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THE ROMANES LECTURE

1903

Modern Views on Matter

BY

SIR OLIVER LODGE, Hon. D.Sc., F.R.S.

DELIVERED

IN THE SHELDONIAN THEATRE, OXFORD
JUNE 12, 1903

FIFTH IMPRESSION

OXFORD
AT THE CLARENDON PRESS
1915

OXFORD UNIVERSITY PRESS
LONDON EDINBURGH GLASGOW NEW YORK
TORONTO MELBOURNE BOMBAY
HUMPHREY MILFORD M.A.
PUBLISHER TO THE UNIVERSITY

FOREWORD

In this edition the Romanes Lecture itself is reprinted without appendices, a clear distinction having been drawn therein between what is certain and what is uncertain or speculative.

The time is not yet ripe for dealing with the uncertain portions in a definite manner; while to treat them in their present stage would introduce technical difficulties and require much space; consequently it is thought better to issue the original lecture simply, as adequately representing the ascertained position to-day, and sufficiently suggesting further developments.

Fuller information can be gained from the author's treatise on 'Electrons.'

December, 1906.

MODERN VIEWS ON MATTER

THE nature of matter has been regarded by philosophers from many points of view, but it is not from any philosophic standpoint that I presume in this University to ask you to consider the subject under my guidance. It is because new views as to the structure and properties of what used to be called the ultimate atom are now being born, and because these views, whether they succeed in ultimately establishing themselves in every detail or not, are of surpassing interest, that I have chosen this very recently deciphered chapter of science as the subject-matter for the lecture to be given this year in remembrance of a man whom I knew as a friend, and whose mind, if he had been alive to-day, would have been widely open to these most modern developments of Physical Science. Nor would the admittedly speculative character of some of the hypotheses now being thrown out have deterred him from hearing about them with the keenest interest.

If I may venture to say so, it is the more philosophical side of Physics which has always seemed to me most suitable for study in this University; and although I disclaim any competence for philosophic treatment in the technical sense, yet I doubt not that the new views, in so far as they turn out to be true views, will have a bearing on the theory of matter in all future writings on Philosophy; besides exercising a profound effect on the pure sciences of Physics and Chemistry, and perhaps having some influence on certain aspects of Biology also.

In admitting that I am going to promulgate a speculative hypothesis, that is, a hypothesis for which there is evidence but not yet conclusive evidence, I must not lead you to suppose that the whole of what I have to say is of this character. On the contrary, much of it is certain, that is to say, is accepted by a consensus of opinion to-day among those who by reason of study are competent to judge. I will endeavour carefully to discriminate between what is in this sense certain and what must still be regarded as doubtful and needing further support.

To treat the subject properly, to give all the evidence as well as the results, would need a volume, or a course of lectures; and in order to be brief I must frequently be dogmatic, but I shall only intend to be so in those places where I feel sure that the physicists present will agree with me. When I have a dogma of this kind to propound I shall call it a thesis. The more speculative opinions I shall plainly denominate hypotheses.

1. My first thesis is that an electric charge possesses the most fundamental and characteristic property of matter, viz. mass or inertia; so that if any one were to speak of a milligramme or an ounce or a ton of electricity, though he would certainly be speaking inconveniently, he might not necessarily be speaking erroneously.

In order to have any appreciable mass, however, an electric charge must either be extremely great or must be extremely concentrated; and, unless it is to be utterly masked by the matter with which it is associated, it must be concentrated: that is to say, it must exist on bodies of far less than ultra-microscopic size. The mass or inertia of a charge depends upon two factors—the quantity of electricity in it, and its potential—and by concentrating a given charge on to a sufficiently small sphere, the latter factor can be raised theoretically to any value we please, and thus any required inertia can be obtained; unless a stage is reached at which it becomes physically impossible to concentrate it any more.

