BEYOND THE ELECTRON

Not so very long ago the atom was thought to be a terminus beyond which it was impossible from the nature of things to penetrate. The atom was regarded as indivisible, impenetrable, eternal, unaffected by heat, electricity or any other physical agent. The inside of the atom was regarded as a territory which the physicist could never enter. Then there came a time when the sanctuary of the atom was invaded, and it was found that the atom was built up of smaller parts—of electrons carrying a charge of negative, and of protons carrying a charge of positive electricity. Means were devised for counting the number of electrons in an atom, and it was found that the atom, instead of being just the little hard solid particle of the original view, was a very complex thing, comparable in complexity with the Solar System. It was found moreover that it was this complexity, this fine structure inside the atom, which endowed matter with its electrical and chemical properties. If we have any insight into these properties, it is due not so much to the idea that matter consists of a large number of small particles as to the knowledge we have obtained of individual particles and their electronic structure. Experiments told us what was the mass of the electron and the total charge of electricity associated with it; they did not however tell us anything about its structure; they did not tell us for example whether it was just a point charge of negative electricity or whether like the atom it was made up of smaller parts, sub-electrons and sub-protons as it were. It is true that there is no evidence that there are different kinds of electrons as there are different kinds of atoms, but this may be because one kind of electron is so much more stable than any other that the number of the latter is quite insignificant. In the absence of definite knowledge it was natural to begin with the simplest assumption and regard the electron as a single point charge surrounded by a structureless medium. The mathematics are simpler on this view than on any other; this however is not conclusive, as there is no evidence that the convenience of mathematicians has been a dominant factor in the scheme of the Universe.

It was therefore not improbable that in the light of further knowledge this view of the electron might prove as untenable as the corresponding view for the atom. My object this afternoon is to point out that this further knowledge has come, and that the electron and its surroundings must have a structure very different from that first assigned to them.

Perhaps some of you may ask, Is not going beyond the electron really going too far, ought one not to draw the line somewhere? It is the charm of Physics that there are no hard and fast boundaries, that each discovery is not a terminus but an avenue leading to country as yet unexplored, and that however long the science may exist there will still be an abundance of unsolved problems and no danger of unemployment for physicists.

The reason why we have to give up the old view of the electron is that it has recently been shown that a moving electron, even a uniformly moving one, is always accompanied by a series of waves. These waves as it were carry it along and determine the way it is to go; thus a moving electron is a much more complicated thing than a small point charge of electricity in uniform motion.

The clearest evidence for the existence of these waves round the electron is, I think, given by a research by my son, Professor G. P. Thomson, on the effects to be observed when electrons pass through exceedingly thin plates of metal—the metal has to be exceedingly thin, far thinner than the thinnest gold leaf. These plates, however, when they are obtained are exceedingly valuable physical instruments, for they enable us to test whether anything passing through them is a stream of particles or a train of waves. For suppose that we have a thin pencil of rays and we wish to determine whether these are a swarm of particles all moving in one direction or a train of waves. In either case if the pencil fell directly on a photographic plate it would produce a sharply defined image. Now let us see what would be the effect on this image of interposing the thin plate of metal. If the pencil consists of particles, these will strike against the molecules of the plate and be deflected by the collisions—how much each particle is deflected is within certain limits very much a matter of chance, so that some particles will be deflected more than others. Thus when they come out of the plate the particles will not all be moving in the same direction; the stream of particles will spread out into a cone; this will make the image they form on the photographic plate bigger and blurred, and it will become just a smudge without any definite pattern.

Suppose, however, that instead of a stream of particles we have a train of waves, then in consequence of the regular spacing of the molecules in the plate, the plate will act like a diffraction grating; and if the distance between the molecules is comparable with the length of the waves, we know from the properties of such gratings that when we interpose the plate in the way of the beam the original spot will not become just a smudge, but will be surrounded by a series of bright rings whose radii bear definite ratios to each other.

Now Fig. 1 represents the effect found by my son when he passed a stream of electrons through the plate. You see a well-developed series of rings,

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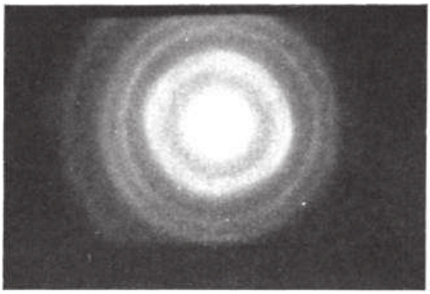

Fig. 1
Rings produced when electrons pass through a thin plate of gold.

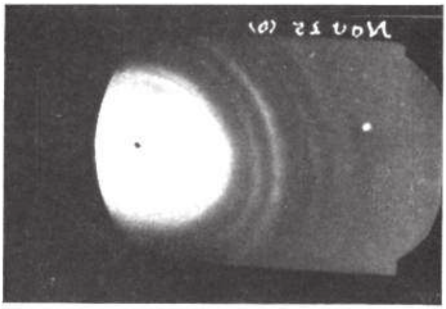

Fig. 2
Deflection of rings by a magnet.

and they are just in the position of the diffraction rings which would be produced if light of suitable wave length passed through the thin plate. That those rings marked the path of electrons was shown by bringing a magnet near the photographic plate; the rings were displaced just as the path of the electrons would be displaced (Fig. 2); this shows that the blackening of the plate is due to electrons and not to waves of light, for these would not have been affected by the magnet. Thus it appears that the electrons in their path through the metal are bent, not like particles would be bent, but in all respects like waves of a suitable wave length. Hence we conclude that the electron is accompanied by a train of waves, and that these waves have complete control over its path; the electron is compelled to follow the lead of the waves.

