which are particularly disposed to part with some of their outlying electrons. Why, we do not know; but the fact is the basis of these small batteries. Electrons from the atoms of zinc pass to the atoms of copper, and their passage is a "current." Each atom gives up an electron to its neighbour. It was further found long ago that if the zinc and copper were immersed in certain chemicals, which slowly dissolve the zinc, and the two metals were connected by a copper wire, the current was stronger. In modern language, there is a brisker flow of electrons. The reason is that the atoms of zinc which are stolen by the chemical leave their detachable electrons behind them, and the zinc has therefore more electrons to pass on to the copper.

[1] The words "positive" and "negative" electricity belong to the days when it was regarded as a fluid. A body overcharged with the fluid was called positive; an undercharged body was called negative. A positively-electrified body is now one whose atoms have lost some of their outlying electrons, so that the positive charge of electricity predominates. The negatively-electrified body is one with more than the normal number of electrons.



ROTATING DISC OF SIR ISAAC NEWTON FOR MIXING COLOURS

The Spectroscope sorts out the above seven colours from sunlight (which is compounded of these seven colours). If painted in proper proportions on a wheel, as shown in the coloured illustration, and the wheel be turned rapidly on a pivot through its centre, only a dull white will be perceived. If one colour be omitted, the result will be one colour —the result of the union of the remaining six.

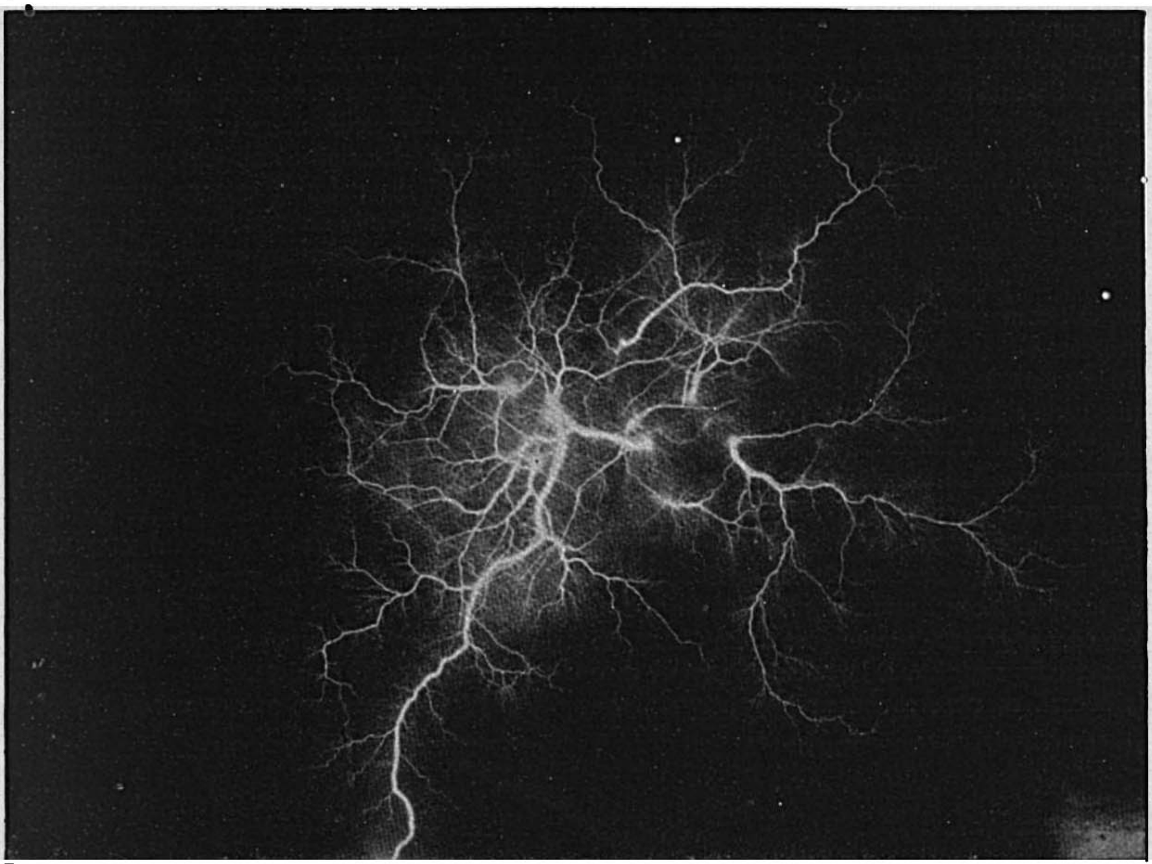


Photo: Leadbeater.

AN ELECTRIC SPARK.

An electric spark consists of a rush of electrons across the space between the two terminals. A state of tension is established in the ether by the electric charges, and when this tension passes a certain limit the discharge takes place.

Such cells are now made of zinc and carbon, immersed in sal-ammoniac, but the principle is the same. The flow of electricity is a flow of electrons; though we ought to repeat that they do not flow in a body, as molecules of water do. You may have seen boys place a row of bricks, each standing on one end, in such order that the first, if it is pushed, will knock over the second, the second the third, and so on to the last. There is a flow of *movement* all along the line, but each brick moves only a short distance. So an electron merely passes to the next atom, which sends on an electron to a third atom, and so on. In this case, however, the movement from atom to atom is so rapid that the ripple of movement, if we may call it so, may pass along at an enormous speed. We have seen how swiftly electrons travel.

But how is this turned into power enough even to ring a bell? The actual mechanical apparatus by which the energy of the electron current is turned into sound, or heat, or light will be described in a technical section later in this work. We are concerned here only with the principle, which is clear. While zinc is very apt to part with electrons, copper is just as obliging in facilitating their passage onward. Electrons will travel in this way in most metals, but copper is one of the best "conductors." So we lengthen the copper wire between the zinc and the carbon until it goes as far as the front door and the bell, which are included in the circuit. When you press the button at the door, two wires are brought together, and the current of electrons rushes round the circuit; and at the bell its energy is diverted into the mechanical apparatus which rings the bell.

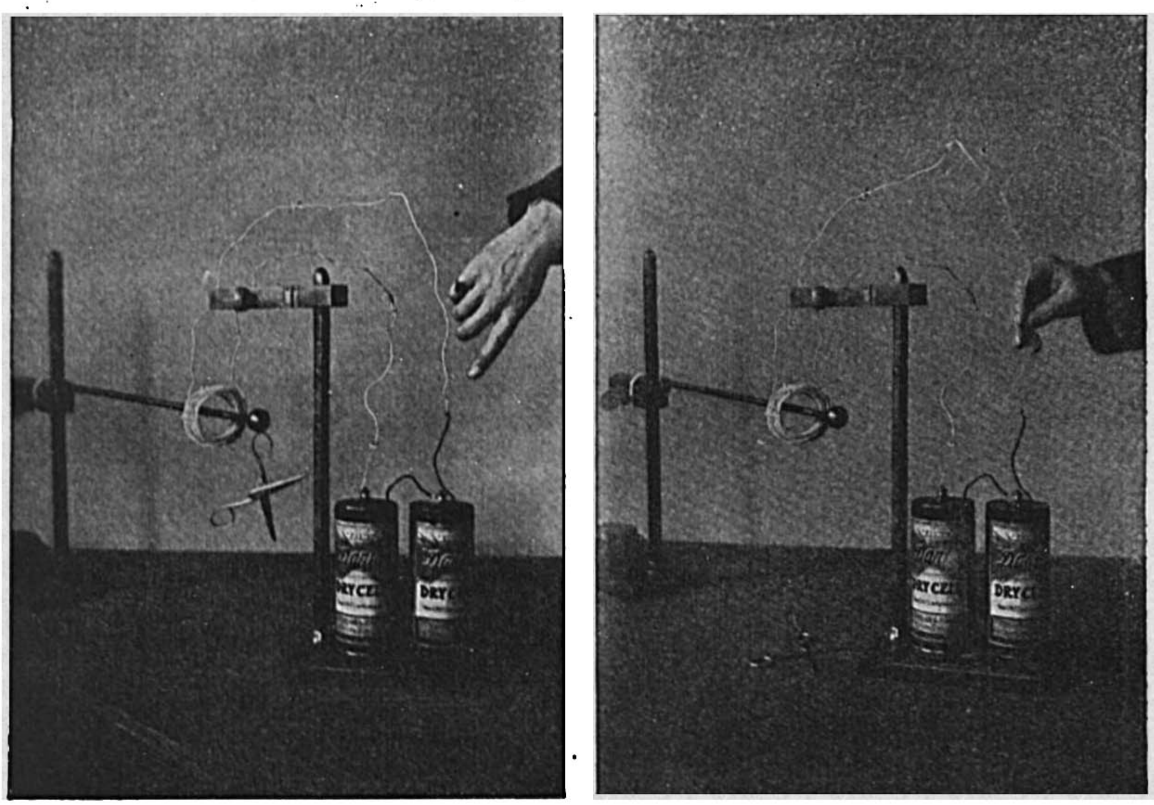
Copper is a good conductor—six times as good as iron—and is therefore so common in electrical industries. Some other substances are just as stubborn as copper is yielding, and we call them "insulators," because they resist the current instead of letting it flow. Their atoms do not easily part with electrons. Glass, vulcanite, and porcelain are very good insulators for this reason.

