printed on to a sensitised gelatine film on the metal cylinder A, and the parts unaffected by light washed away to leave the metal exposed, so that contact may be made with the brush B.

One of the best known practical developments of photo-telegraphy was made by Dr. Korn some twelve years ago. In his apparatus the original picture was photographed on to a transparent film, which was then wrapped round the cylinder A—in this case made of glass. Instead of the contact brush B, a fine pencil of light was used, which, after passing through the film, fell on a sensitive selenium cell and thus modulated the current flowing out to the lines in accordance with the opacity of the film. At the receiver the incoming current was passed through a special form of galvanometer—practically a double-thread Eithoven galvanometer—so that a light aluminium shutter was moved aside to a greater or less extent, depending upon the strength of the current. A beam of light was thus controlled in intensity before falling upon a sensitive film attached to the receiving drum D. The path traced out by this beam followed a spiral track on the surface of D, as in the case of the brush C of the arrangement of Fig. 1, and similar governing or synchronising arrangements were of course required.

A photographic recorder of this type possesses considerable advantages over the simple electrolytic arrangement outlined at first, and enables much more accurate work to be accomplished. It is obviously not the only possible arrangement to obtain the desired result, but, although differing in detail, the other varieties that have been used operate upon similar principles.

The chief disadvantage of the selenium-cell modulator at the transmitting station is to be found in its inertia to rapid changes of illumination, with the consequent limitation of the speed of operation. In the practical apparatus a compensation arrangement was employed to increase the speed of transmission, but better results would be possible with a light sensitive material having less lag. Some of the more recently discovered sensitive materials may prove better in this respect.

An ingenious alternative transmitter has recently

been put to practical test. The photographic print of the original picture at the transmitter is made in gelatine or similar material, giving a relief print when "developed." Instead of passing a metallic contact over such a print, a needle is used in such a manner that difference in relief varies the resistance of a microphonic contact, and thus controls the line current. The reproduction at the receiving station is effected with a photographic apparatus of the type described above.

From the transmission of pictures by wire, it is but a relatively small step to their transmission by radio. In the earlier stages of wireless development attempts were made in this direction with more or less success, but the irregularities of the coherer, which was at that time the only receiver capable of controlling sufficient local energy to operate the recording apparatus, prevented the practical development of the method. With the modern three-electrode valve receivers and relays this difficulty is removed, and their use at the transmitting station as continuous-wave generators is also advantageous. Considerable developments on these lines may therefore be expected in the near future. In particular the last described transmitter, with microphonic control, should be especially easily adaptable to radio work by using any one of the well-known radio-telephone modulation methods.

During the last few months some considerable interest has been aroused by a method of photograph transmission applicable to either wire, cable, or wireless signalling. Strictly speaking, however, this method is not of the same class as the above, in which the picture itself controls the actual signalling currents, as the transmission is effected by a series of code letters, words, or numbers, sent as an ordinary telegraphic message between the two stations. By this method the original picture is divided up into a number of small units, and a code letter used to designate the condition of light or shade in that unit, thus enabling a complete code message to be built up to represent the whole picture. At the receiving station the decoding may be effected in an obvious way, or a mechanical decoding machine may be employed to reproduce the picture.

The Structure of the Atom.¹

By C. G. DARWIN.

III.—The Nucleus.

IN the previous articles we discussed the nucleus mainly in connection with the idea of atomic number. We shall now return to the characters of the nucleus itself; but before doing so it is necessary to say something about the atom as a whole. Comparatively little is known about the electrons surrounding the nucleus—it is not even universally agreed whether they are at rest or in motion—but a successful beginning has been made by the Bohr spectrum theory, which applies

mainly to the specially simple case of hydrogen. On the same lines Sommerfeld has also had some success with the X-ray spectra. It is quite certain, as in all questions of atomics, that the laws of classical dynamics do not hold, and the principal method in research at present consists in a judicious mixture of these laws with the quantum theory. This latter theory is definitely contradictory not only to the laws of mechanics, but also to almost any conceivable modification of them, and its chief justification, an entirely adequate one, is the astounding success with which it has

¹ Continued from p. 83

been extended over more and more branches of physics.