2. The next thesis is a very simple and familiar one, and dates virtually from the time of Faraday, though the conception has gradually gained in clearness and

solidity: it is that every atom of matter can have associated with it a certain definite quantity of electricity called the ionic charge, that some atoms can have double this quantity, some treble, and so on, but that no atom or any piece of matter can have a fraction of this quantity; which therefore appears to be an ultimate unit, a sort of 'atom,' of electricity. The ratio of the charge to the weight of a material atom is measured with accuracy in electrolysis, in accordance with what are called Faraday's laws; and in so far as the mass of the atom itself is otherwise approximately known, the quantity of electricity which can be associated with it is known with a similar degree of approximate accuracy.

3. Now mathematical data were given by J. J. Thomson in 1881 which enable us to say that if the charge of electricity usually associated with a single monad atom of matter were concentrated into a spherical nucleus one hundred-thousandth of an atom's dimension in diameter, it would thereby possess a mass about one-thousandth of that of the lightest atom known, viz. the hydrogen atom.

Such a hypothetical concentrated unit of electricity, especially if it can exist without a material nucleus, it has become customary to call an 'electron': a name invented by Dr. Johnstone Stoney to designate the so-to-speak 'atom' or smallest known unit of electric charge. Every electric charge is to be thought of as due to the possession of a number of electrons, but a fraction of an electron is at present considered impossible; meaning that no indication of any further subdivision has ever loomed even indistinctly above the horizon of practical or theoretical possibility.

The electrification of an atom of matter consists in attaching such an electron to it, or in detaching one from it. An atom of matter possessing an electron in excess is called an 'ion'; and there is reason to know that, considered as a charged body, its charge is that which we have been historically accustomed to designate 'negative'; whereas an atom of matter with one electron in defect is that which has historically been called a 'positive' ion.

This inversion in the natural use of the names positive and negative is inconvenient but accidental and not really serious; it dates from the time of Benjamin Franklin.

These ions or travelling particles of matter have been long known. A liquid or a gas conducts because of the locomotion of its charged particles. The particles travel in an electric field because of their attached charges, all the positive going one way, and all the negative the other way; and each kind of matter possesses an intrinsic or characteristic ionic velocity, when urged by a given field through a given solution. The charges may be likened to horses or other propelling agency, and the atom to the vehicle or heavy body which is dragged along. The speed of travel through liquids is very slow, but through gases is considerably quicker, partly because there is less resistance, and partly because it is easier to maintain a steep gradient of potential in a medium where the ions are not too numerous.

The act of production of such ions is styled 'ionization,' and the process has been employed to explain very many facts in both Physics and Chemistry.

As an example, Röntgen rays passing through air ionize it and so render it conducting for a time: wherefore they are able readily to discharge electrified bodies, in this secondary way.

It may be convenient here to emphasize the dimensions of an electron as above specified, for the arguments in favour of that size are very strong though not absolutely conclusive: we are sure that their mass is of the order one-thousandth of the atomic mass of hydrogen, and we are sure that if they are purely and solely electrical their size must be one hundred-thousandth of the linear dimensions of an atom; a size with which their penetrating power and other behaviour is quite consistent. Assuming this estimate to be true, it is noteworthy how very small these electrical particles are, compared with the atom of matter to which they are attached. If an electron is represented by a sphere an inch in diameter, the diameter of an atom of matter on the same scale is a mile and a half. Or if an atom of matter is represented by the size of this theatre, an electron is represented on the same scale by a printer's full stop. It is well to bear this extreme smallness in mind in what follows.

An atom is not a large thing, but if it is composed of electrons, the spaces between them are enormous compared with their size—as great relatively as are the spaces between the planets in the solar system.

4. My next thesis is that these electrons or minute charged corpuscles can exist separately, for they can be detached from their atoms of matter at an electrode, not only in electrolytic liquids but also in gases, and when thus released from their thousandfold more massive atom, they fly away from the negative electrode with prodigious speed, because they are acted on by the same electrical propelling force as before, but now have hardly anything to move.