What the Dynamo does.

But even several cells together do not produce the currents needed in modern industry, and the flow is produced in a different manner. As the invisible electrons pass along a wire they produce what we call a magnetic field around the wire, they produce a disturbance in the surrounding ether. To be exact, it is through the ether surrounding the wire that the energy originated by the electrons is transmitted. To set electrons moving on a large scale we use a "dynamo." By means of the dynamo it is possible to transform mechanical energy into electrical energy. The modern dynamo, as Professor Soddy puts it, may be looked upon as an electron pump. We cannot go into the subject deeply here, we would only say that a large coil of copper wire is caused to turn round rapidly between the poles of a powerful magnet. That is the essential construction of the "dynamo," which is used for generating strong currents. We shall see in a moment how magnetism differs from electricity, and will say here only that round the poles of a large magnet there is a field of intense disturbance which will start a flow of electrons in any copper that is introduced into it. On account of the speed given to the coil of wire its atoms enter suddenly this magnetic field, and they give off crowds of electrons in a flash.

It is found that a similar disturbance is caused, though the flow is in the *opposite* direction, when the coil of wire leaves the magnetic field. And as the coil is revolving very rapidly we get a powerful current of electricity that runs in alternate directions—an "alternating" current. Electricians have apparatus for converting it into a continuous current where this is necessary.

A current, therefore, means a steady flow of



From "Scientific Ideas of To-day."

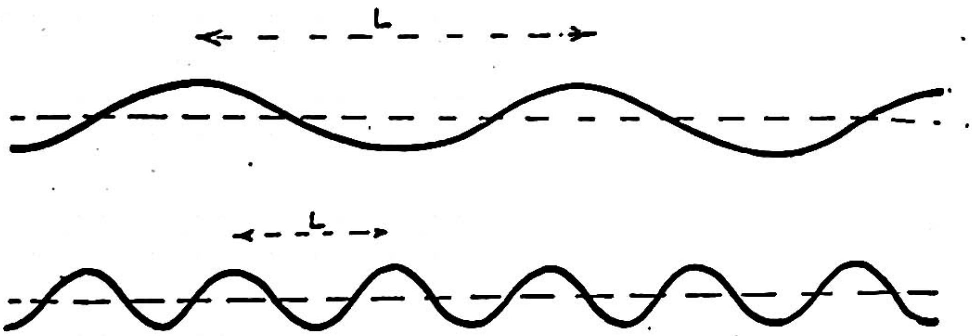
AN ETHER DISTURBANCE AROUND AN ELECTRON CURRENT.

In the left-hand photograph an electric current is passing through the coil, thus producing a magnetic field and transforming the poker into a magnet. The poker is then able to support a pair of scissors. As soon as the electric current is broken off, as in the second photograph the ether disturbance ceases. The poker loses its magnetism, and the scissors fall.

Photo: H. J. Shepstone.

LIGHTNING.

In a thunderstorm we have the most spectacular display in lightning of a violent and explosive rush of electrons (electricity) from one body to another, from cloud to cloud, or to the earth. In this wonderful photograph of an electrical storm note the long branched and undulating flashes of lightning. Each flash lasts no longer than the one hundred-thousandth part of a second of time



LIGHT WAVES.

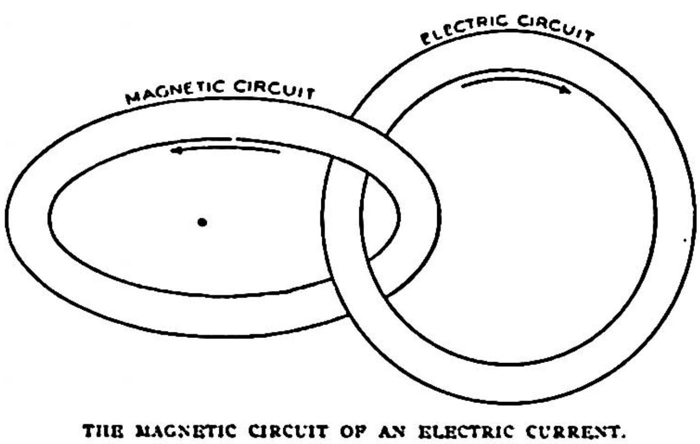
Light consists of waves transmitted through the ether. Waves of light differ in length. The colour of the light depends on the wave-length. Deep-red waves (the longest) are [illegible] inch and deep-violet waves [illegible] inch. The diagram shows two wave-motions of different wave-lengths. From crest to crest, or from trough to trough, is the length of the wave.

the electrons from atom to atom. Sometimes, however, a number of electrons rush violently and explosively from one body to another, as in the electric spark or the occasional flash from an electric tram or train. The grandest and most spectacular display of this phenomenon is the thunder-storm. As we saw earlier, a portentous furnace like the sun is constantly pouring floods of electrons from its atoms into space. The earth intercepts great numbers of these electrons. In the upper regions of the air the stream of solar electrons has the effect of separating positively-electrified atoms from negatively-electrifiedones, and the water-vapour, which is constantly rising from the surface of the sea, gathers more freely round the positively-electrified atoms, and brings them down, as rain, to the earth. Thus the upper air loses a proportion of positive electricity, or becomes "negatively electrified." In the thunderstorm we get both kinds of clouds—some with large excesses of electrons, and some deficient in electrons—and the tension grows until at last it is relieved by a sudden and violent discharge of electrons from one cloud to another or to the earth—an electric spark on a prodigious scale.

§ 11

Magnetism.

We have seen that an electric current is really a flow of electrons. Now an electric current exhibits a magnetic effect. The surrounding space is endowed with energy which we call electro-magnetic energy. A piece of magnetised iron attracting other pieces of iron to it is the popular idea of a magnet. If we arrange a wire to pass vertically through a piece of cardboard and then sprinkle iron filings on the cardboard we shall find that, on passing an electric current through the wire, the iron filings arrange themselves in circles round it. The magnetic force, due to the electric current, seems to exist in circles round the wire, an ether disturbance being set up. Even a single electron, when in movement, creates a magnetic "field," as it is called, round its path. There is no movement of electrons without this attendant field of energy, and their motion is not stopped until that field of energy disappears from the ether. The modern theory of magnetism supposes that all magnetism is produced in this way. All



THE MAGNETIC CIRCUIT OF AN ELECTRIC CURRENT.

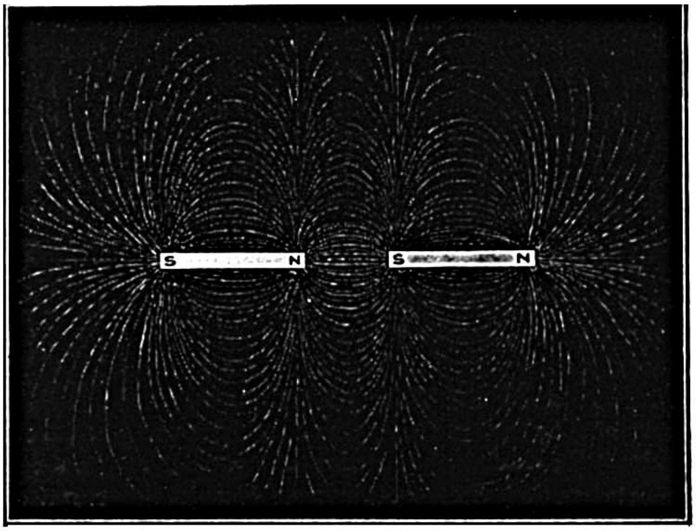
The electric current passing, in the direction of the arrow, round the electric circuit generates in the surrounding space circular magnetic circuits as shown in the diagram. It is this property which lies at the base of the electro-magnet and of the electric dynamo.

magnetism is supposed to arise from the small whirling motions of the electrons contained in the ultimate atoms of matter. We cannot here go into the details of the theory nor explain why, for instance, iron behaves so differently from other substances, but it is sufficient to say that here, also, the electron theory provides the key. This theory is not yet definitely *proved*, but it furnishes a sufficient theoretical basis for future research. The earth itself is a gigantic magnet, a fact which makes the compass possible, and it is well known that the earth's magnetism is affected by those great outbreaks on the sun called sun-spots. Now it has been recently shown that a sunspot is a vast whirlpool of electrons and that it exerts a strong magnetic action. There is doubtless a connection between these outbreaks of electronic activity and the consequent changes in the earth's magnetism. The precise mechanism of the connection, however, is still a matter that is being investigated.

ETHER AND WAVES

Ether and Waves.

The whole material universe is supposed to be embedded in a vast medium called the ether. It is true that the notion of the ether has been abandoned by some modern physicists, but, whether or not it is ultimately dispensed with, the conception of the ether has entered so deeply into the scientific mind that the science of physics cannot be understood unless we know something about the properties attributed to the ether. The ether was invented to explain the phenomena of light, and to account for the flow of energy across empty space. Light takes time to travel. We do not see the sun rise until eight minutes after it has risen. It has taken that eight minutes for the light from the sun to travel that 93,000,000 miles odd which separates it from our earth. Besides the fact that light takes time to travel, it can be shown that light travels in the form of waves. We know that sound travels in waves; sound consists of waves in the air, or water or wood or whatever medium we hear it through. If an electric bell be put in a glass jar and the air be pumped out of the jar, the sound of the bell becomes feebler and feebler until, when enough air has been taken out, we do not hear the bell at all. Sound cannot travel in a vacuum. We continue to *see* the bell, however, so that evidently light can travel in a vacuum. The invisible medium through which the waves of light travel is the ether, and this ether permeates all space *and all matter*. Between us and the stars stretch vast regions empty of all matter.



