RADIATIONS OLD AND NEW.[1]

THE remarkable properties of the rays from radio-active substances which have been examined with such eagerness in recent years throw a curious and interesting light on the older attempts to find a satisfactory theory of radiation. Newton and Huygens, Young and Fresnel, and other thinkers down to our own times have discussed various hypotheses, rejecting, adopting, or amending, and each has given his reasons for his final choice. It is instructive at the present time to examine some of those reasons, and to consider the influences which prompted them to make their great discoveries. More particularly is this the case because some expressed their ideas in the language of a corpuscular theory, and we have now had for some time the opportunity of examining radiations which we know to be corpuscular.

Let me first of all set out some of the facts of the new radiations. Thanks to the recent beautiful experiments of Mr. C. T. R. Wilson, I am able to illustrate my statement by a method which would have been beyond my power even a few months ago. We have been for some years laboriously investigating the paths of the α, β, and γ rays through gases and other material substances. Our work has been conducted in the dark, so to speak, for we have been obliged to rely mainly on electrical methods, to feel our way along those paths in some cases, and in others to arrive at their form by indirect reasoning. Mr. Wilson has shown us how to obtain a clear photographic representation of the whole path of an α or β ray. The ocular demonstration is helpful from a scientific point of view, not only because of the confirmation which it has given of the work we have already done, but also because of its suggestiveness for the future. It is, if I may say so invaluable from a lecturer's point of view, because it enables me to dispense with difficult explanations of the methods by which recent advances have been made, and to show you, on the screen, direct illustrations of the main points that I wish to emphasise.

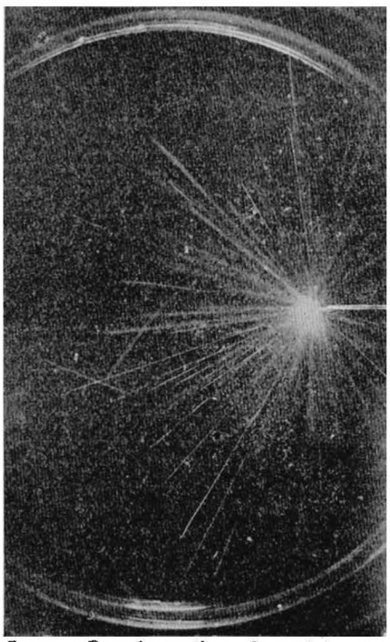

FIG. 1.—α-Rays from radium. Some of the α-particles have traversed the air before the expansion, others after the expansion.

The α ray is, as is well known, an atom of helium projected by the exploding radio-active atom with a speed of some ten or twenty thousand miles a second. Although it moves off at this excessive rate it is able to penetrate only two or three inches of air in its ordinary state, or one or two thousandths of an inch of heavier substances, like aluminium or gold. When it comes to the end of its range, it has spent practically the whole of its energy, it has lost its distinction, and sinks to the level of an atom moving with ordinary speed. Some years ago I showed that it moved in an almost perfectly straight line from start to finish; and it then became evident that on its way through a gas or a metal or any other substance it passed through every atom which it met. It does not push them out of its way, for it meets hundreds of thousands of atoms, each one, as a rule, far heavier than itself; and it does not thread its way between them, for it has no intelligence, and cannot recover a line once lost. In 1907 it was shown by Mr. Geiger, working at Manchester, that the track of the α particle was not absolutely straight, but that the particle was liable to slight deflections, especially when near the end of its path.

On the screen there is now one of Mr. Wilson's photographs of the tracks of α particles radiating from a minute speck of radium (Fig. 1). You will see how straight they are for the most part, and yet a closer examination will show slight, very sudden, deflections.

The next slide is an enlargement of two tracks, one of which shows the deflections very well (Fig. 2).

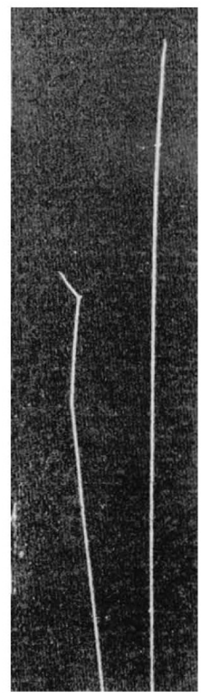

FIG. 2 — α-Rays from radium.