These isolate d flying particles travel a long distance in rarefied gas, and are known as cathode rays. They were studied by Varley, Hittorf, Crookes, Lenard, and others, both inside and outside vacuum-tubes, and they are now known to be flung off spontaneously from many substances. When stopped suddenly by a massive obstacle, they give rise to the X-radiation discovered by Röntgen. At first these cathode rays were thought to be atoms of matter, though their extraordinary penetrating power rendered such a hypothesis difficult of belief, and caused Crookes to speak of them as matter in a fourth state. They are, however, certainly energetic bodies, being able to propel light windmills, to heat platinum to redness, and to charge an electroscope; they are also able to penetrate thin sheets of metal and to affect photographic plates or phosphorescent substances on the other side. They are not so penetrating, however, as are some of the Röntgen rays.

The final definite establishment of the fact that these flying particles are not atoms of matter, but are bits chipped off the atoms, fractions of an atom as it were—the same identical kind of bits being chipped off every kind of chemical atom, their mass always about one-thousandth of that of a hydrogen atom, and moving under favourable circumstances with something not much less than the speed of light—is due to the researches of Professor J. J. Thomson and his coadjutors in the Cavendish Laboratory, Cambridge, and represents a long series of measurements devised and executed with consummate skill.

I have no time to go into detail concerning these important and elaborate and most interesting investigations. Suffice it to say that portions of them are due to your own Wykeham Professor of Physics, Professor Townsend, working in conjunction and collaboration with others, under the leadership of Professor J. J. Thomson; and that this whole series of Cavendish Laboratory researches may be said to constitute the high-water mark of the world's Experimental Physics during the beginning of this century.

5. I must not dwell upon the properties and powers of electrons, nor upon the experimental means by which these measurements were made, for it is far too large a subject. I must exhibit a few diagrams, and briefly summarize a few main facts:—

Electrons have been shown to be shot off from any negatively charged body, especially from negatively electrified metals, when exposed to ultra-violet light.

When shot into a mass of air they dissociate and ionize that air for a time, and render it electrolytically conducting; also of course they can discharge positively electrified bodies themselves, and can thus be most readily detected in small numbers.

Electrons in orbital motion have been shown to constitute the mechanism by which atoms are able to radiate light; and a great mass of semi-astronomical facts concerning these orbits and their perturbations have been obtained by immersing the source of light in a strong magnetic field, and observing the minute but very definite changes of spectra thereby produced: a branch of science with which the names of H. A. Lorentz of Leyden, and Zeeman of Amsterdam, will be inseparably associated.

In all these and other ways the electron has become a familiar object. It constitutes the ionic charge of matter. Multiples of it, but no fractions, are possible. Its mass, its charge, and its speed have been frequently measured by different processes, and always with consistent results. It is the most definite and fundamental and simple unit which we know of in nature.

It has thus displaced the so-called atom of matter from its fundamental place of indivisibility. The atom of matter has been shown capable of losing an electron, of having at least one chipped off it. The electron has been shown to possess in kind, though not in degree, the fundamental properties of the original atom of which it had formed a part; and it becomes a reasonable hypothesis to surmise that the whole of the atom may be built up of positive and negative electrons interleaved together, and of nothing else; an active or charged ion having one electron in excess or defect, but the neutral atom having an exact number of pairs. The oppositely charged electrons are to be thought of, on this hypothesis, as flying about inside the atom, as a few thousand specks like full stops might fly about inside this hall; forming a kind of cosmic system under their strong mutual forces, and occupying the otherwise empty region of space which we call the atom—occupying it in the same sense that a few scattered but armed soldiers can occupy a territory—occupying it by forceful activity, not by bodily bulk.

6. The hypothetical part of the statement about the size of an electron is the following. Whereas both the mass and the charge of an electron is known, it is not yet quite certain that the mass is *wholly* due to the charge. It is possible, but to me very unlikely, that the electron, as we know it, contains a material nucleus

in addition to its charge, so in that case it need not be so concentrated, because a portion of its mass would be otherwise accounted for.

I say 'accounted for,' but it would be equally true to say unaccounted for. The mass which is explicable electrically is to a considerable extent understood, but the mass which is merely material (whatever that may mean) is not understood at all. We know more about electricity than about matter; and the way in which electrical inertia is accounted for electromagnetically, and localized in the ether immediately surrounding the nucleus of charge, is comparatively clear and distinct.