THE MAGNET.

The illustration shows the lines of force between two magnets. The lines of force proceed from the north pole of one magnet to the south pole of the other. They also proceed from the north to the south poles of the same magnet. These facts are shown clearly in the diagram. The north pole of a magnet is that end of it which turns to the north when the magnet is freely suspended.

But we see the stars; their light reaches us, even though it may take centuries to do so. We conceive, then, that it is the universal ether which conveys that light. All the energy which has reached the earth from the sun and which, stored for ages in our coal-fields, is now used to propel our trains and steamships, to heat and light our cities, to perform all the multifarious tasks of modern life, was conveyed by the ether. Without that universal carrier of energy we should have nothing but a stagnant, lifeless world.

We have said that light consists of waves. The ether may be considered as resembling, in some respects, a jelly. It can transmit vibrations. The waves of light are really excessively small ripples, measuring from crest to crest. The distance from crest to crest of the ripples in a pond is sometimes no more than an inch or two. This distance is enormously great compared to the longest of the wave-lengths that constitute light. We say the longest, for the waves of light differ in length; the colour depends upon the length of the light. Red light has the longest waves and violet the shortest. The longest waves, the waves of deep-red light, are seven two hundred and fifty thousandths of an inch in length ($\frac{7}{250,000}$ inch). This is nearly twice the length of deep-violet light-waves, which are $\frac{1}{67,000}$ inch. But light-waves, the waves that affect the eye, are not the only waves carried by the ether. Waves too short to affect the eye can affect the photographic plate, and we can discover in this way the existence of waves only half the length of the deep-violet waves. Still shorter waves can be discovered, until we come to those excessively minute rays, the X-rays.

But we can extend our investigations in the other direction; we find that the ether carries many waves longer than light-waves.

Below the Limits of Visibility.

Special photographic emulsions can reveal the existence of waves five times longer than violet-light waves. Extending below the limits of visibility are waves we detect as heat-waves. Radiant heat, like the heat from a fire, is also a form of wave-motion in the ether, but the waves our senses recognise as heat are longer than light-waves. There are longer waves still, but our senses do not recognise them. But we can detect them by our instruments. These are the waves used in wireless telegraphy, and their length may be, in some cases, measured in miles. These waves are the so-called electro-magnetic waves. Light, radiant heat, and electro-magnetic waves are all of the same nature; they differ only as regards their wave-lengths.

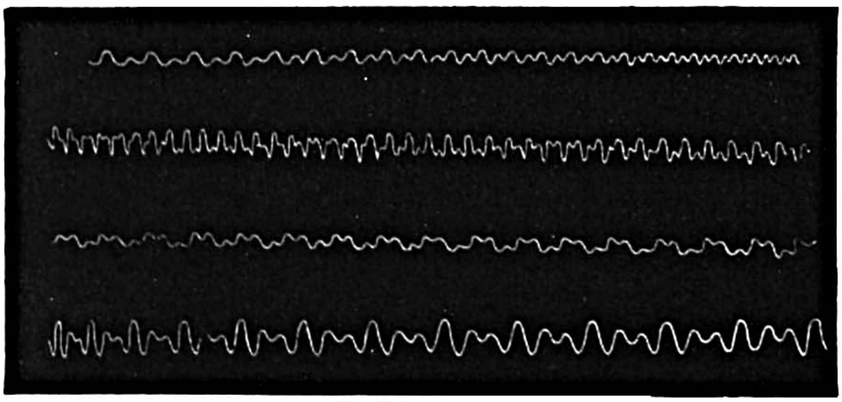
LIGHT—VISIBLE AND INVISIBLE

If Light, then, consists of waves transmitted through the ether, what gives rise to the waves? Whatever sets up such wonderfully rapid series of waves must be something with an enormous vibration. We come back to the electron: all atoms of matter, as we have seen, are made up of electrons revolving in a regular orbit round a nucleus. These electrons may be affected by outside influences, they may be agitated and their speed or vibration increased.

The particles even of a piece of cold iron are in a state of vibration. No nerves of ours are able to feel and register the waves they emit, but your cold poker is really radiating, or sending out a series of wave-movements, on every side.

Electrons and Light.

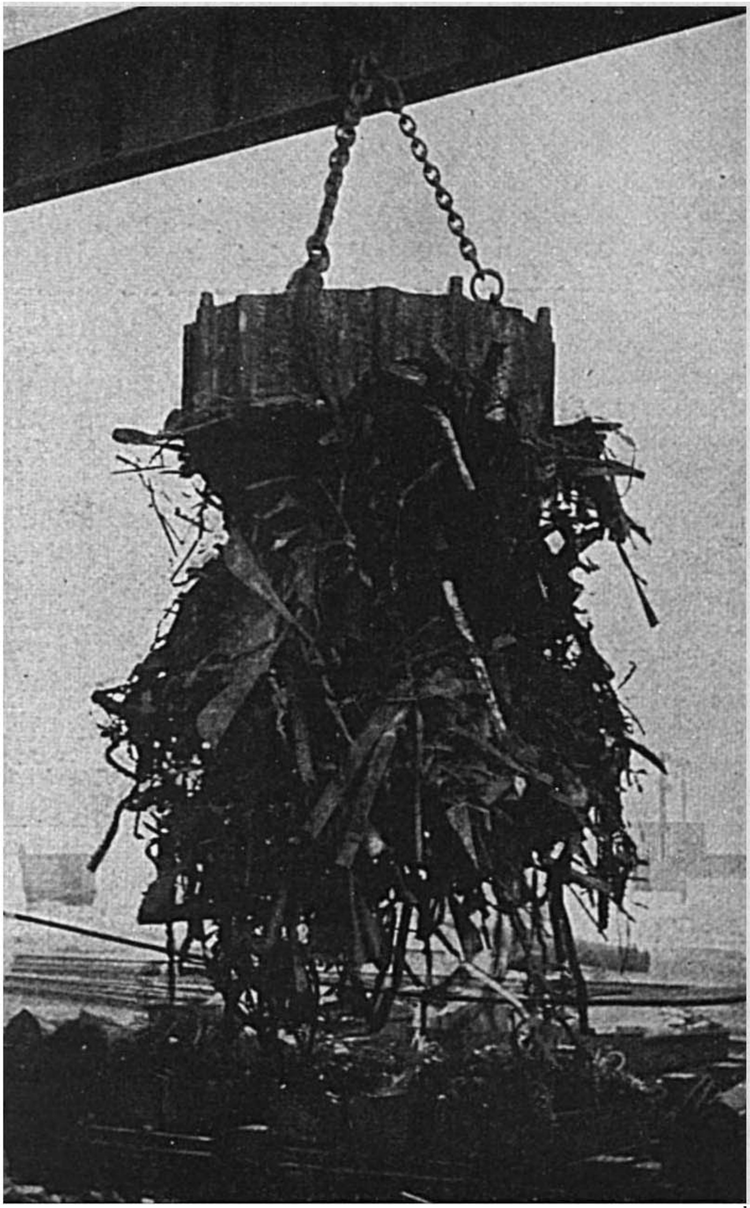
After what we saw about the nature of matter, this will surprise none. Put your poker in the fire for a time. The particles of the glowing coal, which are violently agitated, communicate some of their energy to the particles of iron in the poker. They move to and fro more rapidly, and the



WAVE SHAPES.

Wave-motions are often complex. The above illustration shows some fairly complicated wave shapes. All such wave-motions can be produced by superposing a number of simple wave forms.

waves which they create are now able to affect your nerves and cause a sensation of heat. Put the poker again in the fire, until its temperature rises to 500° C. It begins to glow with a dull red. Its particles are now moving very violently, and the waves they send out are so short and rapid that they can be picked up by the eye—we have *visible* light. They would still not affect a photographic plate. Heat the iron further, and the crowds of electrons now send out waves of various lengths which blend into white light. What is happening is the agitated electrons flying round in their orbits at a speed of billions of times a second. Make the iron "blue hot," and it pours out, in addition to light, the *invisible* waves which alter the film on the photographic plate. And beyond these there is a long range of still shorter waves, culminating in the X-rays, which will pass between the atoms of flesh or stone.



THE POWER OF A MAGNET.

The illustration is that of a "Phœnix" electric magnet lifting scrap from railway trucks. The magnet is 52 inches in diameter and lifts a weight of 26 tons. The same type of magnet, 62 inches in diameter, lifts a weight of 40 tons.

Nearly two hundred and fifty years ago it was proved that light travelled at least 600,000 times faster than sound. Jupiter, as we saw, has moons, which circle round it. They pass behind the body of the planet, and reappear at the other side. But it was noticed that, when Jupiter is at its greatest distance from us, the reappearance of the moon from behind it is 16 minutes and 36 seconds later than when the planet is nearest to us. Plainly this was because light took so long to cover the additional distance. The distance was then imperfectly known, and the speed of light was underrated. We now know the distance, and we easily get the velocity of light.