It is difficult to realise that we are looking at a picture of the path of a single atom through the air, recorded by its own efforts; and we may well ask how Mr. Wilson has managed to obtain so wonderful a result. As a matter of fact his method is an improvement on one which he had used and explained some years ago, but it will be well to describe it briefly once more. A short glass cylinder of about six inches in diameter—its outline can be seen in Fig. 1—is closed at one end by a glass plate; at the other end is a movable piston. The chamber is filled with moist air, which is chilled if the chamber is suddenly enlarged by the withdrawal of the piston. A fog is then formed, which settles in the first place on any "ions" which may be present. In the track of α and β rays there are trails of ions formed by the rays. It is only necessary therefore to illuminate the fog, and to photograph it, and we have such a picture as that on the screen.

The picture confirms so far as it goes the main conclusions we had already drawn as to the path of the α ray. On the screen is now a copy of a drawing which I made a year or two ago to show the various forms of the path as we then pictured them to our-

[1] Evening discourse delivered on September 6 before the British Association at Dundee by Prof. W. H. Bragg, F.R.S.

selves (Fig. 3). The paths, it should be explained, are shown starting parallel from a common line instead of radiating from a point. Mr. Wilson's picture shows that I have somewhat exaggerated the deflections to which I wished to direct attention; but otherwise the agreement is satisfactory.

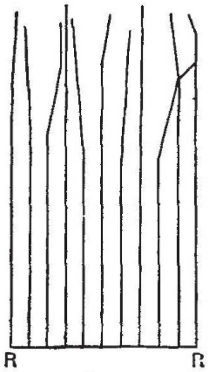

FIG. 3.

The results which I would emphasise are these, that an atom of helium can and does sometimes move at a rate comparable with that of light, and when endowed with that speed can penetrate other atoms with ease.

Before leaving the α ray, there is one other point I should like to mention. If we consider how it can be that deflections of the α particle are so rare, and yet so sharp, we find ourselves driven to consider with Rutherford that the deflection is due to a force exerted from a very small centre or central core within the atom, backed by all the mass of the atom. It is only when the flying α particle tries to pass very close to this centre that a noticeable deflection is produced. We may picture to ourselves the electrons belonging to the atom as revolving about this central core, which we must then take to be electrically positive, just as the planets move about the sun. When an α or β particle penetrates an atom and is deflected it is the central core that is in the main responsible; electron satellites are of no account. A rough analogy is to be found in the motion of a comet through the solar system.

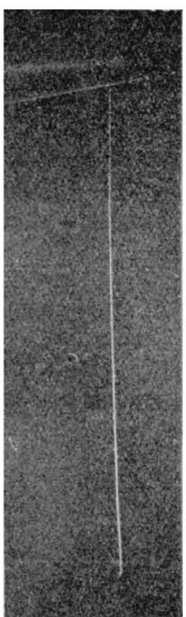

FIG. 4.—A complete α-ray from radium emanation.

When a deflection takes place we may expect a recoil of the atom in which it occurs. In some of the illustrations you will observe that there is a slight enlargement of the track at its beginning (Fig. 4). This may well be the recoil of the radio-active atom from which the α particle has been ejected. We have for some time been familiar with this recoil effect, which has been made the basis of certain important electrical methods of radio-active investigation. It is very interesting to see a well-marked little spur on one of the α ray tracks in Fig. 2, just where we should expect to find the effects of an atom of oxygen or nitrogen recoiling from its effort to turn the helium atom out of its path.

A β ray does not leave such an obvious track. It is the single electron moving with velocity very closely approaching in some cases to that of light. When it moves so fast it only ionises occasionally, so that its fog track is fainter. On these slides, some β ray tracks are clearly shown (Figs. 5 and 6); some are quite straight and are due to rays of high velocity, others show much bending, and these are made by β particles which have lost their great speed, and are knocked hither and thither by collision with the atoms of the air. It is to be remembered that the β particle is many thousands of times lighter than the α particle.