There *may* possibly be two different kinds of inertia, which exactly simulate each other, one electrical and the other material; and those who hold this as a reasonable possibility are careful to speak of electrons as 'corpuscles,' meaning charged particles of matter of extremely small size, much smaller than an atom, consisting of a definite electric charge and an unknown material nucleus; which nucleus, as they recognize but have not yet finally proved, may quite possibly be zero. [By 1906 it has proved to be zero.]

The chief defect in the electrical theory of matter at present is that the *positive* electron, if it exists, has never yet been isolated from the rest of an atom of matter. It has never been found detached from a mass less than the hydrogen atom; whereas the negative electron is constantly and freely encountered flying about alone, its mass being little more than the thousandth part of an atom of hydrogen.

Until a positive electron can be similarly isolated, the hypothesis that an atom is really composed solely of electricity—that is to say, of equal quantities of positive and negative electricity associated together in some unknown way, the negative at any rate being a grouping of concentrated charges of electricity of known amount—must remain a hypothesis.

7. It is a fascinating guess that the electrons constitute the fundamental substratum of which all matter is com-

posed. That a grouping of say 700 electrons, 350 positive and 350 negative, interleaved or interlocked in a state of violent motion so as to produce a stable configuration under the influence of their centrifugal inertia and their electric forces, constitutes an atom of hydrogen. That sixteen times as many, in another stable grouping, constitute an atom of oxygen. That some 16,000 of them go to form an atom of sodium; about 100,000 an atom of barium; and 160,000 an atom of radium.

On this view all the elements would be regarded as different groupings of one fundamental constituent. Of all the groupings possible, doubtless most are so unstable as never to be formed; but some are stable, or at least relatively stable, and these stabler groupings constitute the chemical elements that we know. The fundamental ingredient of which, on this view, the whole of matter is made up, is nothing more or less than electricity, in the form of an aggregate of an equal number of positive and negative unit electric charges.

This, when established, will be a unification of matter such as has through all the ages been sought; it goes further than had been hoped, for the substratum is not an unknown and hypothetical protyle, but the familiar electric charge. Nevertheless, of course, it is no *ultimate* explanation. The questions remain, what then is an electric charge? what is the internal structure and constitution of an electron? wherein lies the difference between positive and negative electricity? and what is their relation to the ether of space? Definite questions these, and doubtless some day answerable; indeed, powerful methods of attack on this position have been already contrived by Dr. J. Larmor and others; but they are questions of a higher order of difficulty than those which occupy us to-day, and it must remain for a future Romanes Lecturer to report progress in these directions, whenever adequate progress has in fact been made.

8. That is the end of the first half of my lecture; and, six months ago, that, somewhat expanded, might have been the whole of it, because the next portion would

have seemed too fanciful; but discoveries have been made, chiefly in France and in Canada—some of the most striking of them within the present year—which remove the treatment of the next part of my subject from the realm of fancy to the region of probability, and justify my proceeding further with some of the theoretical consequences deducible from an electric theory of matter.

I referred above briefly to the origin of radiation, saying that by the method of applying a powerful magnet to a source of light, and examining the minute perturbations in the lines of the spectrum thus produced, it had been proved that the real source of radiation was an electric charge in rapid orbital motion; and I now go on to say that by careful measurement of the amount of perturbation it has been definitely proved that it is our friends the negative electrons, with a mass about one-thousandth of the smallest known atom of matter, that are responsible for the excitation of ether waves or the production of light. Larmor and others have indeed shown mathematically that whenever an electric charge is subject to acceleration, an emission of some amount of radiation is inevitable, by reason of the interaction of its electric and magnetic fields; and it is probable that there is no other source of light or radiation possible except this change in the motion of electrons. It is known, for instance, that the violent acceleration or retardation of electrons when they encounter an obstacle is responsible for the excitation of Röntgen rays. All light, and all the Hertz waves or pulses employed in wireless telegraphy, are due to electric acceleration, and the greater the rate of change of velocity the more violent is the radiation emitted.