No doubt it seems far more wonderful to discover this within the walls of a laboratory, but it was done as long ago as 1850. A cogged wheel is so mounted that a ray of light passes between two of the teeth and is reflected back from a mirror. Now, slight as is the fraction of a second which light takes to travel that distance, it is possible to give such speed to the wheel that the next tooth

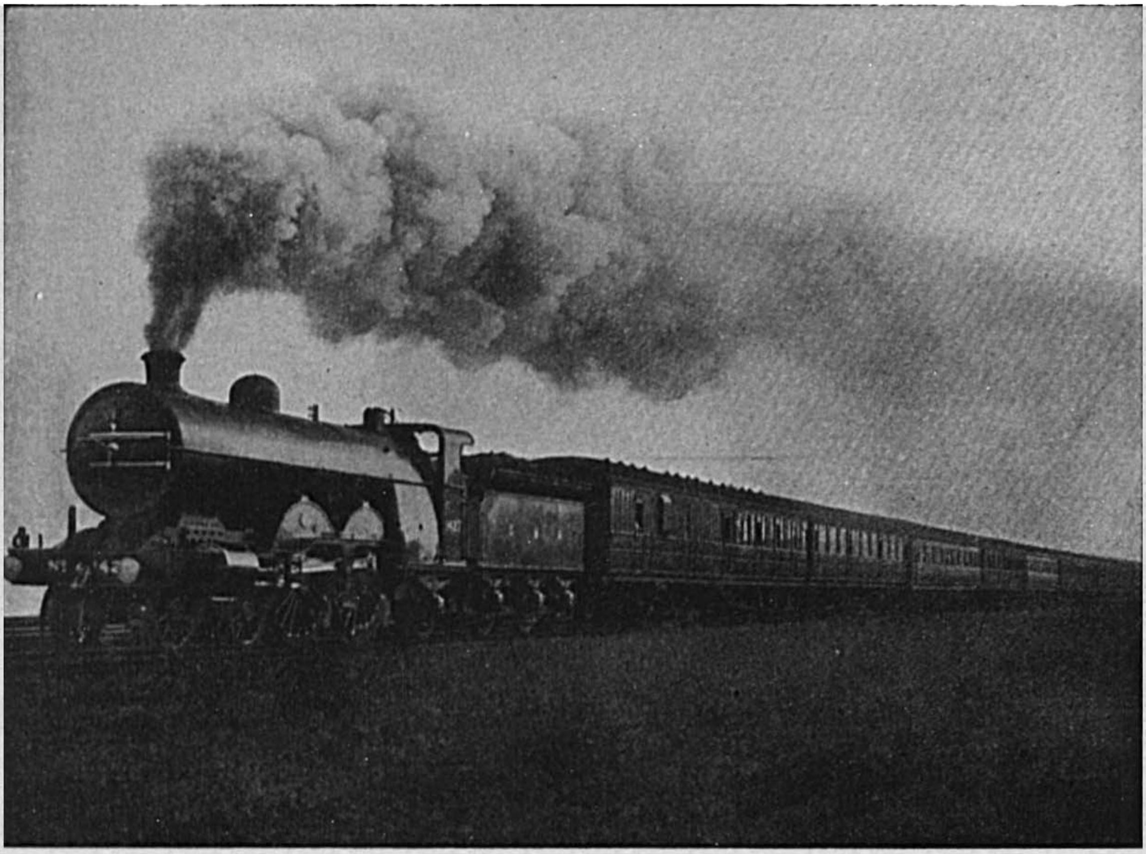


Photo: The Locomotive Publishing Co., Ltd.

THE SPEED OF LIGHT.

A train travelling at the rate of sixty miles per hour would take rather more than seventeen and a quarter days to go round the earth at the equator, i.e. a distance of 25,000 miles. Light, which travels at the rate of 186,000 miles per second, would take between one-seventh and one-eighth of a second to go the same distance.

catches the ray of light on its return and cuts it off. The speed is increased still further until the ray of light returns to the eye of the observer through the notch *next* to the one by which it had passed to the mirror! The speed of the wheel was known, and it was thus possible again to gather the velocity of light. If the shortest waves are $\frac{1}{67,000}$ of an inch in length, and light travels at 186,000 miles a second, any person can work out that about 800 billion waves enter the eye in a second when we see "violet."

Sorting out Light-waves.

The waves sent out on every side by the energetic electrons become faintly visible to us when they reach about $\frac{1}{34,000}$ of an inch. As they become shorter and more rapid, as the electrons increase their speed, we get, in succession, the colours red, orange, yellow, green, blue, indigo, and violet. Each distinct sensation of colour means a wave of different length. When they are all mingled together, as in the light of the sun, we get white light. When this white light passes through glass, the speed of the waves is lessened; and, if the ray of light falls obliquely on a triangular piece of glass, the waves of different lengths part company as they travel through it, and the light is spread out in a band of rainbow-colour. The waves are sorted out according to their lengths in the "obstacle race" through the glass. Anyone may see this for himself by holding up a wedge-shaped piece of crystal between the sunlight and the eye; the prism separates the sunlight into its constituent colours, and these various colours will be seen quite readily. Or the thing may be realised in another way. If the seven colours are painted on a wheel as shown on page 209 (in the proportion shown), and the wheel rapidly revolved on a pivot, the wheel will appear a dull white, the several colours will not be seen. But *omit* one of the colours, then the wheel, when revolved, will not appear white, but will give the impression of one colour, corresponding to what the union of six colours gives. Another experiment will show that some bodies held up between the eye and a white light will not permit all the rays to pass through, but will intercept some; a body that intercepts all the seven rays except red will give the impression of red, or if all the rays except violet, then violet will be the colour seen.

The Fate of the World.

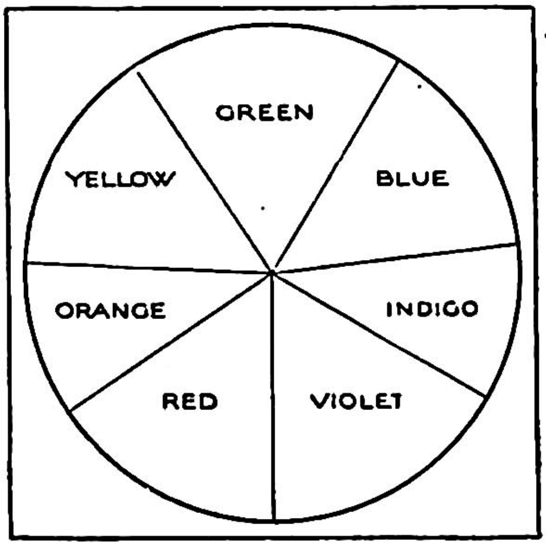
Professor Soddy has given an interesting picture of what might happen when the sun's light and heat is no longer what it is. The human eye "has adapted itself through the ages to the peculiarities of the sun's light, so as to make the most of that wave-length of which there is most. . . . Let us indulge for a moment in these gloomy prognostications, as to the consequences to this earth of the cooling of the sun with the lapse of ages, which used to be in vogue, but which radioactivity has so rudely shaken. Picture the fate of the world when the sun has become a dull red hot ball, or even when it has cooled so far that it would no longer emit light to us. That does not all mean that the world would be in inky darkness, and that the sun would not emit light to the people then inhabiting this world, if any had survived and could keep themselves from freezing. To such, if the eye continued to adapt itself to the changing conditions, our blues and violets would be ultra-violet and invisible, but our dark heat would be light and hot bodies would be luminous to them which would be dark to us."

§ 12

What the Blue "Sky" means.

We saw in a previous chapter how the spectroscope splits up light-waves into their colours. But nature is constantly splitting the light into its different-lengthed waves, its colours. The rainbow, where dense moisture in the air acts as a spectroscope, is the most familiar example. A piece of mother-of-pearl, or even a film of oil on the street or on water, has the same effect, owing to the fine inequalities in its surface. The atmosphere all day long is sorting out the waves. The blue "sky" overhead means that the fine particles in the upper atmosphere catch the shorter waves, the blue waves, and scatter them. We can make a tubeful of blue sky in the laboratory at any time. The beautiful pink-flush on the Alps at sunrise, the red glory that lingers in the west at sunset, mean that, as the sun's rays must struggle through denser masses of air when it is low on the horizon, the long red waves are sifted out from the other shafts.

Then there is the varied face of nature which, by absorbing some waves and reflecting others, weaves its own beautiful robe of colour. Here and there is a black patch, which *absorbs* all the light. White surfaces *reflect* the whole of it.



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What is reflected depends on the period of vibration of the electrons in the particular kind of matter. Generally, as the electrons receive the flood of billions of waves, they absorb either the long or the medium or the short, and they give us the wonderful colour-scheme of nature. In some cases the electrons continue to radiate long after the sunlight has ceased to fall upon them. We get from them "black" or invisible light, and we can take photographs by it. Other bodies, like glass, vibrate in unison with the period of the light-waves and let them stream through.

Light without Heat.