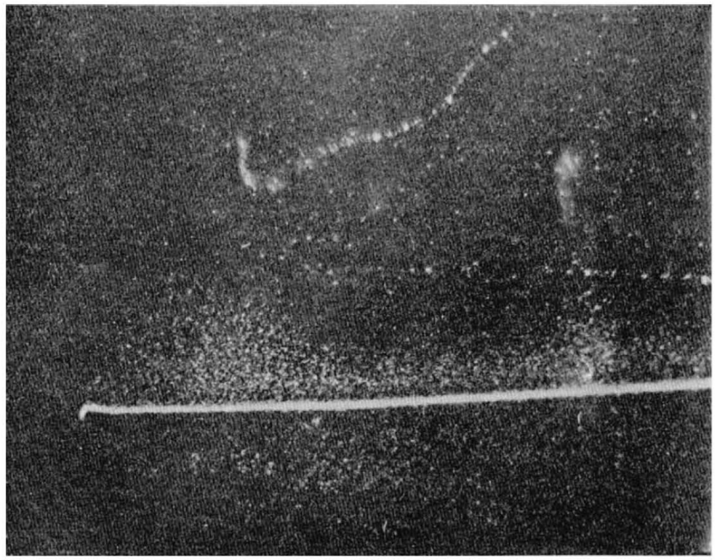

FIG. 5.—α- and β-Rays from radium.

Now we come to the third type of rays emitted by the radio-active substances, the γ ray, which is the same in kind as the Rontgen ray.

FIG. 6.—β-Rays produced by γ-radiation.

The fog apparatus shows no tracks which can be directly assigned to such rays. When the β and γ rays act together, only β ray tracks are found. When a stream of X-rays passes through the chamber the result is such as is shown in the figure (Fig. 7), a mass of short, tortuous tracks originating within the path of the X-rays, and ending indiscriminately inside or outside. Photographs made by weaker beams show the individual rays more clearly. The tracks are of the same character in the two cases, and the intensity only affects the number. These are tracks such as we should expect to be made by slow β rays—slow because they are very tortuous and do not go very far. Here is one greatly magnified, showing the individual water drops deposited along the track (Fig. 8). They are actually a few millimetres long. But the X-rays are passing in straight lines across the chamber, and you see that they leave no trace behind.

FIG. 7.—Ionisation by X-ray beam about 5 mm. in diameter.

These strange results were all expected from previous investigation. It has been known for some time that X or γ rays can excite β rays in matter on which they fall; I have in recent years tried to show that the X and γ rays can do nothing else. They do not themselves ionise the air or metal or other substance through which they pass; they merely bring to birth β rays which do. When X-rays fall upon a photographic plate and bring about a chemical change, or upon the animal skin and cause a "burn," as we vaguely denote the physiological effect, the X-rays have not been the direct agents, but the β rays, which spring from them. We may venture to make a guess as to how the action takes place. When an α particle passes through a molecule it may ionise more than one atom in that molecule; in the case of a very complex molecule it must often ionise several of the atoms. Such a molecule might be expected to break up or dissociate; and it is actually found that α particles do cause dissociation. Now the β particle ionises but rarely, as the pictures show; it will be a very complex molecule in which the β particle causes ionisation of two or three of the atoms of which it is constituted. Colwell and Russ have lately shown that X-rays can break down the starch molecule, a starch solution irradiated by X-rays becoming less viscous and showing the presence of dextrin. It is reasonable to expect the very large and complex starch molecule to be broken up by the β rays which the X-rays produce; and by this direct action of the β rays on large molecules we may perhaps be able to explain all the physiological actions of radium and of X-rays.

FIG. 8.—Portions of Fig. 7 enlarged, showing the individual ions produced along a portion of one of the kathode-ray tracks.