We shall not deal here with these spectroscopic questions, but it will be convenient to have a definite idea of the scale on which the atom is built. The proportions of its parts vary over so wide a range that no drawing can possibly represent them. We shall be dealing with magnitudes as small as 10^{-16} cm., and as these large negative indices convey little definite to the mind, it will be convenient in describing the atom to raise the whole scale by 10^{13} . On this scale 1 cm. would become a length about two-thirds of the distance from the earth to the sun. The outermost electrons of the atom would be about a kilometre from the nucleus, and for the heavier elements the innermost, perhaps three in number, would be roughly 10 metres from it. As to the nucleus itself, there is definite evidence that it is less than 30 cm. in radius, and, in some cases at any rate, that it is greater than 2 cm. Other physical quantities which we shall require are of a slightly more hypothetical nature. On the theory that all mass is electromagnetic, we can calculate the radius of an electron, since we know its charge and mass. This radius comes to about 2 cm. (actually 1.88×10^{-13} cm.). By a similar calculation the hydrogen nucleus has a radius of about one-hundredth of a millimetre. The same argument would make the radii of heavier nuclei about as small as this, but would not be justifiable, because, as we shall see, there is clear evidence that these nuclei owe their large mass to their being composite structures built up from hydrogen nuclei and electrons. From the extraordinary smallness of the quantities we have considered, it is not surprising that experiments with the nucleus should be very difficult. We now turn to these experiments.

When first describing the nucleus, in the first article, we saw that when an α -particle goes near it, it describes a calculable orbit, so that we can find a distance of closest approach between the two. As the predicted law of scattering was borne out by experiment, we can conclude that the law of force at this distance of closest approach (3×10^{-12} cm. for gold, above called 30 cm.) is still the inverse square law. Therefore the sum of the radii of the α -particle and the nucleus must be less than this. But a different case has been studied in great detail by Rutherford. Where the α -particles are passing through hydrogen, the repulsive forces between the nuclei are much weaker than for other substances, because the atomic number of hydrogen is only 1, and so the nuclei can get much closer together. But there is also another difference, for the hydrogen nucleus has mass only a quarter of that of the α -particle. Consequently, if there is a "straight on" collision the hydrogen is shot forward at a speed higher than that of the colliding α -particle, and the latter follows on behind with reduced speed. This new type of particle, the H-particle, then proceeds to traverse

any matter in its path, losing speed in the same sort of way as does an α -particle, and it can be calculated that, whereas the fastest α -particles go through only 7 cm. of air, the fastest of these H-particles should go through 28 cm. (Fig. 2). Experiment bore out this prediction, but when the calculation was pushed further so as to show how many should go various distances from 28 cm. downwards, a very wide difference was found between theory and experiment. This indicates that there is something wrong with the theory—in fact, that the approach between the nuclei is so close that the ordinary law of repulsion fails. This ordinary law would give 2×10^{-13} cm. as the distance of closest approach, and we therefore conclude that the sum of the radii of the hydrogen and helium nuclei is greater than this. Now the

FIG. 2.—From Sir Ernest Rutherford's paper "The Collision of α -Particles with Light Atoms" (*Phil. Mag.*, xxxvii., p. 549). The wide difference between the "observed" and "calculated" curves shows that the assumed law of force between α -particle and H-nucleus is wrong; in fact, that a lower limit has been obtained to the size of the nucleus.

radius of the electron is about 2×10^{-13} cm., and the coincidence of these two numbers tends to support the view that there are electrons in the nucleus of the helium atom.

Turning now to the constitution of the nucleus, the first piece of information is provided by radio-activity. In successive radio-active transformations α - and β -particles are projected from the nucleus. Therefore the latter must contain both—that is, helium nuclei and electrons. Next we have the evidence from Rutherford's transmutation of elements. The experiments in which this occurred consisted in the bombardment of various elements by α -particles. When nitrogen was tried, he observed that a certain number of H-particles was obtained. As no hydrogen was present, we are compelled to conclude that these particles were knocked off the nuclei of the nitrogen atoms; so we can be confident that these nuclei contain hydrogen nuclei. In recent work Rutherford has got even further, for he has found another entirely new type of particle which is sometimes knocked off nitrogen and oxygen. These particles have atomic mass 3 and number 2, so that if they were obtained in bulk they would be helium of density 25 per cent. less than ordinary helium. It is at present unknown what happens to the remainder of the nucleus after these losses. A point of great

interest in this work is that the new particles come off with greater energy than that of the bombarding α -particles. If we carry over the language of chemistry to this new domain we should say that the reaction is exothermic, and nitrogen in a metastable state.