There are substances—"phosphorescent" things we call them—which give out a mysterious cold light of their own. It is one of the problems of science, and one of profound practical interest. If we could produce light without heat our "gas bill" would shrink amazingly. So much energy is wasted in the production of heat-wavec and ultra-violet waves which we do not want, that 90 per cent. or more of the power used in illumination is wasted. Would that the glow-worm, or even the dead herring, would yield us its secret! Phosphorus is the one thing we know as yet that suits the purpose, and—it smells! Indeed, our artificial light is not only extravagant in cost, but often poor in colour. The unwary person often buys a garment by artificial light, and is disgusted next morning to find in it a colour which is not wanted. The colour disclosed by the sun was not in the waves of the artificial light.

Beyond the waves of violet light are the still shorter and more rapid waves—the "ultra-violet" waves—which are precious to the photographer. As every amateur knows, his plate may safely be exposed to light that comes through a red or an orange screen. Such a screen means "no thoroughfare" for the blue and "beyond-blue" waves, and it is these which arrange the little grains of silver on the plate. It is the same waves which supply the energy to the little green grains of matter (chlorophyll) in the plant, preparing our food and timber for us, as will be seen later. The tree struggles upward and spreads out its leaves fanwise to the blue sky to receive them. In our coal-measures, the mighty dead forests of long ago, are vast stores of sunlight which we are prodigally using up.

The X-rays are the extreme end, the highest octave, of the series of waves. Their power of penetration implies that they are excessively minute, but even these have not held their secret from the modern physicist. From a series of beautiful experiments, in which they were made to pass amongst the atoms of a crystal, we learned their length. It is about the ten-millionth of a millimetre, and a millimetre is about the $\frac{1}{25}$ of an inch!

One of the most recent discoveries, made during a recent eclipse of the sun, is that light is subject to gravitation. A ray of light from a star is bent out of its straight path when it passes near the mass of the sun. Professor Eddington tells us that we have as much right to speak of a pound of light as of a pound of sugar. Professor Eddington even calculates that the earth receives 160 tons of light from the sun every year!

ENERGY: HOW ALL LIFE DEPENDS ON IT

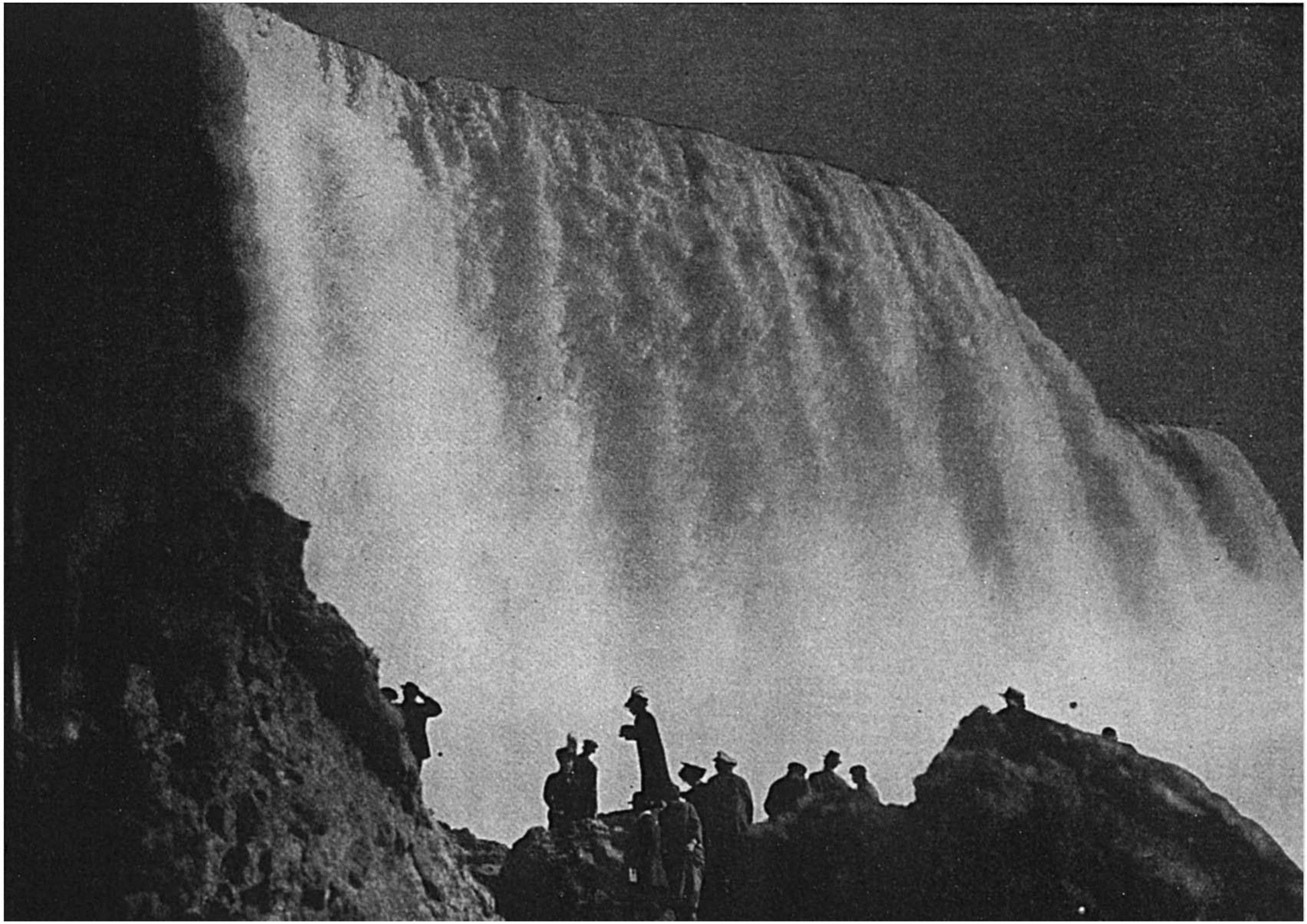
As we have seen in an earlier chapter, one of the fundamental entities of the universe is matter. A second, not less important, is called energy. Energy is indispensable if the world is to continue to exist, since all phenomena, including life, depend on it. Just as it is humanly impossible to create or to destroy a particle of matter, so is it impossible to create or to destroy energy. This statement will be more readily understood when we have considered what energy is.

Energy, like matter, is indestructible, and just as matter exists in various forms so does energy. And we may add, just as we are ignorant of what the negative and positive particles of electricity which constitute matter really are, so we are ignorant of the true nature of energy. At the same time, energy is not so completely mysterious as it once was. It is another of nature's mysteries which the advance of modern science has in some measure unveiled. It was only during the nineteenth century that energy came to be known as something as distinct and permanent as matter itself.

Forms of Energy.

The existence of various forms of energy had been known, of course, for ages; there was the energy of a falling stone, the energy produced by burning wood or coal or any other substance, but the essential *identity* of all these forms of energy had not been suspected. The conception of energy as something which, like matter, was constant in amount, which could not be created nor destroyed, was one of the great scientific acquisitions of the past century.

It is not possible to enter deeply into this subject here. It is sufficient if we briefly out-



NIAGARA FALLS.

The energy of this falling water is prodigious. It is used to generate thousands of horse power in great electrical installations. The power is used to drive electric trams in cities 150 to 250 miles away.

line its salient aspects. Energy is recognised in two forms, kinetic and potential. The form of energy which is most apparent to us is the *energy of motion*; for example, a rolling stone, running water, a falling body, and so on. We call the energy of motion *kinetic energy*. Potential energy is the energy a body has in virtue of its position—it is its capacity, in other words, to acquire kinetic energy, as in the case of a stone resting on the edge of a cliff.

Energy may assume different forms; one kind of energy may be converted directly or indirectly into some other form. The energy of burning coal, for example, is converted into heat, and from heat energy we have mechanical energy, such as that manifested by the steam-engine. In this way we can transfer energy from one body to another. There is the energy of the great waterfalls of Niagara, for instance, which are used to supply the energy of huge electric power stations.

An important fact about energy is, that all energy *tends to take the form of heat energy*. The impact of a falling stone generates heat; a waterfall is hotter at the bottom than at the top—the falling particles of water, on striking the ground, generate heat; and most chemical changes are attended by heat changes. Energy may remain latent indefinitely in a lump of wood, but in combustion it is liberated, and we have heat as a result. The atom of radium or of any other radio-active substance, as it disintegrates, generates heat. "Every hour radium generates sufficient heat to raise the temperature of its own weight of water, from the freezing point to the boiling point." And what is heat? *Heat is molecular motion*. The molecules of every substance, as we have seen on a previous page, are in a state of continual motion, and the more vigorous the motion the hotter the body. As wood or coal burns, the invisible molecules of these substances are violently agitated, and give rise to ether waves which our senses interpret as light and heat. In this constant movement of the molecules, then, we have a manifestation of the energy of motion and of heat.

What Heat is.

That energy which disappears in one form reappears in another has been found to be universally true. It was Joule who, by churning water, first showed that a measurable quantity of mechanical energy could be transformed into a measurable quantity of heat energy. By causing an apparatus to stir water vigorously, that apparatus being driven by falling weights or a rotating flywheel or by any other mechanical means, the water became heated. A certain amount of mechanical energy had been used up and a certain amount of heat had appeared. The relation between these two things was found to be invariable. Every physical change in nature involves a transformation of energy, but the total quantity of energy in the universe remains unaltered. This is the great doctrine of the Conservation of Energy.