There is good evidence to show that each of the β rays the tracks of which you see upon the screen is due to one X-ray and no more, and that the X-ray in forming the β ray gives it all the energy which it possesses. Further, if we consider the production of X-rays, we find that each X-ray that comes out of the bulb carries with it the energy of one, and only one, of the β rays which are hurled against the antikathode. Thus in the picture I have drawn (Fig 9) β rays striking the antikathode A, X-rays move off, each inheriting the energy of one of the β rays. The β rays of the X-rays tube have themselves but very little power of penetrating materials; they move at only one-third (or thereabouts) of the speed of the β rays of radium; but the X-ray carrying the same energy is hundreds of times as penetrating, and a large number of those which are produced at the antikathode in the bulb penetrate the glass walls. Each

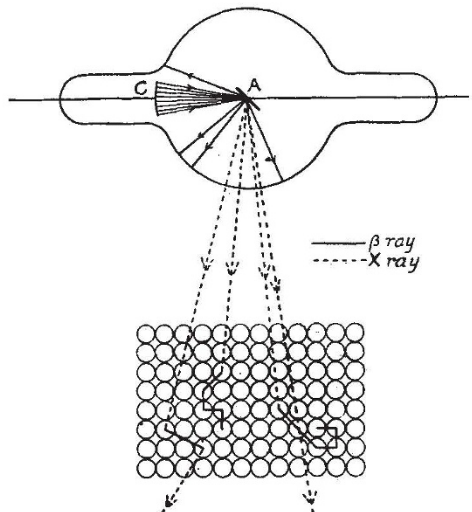

FIG. 9.

of these meets its fate sooner or later. In passing through some atom the reverse change takes place, and the X-ray disappears, handing over its energy to a β ray, which starts off with a velocity equal to that with which the original β ray finished when it disappeared in favour of the X-ray. It is as if the X-ray picked up the β ray, moved off in a straight line with it, and started it again somewhere else; or as if the β ray disappeared like a river going underground, only to reappear and continue its course. The β ray and the X-ray are interchangeable forms of energy-carrier. Further transformations may occur before the energy is spent. We may consider ourselves to be following the history of a small quantity of energy which is carried first by a β ray, then by an X-ray, then by a β ray again, and so on. The energy is kept intact in the X-ray form, but gradually frittered away in the β ray form, until finally it sinks to so low a value that it can no longer ionise or record its motion in a fog picture, and it is lost to view. Just as the α particle settles down to ordinary life as a helium atom at the end of its royal progress, so the moving electron, the β ray, becomes at last one of a crowd of electrons which are always on the move in matter, and are the carriers of heat and electricity. Whether it still undergoes transformations is a question we may well ask; I will consider it very briefly in a few minutes.

Transformation in either direction can only take place during the traverse of an atom. The atom is the transforming agent, but atoms differ in their transforming power. Usually the heavier the atom the more apt it is to bring about the transformation in an X-ray which tries to cross it, but there are regular exceptions. Every atom possesses one or more critical energy quantities; if the energy of the X-ray exceeds the critical value of the atom it is much more likely to undergo transformation than if it falls short. The critical values grow with the atomic weights, and are on the whole nearly proportional to the squares of the latter. Thus the critical energy of the zinc atom is about $1{\cdot}75 \times 10^{-8}$ ergs, of the nickel atom about $1{\cdot}67 \times 10^{-8}$ ergs. An X-ray, having an energy less than both these, is absorbed or transformed rather more readily by zinc than by nickel, but an X-ray having an energy greater than the lower but not greater than the higher (*e.g.* the X-ray given off by zinc when irradiated by sufficiently penetrating primary X-rays, and now known as the Zn X-ray) is actually much more readily transformed by the nickel than by the zinc.

Moreover, I believe this to be capable of extension. It is not only the X-ray that must possess energy greater than the critical value of the atom if transformation is to take place readily, but also a β ray must possess energy above the same limit if it is to be turned readily into an X-ray. Consequently a β ray is more apt to disappear in its energy exceeds the limit than if it falls short, and a stream of β rays seems actually to have less penetration than it would have if the individual rays were moving more slowly. I think I am in a position to show this as the result of recent experiment; I have found it to be so in the few cases I have tried, but there are very few cases which it is possible to try.