We have so far discussed the special properties of particular elements. The next evidence is very much more general, and holds out great promise of extension. This is the recent work of Aston with the "positive rays." It was undertaken in order to detect whether ordinary elements were composed of isotopes. He found that this was true of the majority of those he examined (his numerical results are given in the table in the first article), but the important result from our present point of view is that in all his elements the atomic weight of each isotope was almost exactly an integer. This will be slightly qualified in the next paragraph. Aston has so far examined eighteen elements and found the rule true, and it is scarcely credible, therefore, that it should not be universal. But if so, it can only mean that all nuclei are constructed out of hydrogen nuclei. That would satisfy the conditions as to mass, and in order to make the atomic number correct we must then suppose that these hydrogen nuclei are cemented together by electrons. For example, chlorine has atomic number 17. Its atomic weight, determined chemically, is 35.5, and Aston finds that it is composed of two isotopes at 35 and 37. Therefore three-quarters of the chlorine atoms have nuclei composed of 35 hydrogen nuclei and 18 electrons, while for the remaining quarter the numbers are 37 and 20 respectively. This is the revived form of the famous hypothesis of Prout.

Aston's experiments have not hitherto been sufficiently accurate to detect any departures from the whole number rule, except in the case of hydrogen. In this case his work confirms the chemical result that the atomic weight is 1.008 instead of being 1. At first sight this would

appear to dispose entirely of the validity of our interpretation of the whole number rule, but that is not so, and by the use of arguments based on the work of Einstein on relativity, the departure from whole numbers can be made to yield valuable information. Einstein's theory implies that all energy must have mass (and also that all mass must have weight). Thus the mass of a helium nucleus (at. no. 2 and at. wt. 4) will not be simply the sum of the masses of its four α -particles and two electrons, but will also include the mass of its energy of formation. As the helium is lighter than the sum of the weights of these particles, we conclude that this energy is negative—that is to say, an atom of helium has less energy than its separated particles. Lenz has calculated the difference and finds that it corresponds to the energy of about three of the fastest α -particles. So helium is an exceedingly stable substance, and it need create no surprise that its nuclei, when projected as α -particles, can undergo the most violent collisions without disruption. It also makes it not unnatural that in radio-active disintegration it is helium, and not hydrogen, that is emitted. Moreover, it is well known that the atomic weights of most elements are nearer whole numbers when helium is taken as standard at 4 than when hydrogen is taken as 1. This indicates that in most atoms the majority of the hydrogen nuclei are bound together in helium sub-groups.

It will thus be seen that a very promising beginning has been made in the study of the nucleus. We know that it is built up of hydrogen nuclei and electrons, and that there is a strong tendency to form helium sub-groups. We know the number of hydrogen nuclei and electrons in the nuclei of many of the elements, and may expect to know those of the majority at no distant date. Most encouraging of all, we may hope that it will not be very long before a definite theory of the structure of nuclei is made, based on exact knowledge of the energy of formation of the various elements.

Obituary.

THE RIGHT HON. SIR WILLIAM MATHER.

WE deeply regret to record the death of Sir William Mather, at his residence in the New Forest, on Saturday last, September 18. Sir William was born in Manchester in 1838, and educated at private schools, and his studies were continued under one of his English tutors at Dresden. Afterwards he entered his father's engineering firm, well known as the Salford Iron Works, and worked the usual hours of apprentices, in the evenings attending lectures at the Owens College, Manchester. In 1862, when he was twenty-four years of age, he became solely responsible for the management of the business. The firm enjoyed great repute as makers of bleaching,

dyeing, finishing, and other textile machinery, exporting its products abroad, especially to Russia and the United States, in which countries Sir William travelled extensively. He took the greatest interest in the well-being of his employees, his firm being among the first to establish the eight hours' day, and providing for his young workers, more than forty years ago, the means of continued instruction in the fundamental principles of engineering science, at the hands of his chief technical officers, and with striking results, many of the students gaining Whitworth and other science scholarships.

Sir William Mather took a deep interest in local affairs and movements, was a member of the