§ 13

Consider the source of nearly all the energy which is used in modern civilisation—coal. The great forests of the Carboniferous epoch now exist as beds of coal. By the burning of coal—a chemical transformation—the heat energy is produced on which at present our whole civilization depends. Whence is the energy locked up in the coal derived? From the sun. For millions of years the energy of the sun's rays had gone to form the vast vegetation of the Carboniferous era and had been transformed, by various subtle processes, into the potential energy that slumbers in those immense fossilized forests.

Substitutes for Coal.

The exhaustion of our coal deposits would mean, so far as our knowledge extends at present, the end of the world's civilisation. There are other known sources of energy, it is true. There is the energy of falling water; the great falls of Niagara are used to supply the energy of huge electric power stations. Perhaps, also, something could be done to utilise the energy of the tides—another instance of the energy of moving water. And attempts have been made to utilise directly the energy of the sun's rays. But all these sources of energy are small compared with the energy of coal. A suggestion was made at a recent British Association meeting that deep borings might be sunk in order to utilise the internal heat of the earth, but this is not, perhaps, a very practical proposal. By far the most effective substitutes for coal would be found in the interior energy of the atom, a source of energy which, as we have seen, is practically illimitable. If the immense electrical energy in the interior of the atom can ever be liberated and controlled, then our steadily decreasing coal supply will no longer be the bugbear it now is to all thoughtful men.

The stored-up energy of the great coal-fields can be used up, but we cannot replace it or create fresh supplies. As we have seen, energy cannot be destroyed, but it can become *unavailable*. Let us consider what this important fact means.

Photo: Stephen Cribb.

TRANSFORMATION OF ENERGY.

An illustration of Energy. The chemical energy brought into existence by firing the explosive manifesting itself as mechanical energy, sufficient to impart violent motion to tons of water.

§ 14

Dissipation of Energy.

Energy may become dissipated. Where does it go? since if it is indestructible it must still exist. It is easier to ask the question than to give a final answer, and it is not possible in this OUTLINE, where an advanced knowledge of physics is not assumed on the part of the reader, to go fully into the somewhat difficult theories put forward by physicists and chemists. We may raise the temperature, say, of iron, until it is white-hot. If we stop the process the temperature of the iron will gradually settle down to the temperature of surrounding bodies. As it does so, where does its previous energy go? In some measure it may pass to other bodies in contact with the piece of iron, but ultimately the heat becomes radiated away in space where we cannot follow it. It has been added to the vast reservoir of *unavailable* heat energy of uniform temperature. It is sufficient here to say that if all bodies had a uniform temperature we should experience no such thing as heat, because heat only travels from one body to another, having the effect of cooling the one and warming the other. In time the two bodies acquire the same temperature. The sum-total of the heat in any body is measured in terms of the kinetic energy of its moving molecules.

There must come a time, so far as we can see at present, when, even if all the heat energy of the universe is not radiated away into empty infinite space, yet a uniform temperature will prevail. If one body is hotter than another it radiates heat to that body until both are at the same temperature. Each body may still possess a considerable quantity of heat energy, which it has absorbed, but that energy, so far as reactions between those two bodies are con-

Photo: Underwood & Underwood.

"BOILING" A KETTLE ON ICE.

When a kettle containing liquid air is placed on ice it "boils," because the ice is intensely hot *when compared with the very low temperature of the liquid air.*

cerned, ***is now unavailable.*** The same principle applies whatever number of bodies we consider. Before heat energy can be utilised we must have bodies with different temperatures. If the whole universe were at some uniform temperature, then, although it might possess an enormous amount of heat energy, this energy would be unavailable.

And what does this imply? It implies a great deal: for if all the energy in the world became unavailable, the universe, as it now is, would cease to be. It is possible that, by the constant interchange of heat radiations, the whole universe is tending to some uniform temperature, in which case, although all molecular motion would not have ceased, it would have become unavailable. In this sense it may be said that the universe is running down.

What a Uniform Temperature would mean.

If all the molecules of a substance were brought to a standstill, that substance would be at the absolute zero of temperature. There could be nothing colder. The temperature at which all molecular motions would cease is known: it is -273° C. No body could possibly attain a lower temperature than this: a lower temperature could not exist. Unless there exists in nature some process, of which we know nothing at present, whereby energy is renewed, our solar system must one day sink to this absolute zero of temperature. The sun, the earth, and every other body in the universe is steadily radiating heat, and this radiation cannot go on for ever, because heat continually tends to diffuse and to equalise temperatures.

But we can see, theoretically, that there is a way of evading this law. If the chaotic molecular motions which constitute heat could be ***regulated***, then the heat energy of a body could be utilised directly. Some authorities think that some of the processes which go on in the living body do not involve any waste energy, that the chemical energy of food is transformed directly into work without any of it being dissipated as useless heat energy. It may be, therefore, that man will finally discover some way of escape from the natural law that, while energy cannot be destroyed, it has a tendency to become unavailable.

The primary reservoir of energy is the atom; it is the energy of the atom, the atom of elements in the sun, the stars, the earth, from which nature draws for all her supply of energy. Shall we ever discover how we can replenish the dwindling resources of energy, or find out how we can call into being the at present unavailable energy which is stored up in uniform temperature? "It looks as if our successors would witness an interesting race, between the progress of science on the one hand and the depletion of natural resources upon the other. The natural rate of flow of energy from its primary atomic reservoirs to the sea of waste heat energy of uniform temperature, allows life to proceed at a complete pace sternly regulated by the inexorable laws of supply and demand, which the biologists have recognised in their field as the struggle for existence." [1]

It is certain that energy is an actual entity just as much as matter, and that it cannot be created or destroyed. Matter and ether are receptacles or vehicles of energy. As we have said, what these entities really are in themselves we do not know. It may be that all forms of energy are in some fundamental way aspects of the same primary entity which constitutes matter: how all matter is constituted of particles of electricity we have already seen. The question to which we await an answer is: What is electricity?

§ 15

MATTER, ETHER, AND EINSTEIN

The supreme synthesis, the crown of all this progressive conquest of nature, would be to discover that the particles of positive and negative electricity, which make up the atoms of matter, are points or centres of disturbances of some kind in a universal ether, and that all our "energies" (light, magnetism, gravitation, etc.) are waves or strains of some kind set up in the ether by these clusters of electrons.

It is a fascinating, tantalising dream. Larmor suggested in 1900 that the electron is a tiny whirlpool, or "vortex," in ether; and, as such a vortex may turn in either of two opposite ways, we seem to see a possibility of explaining positive and negative electricity. But the difficulties have proved very serious, and the nature of the electron is unknown. A recent view is that it is "a ring of negative electricity rotating about its axis at a high speed," though that does not carry us very far. The unit of positive electricity is even less known. We must be content to know the general lines on which thought is moving toward the final unification.

We say "unification," but it would be a grave error to think that ether is the only possible basis for such unity, or to make it an essential part of one's philosophy of the universe. Ether was never more than an imagined entity to which we ascribed the most extraordinary properties, and which seemed then to promise considerable aid. It was conceived as an elastic solid of very great density, stretching from end to end of the universe, transmitting waves from star to star at the rate of 186,000 miles a second; yet it was believed that the most solid matter passed through it as if it did not exist.

Some years ago a delicate experiment was tried for the purpose of detecting the ether. Since the earth, in travelling round the sun, must move through the ether if the ether exists, there ought to be a stream of ether flowing through every laboratory; just as the motion of a ship through a still atmosphere will make "a wind." In 1887 Michelson and Morley tried to detect this. Theoretically, a ray of light in the direction of the stream ought to travel at a different rate from a ray of light against the stream or across it. They found no difference, and scores of other experiments have failed. This does not prove that there is no ether, as there is reason to suppose that our instruments would appear to shrink in precisely the same proportion as the alteration of the light; but the fact remains that we have no proof of the existence of ether. J. H. Jeans says that "nature acts as if no such thing existed." Even the phenomena of light and magnetism, he says, do not imply ether; and he thinks that the hypothesis may be abandoned. The primary reason, of course, for giving up the notion of the ether is that, as Einstein has shown, there is no way of detecting its existence. If there is an ether, then, since the earth is moving through it, there should be

[1] *Matter and Energy*, by Professor Soddy.

some way of detecting this motion. The experiment has been tried, as we have said, but, although the method used was very sensitive, no motion was discovered. It is Einstein who, by revolutionising our conceptions of space and time, showed that no such motion ever could be discovered, whatever means were employed, and that the usual notion of the ether must be abandoned. We shall explain this theory more fully in a later section.