(*To be continued.*)

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

MILL HILL SCHOOL has recently received a gift of 5000*l.* from Mrs. Richardson, one of the nieces of the late Lord Winterstoke, formerly chairman of the governors of the school.

MAJOR SIR RONALD ROSS, K.C.B., F.R.S., formerly professor of tropical medicine, University of Liverpool, is now professor of tropical sanitation, University of Liverpool, lecturer on malaria, Liverpool School of Tropical Medicine, and physician for tropical diseases, King's College Hospital, London.

THE REV. JOHN H. ELLIS, who died in November last, has left, subject to his widow's life interest, the residue of his property, which will amount to at least 90,000*l.*, to "the University of Cambridge to be enjoyed and applied both as to capital and income by them for the general purposes of the University in such manner as they may think fit."

THE December issue of *The Reading University College Review*, in addition to its very interesting notes summarising the work recently accomplished at the college, contains an article explaining the general idea of the scheme of new buildings which the council of the University College at Reading proposes to carry out upon the main site. Another article, by Mr. J. P. Clatworthy, lecturer in mathematics at the college, deals with mathematics and the biological sciences.

THE danger of over-specialisation in higher education forms the keynote of a paper on the functions of the American college, by Prof. A. K. Rogers, in *The Popular Science Monthly* for December. As the author points out, there is a constant tendency among college teachers to cater more and more for the specialist in their own particular study, whereas if the college is to maintain its influence, it should rather aim at broadening the minds of the large majority of students of average ability. The author remarks that "the exceptional man is pretty apt to look out for himself. He will thrive probably in spite of our attempts to educate him quite as much as because of them."

THE President of the Board of Education has decided to appoint an advisory council for the Victoria and Albert Museum. The following persons have already consented to serve:- The Right Hon. Lord Reay (chairman), Mr. R. H. Benson, Mr. R. Blomfield, Sir Edward T. Cook, Mr. J. H. Fitzhenry, Mr. R. E. Fry, Mr. Frank Green, Lady Horner, Mr. Elijah Howarth, the Earl of Lytton, the Countess of Plymouth, Sir Isidore Spielmann, C.M.G. The council will be asked to advise the Board on questions of principle and policy arising from time to time, and to make an annual report on their proceedings to the Board, together with any observations on the condition and needs of the museum which they may think fit to make. It will be open to the council to constitute subcommittees on which persons who are specially qualified to advise on particular questions referred to the council may be invited by the Board to serve in addition to the ordinary members of the council.

THE fourteenth of a series of articles which has been appearing in the Journal of the Department of Agricultural and Technical Instruction for Ireland has now been issued in pamphlet form. It is written by Mr. T. Clearkin, and is concerned with technical instruction in Larne. Larne differs from many small towns of Ireland, as it has various flourishing industries giving constant employment to a considerable number of skilled workers—men and women. Many of these industries have grown up within the last twenty years, *e.g.* the manufacture of aluminium, linen-weaving, and paper-making. The shipping industry, too, is of some importance, and the engineering and building trades give employment to a fair number of apprentices. The object of the municipal technical school which has now been established in Larne is to instruct in the scientific and artistic knowledge necessary for a thorough understanding of the several callings in which the inhabitants are already engaged.

THE scheme of the competitive examination, held under the direction of the Civil Service Commissioners, for admission to the Indian Police Force is to be modified, by requiring candidates to take up English history and geography as a compulsory subject. The change will come into operation for the examination of 1914. There will then be four obligatory subjects which must be taken by all candidates, viz. English, elementary mathematics, French or German, and English history and geography. There are six optional subjects, of which candidates may take two; but, if one of the subjects selected is a modern language, it must be different from that taken as an obligatory subject. The optional subjects are intermediate mathematics, higher mathematics, German or French, Latin, Greek, and science (physics and chemistry). In addition, candidates may take up free-hand drawing. The maximum mark obtainable is the same for all subjects, except free-hand drawing,