The thin metal film does more than detect the waves, it enables us to measure their wave length. My son did this and the results are most interesting, for it turns out that these electronic waves are of extraordinary high pitch; the pitch of the lowest is nearly a million times that of visible light, it is far higher than that of Röntgen rays, higher than all but the very hardest of the highest pitched rays hitherto known, the γ-rays emitted by radio-active substances. They introduce us to a new type of radiation whose properties may differ funda-

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mentally from any type of radiation with which we are acquainted.

Just as it was found necessary to supplement the corpuscles which, on the old corpuscular theory constituted light, by systems of waves, so it turns out that bare corpuscles of electricity are insufficient to explain the properties of electrons, and that these, like the corpuscles of light, must be accompanied by systems of waves. This duality of corpuscles and waves seems to be in evidence in many regions of physics and may be of the nature of things.

To appreciate the importance of this we must consider for a moment how energy travels from one place to another. For example, when an electron changes its position its energy moves from the old position of the electron to the new: how does this energy travel? I may perhaps make the meaning of the question clearer if I take for a moment the old idea of the electron as a sphere 10^{-13} cm. in radius. When this moves does the energy travel, so to speak, as an inside passenger within the sphere, or is the energy located in the space outside the sphere, and so has to buffet its way through the ether when it moves from one place to another? If, as I do, we believe with Faraday and Clerk Maxwell that the properties of charged bodies are due to lines of force which spread out from them into the surrounding ether, we must place the energy of the electron in the space outside the

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little sphere which is supposed to represent the electron. On this view all energy is in the ether and must travel from one place to another as waves through the ether. This transmission of energy through the ether instead of through the more obvious channels, was first put in a clear and precise form by my old friend Professor John Henry Poynting. His views lead to results which, though I believe them to be absolutely sound, are somewhat startling. For example, I suppose that most of you take for granted that the energy for the electric lamps flows from the power station to the lamps inside the copper wire which connects the one with the other. On Poynting's view this is not so, the energy does not travel inside the wire but keeps coming into the wire sideways from the space around it. The function of the wire is not so much to carry the energy inside as to guide the path of energy travelling outside. The energy travels as waves through the ether outside the wire at a speed which does not depend materially upon the size of the wire or the material of which it is made.

It is generally recognised that the transmission of electrical energy is by waves through the ether: can we go further and say that energy of all kinds is transmitted in this way? It may quite well be that this is not really going further, for all energy may be of the same kind, located in the ether and having to travel through it. When we attempt to extend the wave transmission of energy from electrical energy to what seem other kinds of energy, we are met with what at first sight might seem an insuperable difficulty, which is this: All electrical waves, whatever their wave length, travel with the same speed, that of light, through the ether, and the energy they carry must therefore travel with this speed. But when you or I move from one place to another and carry our energy with us, even the youngest of us are left sadly far behind by light. We must face the fact that energy may travel at any speed, and show that this is not inconsistent with its transmission through the ether. I think we can do this, for though it is true that electrical waves, long and short, all travel through a structureless ether with the same velocity, yet, if the ether has mixed with it electrons or any bodies charged with electricity, the conditions are entirely changed. The charged bodies are set in motion by the electrical waves, and as a consequence emit electrical waves themselves; these secondary waves unite with the primary one, change its character, e.g. alter its wave length without altering its frequency, and thus alter its velocity.

There is in the upper parts of the atmosphere a region called the Heaviside layer which on almost a cosmical scale is an example of the effect we are considering.

The Heaviside layer—whose existence, by the way, makes very long distance wireless possible—

is a region at a great altitude where the gaseous pressure is very low, and where the radiation coming from outside is much more intense than it is at the surface of the earth where the greater part has been absorbed by the atmosphere. In the Heaviside layer the radiation is so intense that it is able to split up many of the molecules of air into electrons and positive ions, so that this region, like the one we are contemplating, contains a supply of positive and negative charges. The behaviour of this Heaviside layer towards electrical waves is entirely different from that of the space close to the ground where there are no free electrons. In the lower regions all the waves, whatever their wave length, travel with the velocity of light; in the Heaviside layer none travel so slowly as this, and no two waves travel with the same velocity, unless they have the same wave length; the longer the wave length the greater the velocity of the waves. The connection between the velocity of the waves and the wave length is illustrated in the graph *APL* in Fig. 3, where the velocity is measured horizontally, the wave length vertically*. I shall call a medium of this type a super-dispersive medium.

* The algebraical relation between the velocity V and the wave length λ is

$$V^2 = c^2 + B\lambda^2;$$

B is a quantity proportional to the number of electrons per unit volume.