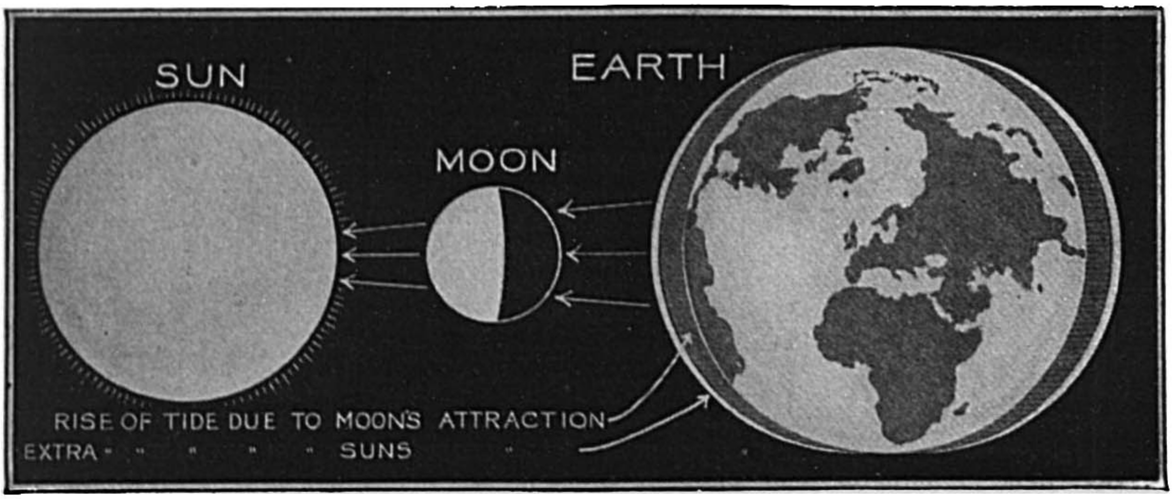
INFLUENCE OF THE TIDES: ORIGIN OF THE MOON: THE EARTH SLOWING DOWN

§ 16

Until comparatively recent times, until, in fact, the full dawn of modern science, the tides ranked amongst the greatest of nature's mysteries. And, indeed, what agency could be invoked to explain this mysteriously regular flux and reflux of the waters of the ocean? It is not surprising that that steady, rhythmical rise and fall suggested to some imaginative minds the breathing of a mighty animal. And even when man first became aware of the fact that this regular movement was somehow associated with the moon, was he much nearer an explanation? What bond could exist between the movements of that distant world and the diurnal variation of the waters of the earth? It is reported that an ancient astronomer, despairing of ever resolving the mystery, drowned himself in the sea.

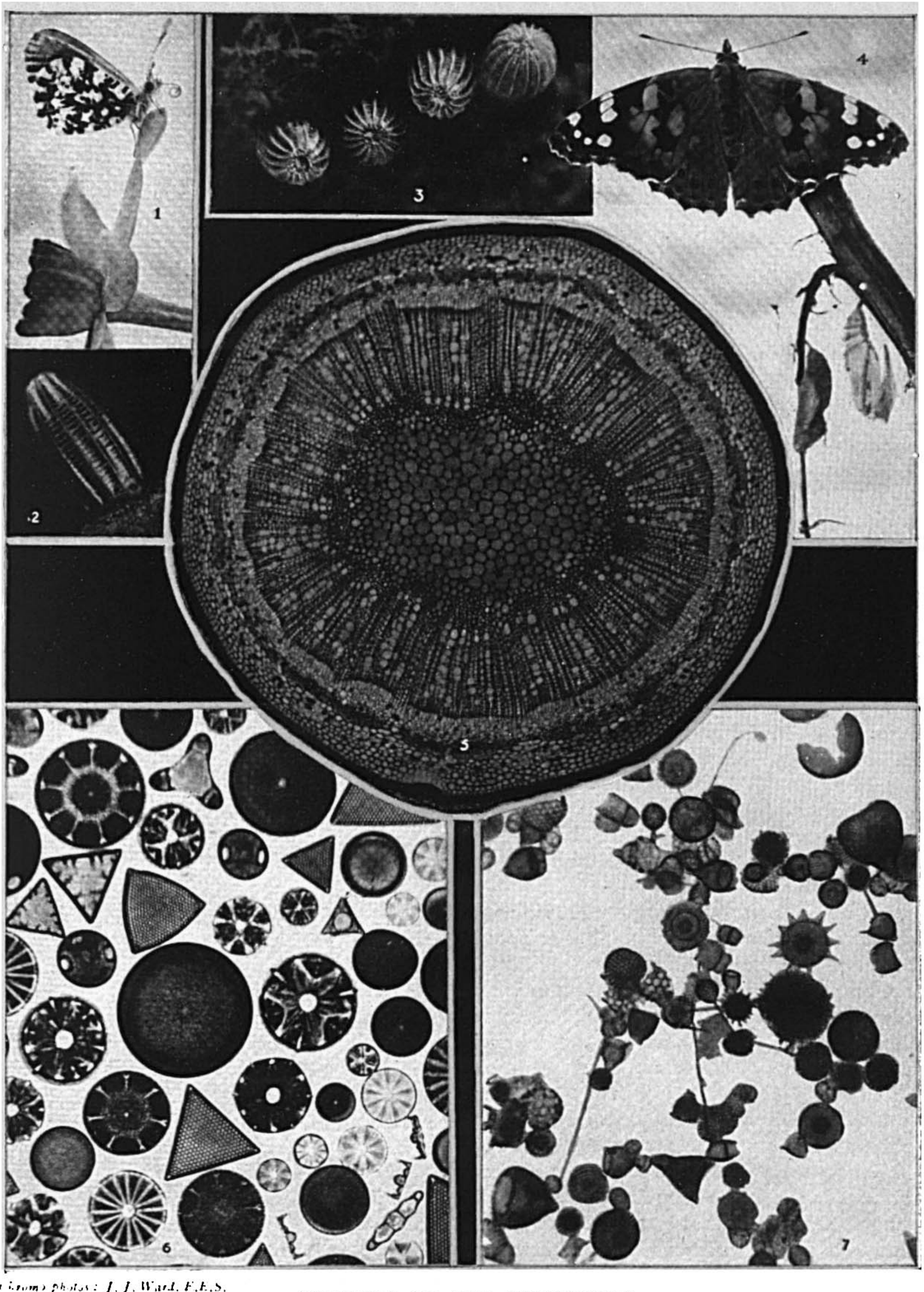
But it was part of the merit of Newton's mighty theory of gravitation that it furnished an explanation even of this age-old mystery. We can see, in broad outlines at any rate, that the theory of universal attraction can be applied to this case. For the moon, Newton taught us, pulls every particle of matter throughout the earth. If we imagine that part of the earth's surface which comprises the Pacific Ocean, for instance, to be turned towards the moon, we see that the moon's pull, *acting on the loose and mobile water*, would tend to heap it up into a sort of mound. The whole earth is pulled by the moon, but the water is more free to obey this pull than is the solid earth, although small tides are also caused in the earth's solid crust. It can be shown also that a corresponding hump would tend to be produced on the other side of the earth, owing, in this case, to the tendency of the water, being more loosely

The Earth pulled by the Moon.



THE CAUSE OF TIDES.

The tides of the sea are due to the pull of the moon, and, in lesser degree, of the sun. The whole earth is pulled by the moon, but the loose and mobile water is more free to obey this pull than is the solid earth, although small tides are also caused in the earth's solid crust. The effect which the tides have on slowing down the rotation of the earth is explained in the text.



Chromo photos: J. J. Ward, F.E.S.

WONDERS OF THE MICROSCOPE

1. Male Orange-tip Butterfly (*Euchloe cardamines*) uncoiling its proboscis. 2. Egg of Orange-tip Butterfly, magnified 25 diameters. 3. Eggs of Painted Lady Butterfly, magnified 25 diameters. 4. Painted Lady Butterfly (*Pyrameis cardui*), just emerged from its chrysalis; the broken pupa skin is seen beneath. 5. Transverse section of young twig of Beech (*Fagus sylvatica*) with tissues artificially stained to aid in their identification, e.g. innermost the pith (green), the wood (blue), magnified 40 diameters. 6. Siliceous shells which enclose the microscopic plants called Diatoms, magnified 100 diameters. 7. Siliceous skeletons of the unicellular animals known as Radiolaria, magnified 100 diameters.

connected, to lag behind the solid earth. If the earth's surface were entirely fluid the rotation of the earth would give the impression that these two humps were continually travelling round the world, once every day. At any given part of the earth's surface, therefore, there would be two humps daily, i.e. two periods of high water. Such is the simplest possible outline of the gravitational theory of the tides.

The actually observed phenomena are vastly more complicated, and the complete theory bears very little resemblance to the simple form we have just outlined. Everyone who lives in the neighbourhood of a port knows, for instance, that high water seldom coincides with the time when the moon crosses the meridian. It may be several hours early or late. High water at London Bridge, for instance, occurs about one and a half hours after the moon has passed the meridian, while at Dublin high water occurs about one and a half hours before the moon crosses the meridian. The actually observed phenomena, then, are far from simple; they have, nevertheless, been very completely worked out, and the times of high water for every port in the world can now be prophesied for a considerable time ahead.

The Action of Sun and Moon.

It would be beyond our scope to attempt to explain the complete theory, but we may mention one obvious factor which must be taken into account. Since the moon, by its gravitational attraction, produces tides, we should expect that the sun, whose gravitational attraction is so much stronger, should also produce tides and, we would suppose at first sight, more powerful tides than the moon. But while it is true that the sun produces tides, it is not true that they are more powerful than those produced by the moon. The sun's tide-producing

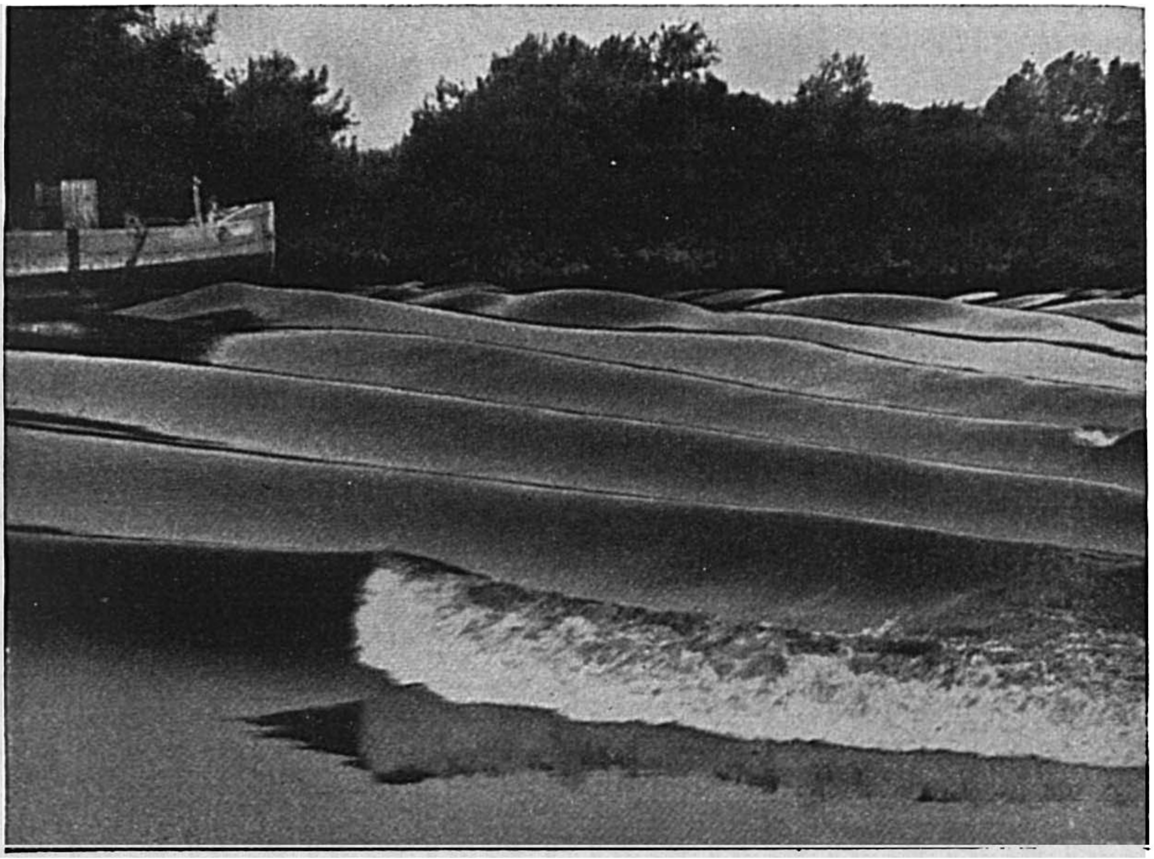


Photo: G. Brocklehurst.

THE AEGIR ON THE TRENT.

An exceptionally smooth formation due to perfect weather conditions. The wall-like formation of these tidal waves (see also page 219) will be noticed. The reason for this is that the downward current in the river heads the sea-water back, and thus helps to exaggerate the advancing slope of the wave. The exceptional spring tides are caused by the combined operation of the moon and the sun, as is explained in the text.

power is, as a matter of fact, less than half that of the moon. The reason of this is that *distance* plays an enormous rôle in the production of tides. The mass of the sun is 26,000,000 times that of the moon; on the other hand it is 386 times as far off as the moon. This greater distance more than counterbalances its greater mass, and the result, as we have said, is that the moon is more than twice as powerful. Sometimes the sun and moon act together, and we have what are called spring tides; sometimes they act against one another, and we have neap tides. These effects are further complicated by a number of other factors, and the tides, at various places, vary enormously. Thus at St. Helena the sea rises and falls about three feet, whereas in the Bay of Fundy it rises and falls more than fifty feet. But here, again, the reasons are complicated.

§ 17

Origin of the Moon.

But there is another aspect of the tides which is of vastly greater interest and importance than the theory we have just been discussing. In the hands of Sir George H. Darwin, the son of Charles Darwin, the tides had been made to throw light on the evolution of our solar system. In particular, they have illustrated the origin and development of the system formed by our earth and moon. It is quite certain that, long ages ago, the earth was rotating immensely faster than it is now, and that the moon was so near as to be actually in contact with the earth. In that remote age the moon was just on the point of separating from the earth, of being thrown off by the earth. Earth and moon were once one body, but the high rate of rotation caused this body to split up into two pieces; one piece became the earth we now know, and the other became the moon. Such is the conclusion to which we are led by an examination of the tides. In the first place let us consider the energy produced by the tides. We see evidences of this energy all round the world's coastlines. Estuaries are scooped out, great rocks are gradually reduced to rubble, innumerable tons of matter are continually being set in movement. Whence is this energy derived? Energy, like matter, cannot be created from nothing; what, then, is the source which makes this colossal expenditure possible.

The answer is simple, but startling. *The source of tidal energy is the rotation of the earth.*

The Earth slowing down.

The massive bulk of the earth, turning every twenty-four hours on its axis, is like a gigantic flywheel. In virtue of its rotation it possesses an enormous store of energy. But even the heaviest and swiftest flywheel, if it is doing work, or even if it is only working against the friction of its bearings, cannot dispense energy for ever. It must, gradually, slow down. There is no escape from this reasoning. It is the rotation of the earth which supplies the energy of the tides, and, as a consequence, the tides must be slowing down the earth. The tides act as a kind of brake on the earth's rotation. These masses of water, *held back by the moon*, exert a kind of dragging effect on the rotating earth. Doubtless this effect, measured by our ordinary standards, is very small; it is, however, continuous, and in the course of the millions of years dealt with in astronomy, this small but constant effect may produce very considerable results.

But there is another effect which can be shown to be a necessary mathematical consequence of tidal action. It is the moon's action on the earth which produces the tides, but they also react on the moon. The tides are slowing down the earth, and they are also driving the moon farther and farther away. This result, strange as it may seem, does not permit of doubt, for it is the result of an indubitable dynamical principle, which cannot be made clear without a mathematical discussion. Some interesting consequences follow.

Since the earth is slowing down, it follows that it was once rotating faster. There was a period, a long time ago, when the day comprised only twenty hours. Going farther back still we come to a day of ten hours, until, inconceivable ages ago, the earth must have been rotating on its axis in a period of from three to four hours.

At this point let us stop and inquire what was happening to the moon. We have seen that at present the moon is getting farther and farther away. It follows, therefore, that when the day was shorter the moon was nearer. As we go farther back in time we find the moon nearer and nearer to an earth rotating faster and faster. When we reach the period we have already mentioned, the period when the earth completed a revolution in three or four hours, we find that the moon was so near as to be almost grazing the earth. This fact is very remarkable. Everybody knows that there is a *critical velocity* for a rotating flywheel, a velocity beyond which the flywheel would fly into pieces, because the centrifugal force developed is so great as to overcome the cohesion of the molecules of the flywheel. We have already likened our earth to a flywheel, and we have traced its history back to the point where it was rotating with immense velocity. We have also seen that, at that moment, the moon was barely separated from the earth. The conclusion is irresistible. In an age more remote the earth *did* fly in pieces, and one of those pieces is the moon. Such, in brief outline, is the tidal theory of the origin of the earth–moon system.

The Day becoming longer.

At the beginning, when the moon split off from the earth, it obviously must have shared the earth's rotation. It flew round the earth in the same time that the earth rotated, that is to say, the month and the day were of equal length. As the moon began to get farther from the earth, the month, because the moon took longer to rotate round the earth, began to get correspondingly longer. The day also became longer, because the earth was slowing down, taking longer to rotate on its axis, but the month increased at a greater rate than the day. Presently the month became equal to two days, then to three, and so on. It has been calculated that this process went on until there were twenty-nine days in the month. After that the number of days in the month began to decrease until it reached its present value or magnitude, and will continue to decrease until once more the month and the day are equal. In that age the earth will be rotating very slowly. The braking action of the tides will cause the

Photo: G. Brocklehurst.

A BIG SPRING TIDE, THE AEGIR ON THE TRENT.

earth always to keep the same face to the moon; it will rotate on its axis in the same time that the moon turns round the earth. If nothing but the earth and moon were involved this state of affairs would be final. But there is also the effect of the solar tides to be considered. The moon makes the day equal to the month, but the sun has a tendency, by still further slowing down the earth's rotation on its axis, to make the day equal to the year. It would do this, of course, by making the earth take as long to turn on its axis as to go round the sun. It cannot succeed in this, owing to the action of the moon, but it can succeed in making the day rather longer than the month.

Surprising as it may seem, we already have an illustration of this possibility in the satellites of Mars. The Martian day is about one half-hour longer than ours, but when the two minute satellites of Mars were discovered it was noticed that the inner one of the two revolved round Mars in about seven hours forty minutes. In one Martian day, therefore, one of the moons of Mars makes more than three complete revolutions round that planet, so that, to an inhabitant of Mars, there would be more than three months in a day.

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