The charge may oscillate, as in a Hertz vibrator; or it may revolve, as in a source of ordinary light such as a sodium flame. In order to emit perceptible radiation by revolving, it must revolve with extreme speed in a very small orbit, so that its rate of curvature or centripetal acceleration may be considerable; for it is on the square of the value of the average acceleration that the energy of radiation depends.

9. All this is of the nature of a definite and certain thesis; but now we are going to apply it to our hypothesis that the atom of matter is either wholly or partially composed of electrons in a state of vigorous motion among themselves. Such revolving or vibrating electrons are subject to acceleration, either radial or tangential, and must therefore to a greater or less extent necessarily emit radiation; it becomes natural to inquire whence comes the energy that is radiated away.

Now in ordinary familiar cases it is the irregular agitation of molecules which we call 'heat' that is being radiated away; and in that case the result is a mere cooling, or diminution of the molecular agitation, which can readily be made up by receipt of similar energy from the enclosures or from surrounding bodies; or, if not made up, it can produce the ordinary well-known effects of 'cold.' But to the motion of the internal parts of an atom the ideas of heat and temperature do not apply. The atom, if it lose energy, must lose what is to it an essential ingredient; and hence this inevitable radiating power of the constituents of an atom seemed to constitute a difficulty, for it suggested that an atom of matter was not really a permanent and eternal thing, but that it contained within itself the seeds of its own decay and ultimate dissipation into the separate electrons of which it was composed. The process might indeed be exceedingly slow, the radiation loss might be almost imperceptible, but, in so far as an atom is composed of revolving electrons, it is inevitable that radiation of energy must go on from it, and that this must in the long run have some perceptible degenerative result.

10. That result has quite recently, I believe, been experimentally discovered, and is a part of the phenomenon known as 'radio-activity.'

So now we come to the most remarkable and probably the most interesting step of all.

The phenomenon of spontaneous radio-activity, discovered first by Becquerel in uranium and thorium, and greatly extended by the brilliant chemical researches of M. and Mme. Curie which resulted in the discovery of radium, was at first supposed to consist in the emission of a sort of X-ray or ether pulse; and was subsequently assumed to consist chiefly in the bodily emission of electrons, which were shot off from the radio-active substance as they are from a negative electrode in a vacuum-tube, or as they are in air when ultra-violet light falls upon clean negatively charged surfaces.

As a matter of fact both these modes of radiation—the wave form and the corpuscular form—*are* emitted by radio-active bodies, but they turn out to be of subordinate importance, and must be regarded as secondary or subsidiary consequences of the main phenomenon.

The main fact of radio-activity has been shown by Professor Rutherford of Montreal, in a paper published in the month of February this very year, to consist in the flinging away with great violence of actual atoms of matter: atoms electrified indeed, but not negatively like electrons, and not small or penetrating like them, but full-sized atoms, such as are easily stopped by a thin sheet of metal, or even by a sheet of paper—atoms which are positively charged and possessed of a remarkable amount of energy, ionizing the air which they bombard to an extraordinary extent, and likewise generating quite a perceptible amount of heat wherever they strike; producing indeed a flash when they strike a suitable target, as Crookes has shown, quite like the impact of a cannon-ball on an armour-plate. Their speed, indeed, far exceeds that of any cannon-ball that ever existed, being as much faster than a cannon-ball as that is faster than a snail's crawl; a hundred times faster than the fastest flying star, these atomic projectiles constitute the fastest moving matter known. This furious bombardment from a radio-active substance continues without intermission, and apparently without sign of diminution or cessation. There is every reason to believe that a minute scrap of radium, scarcely perceptible to the eye, may go on emitting these energetic projectiles for hundreds of years.

11. At first sight the fact that it is merely atoms of matter which are being flung off by most radio-active substances, and that ethereal and other effects are subsidiary to this emission of substance, seems to lessen the interest attaching to the phenomenon, reducing it to something of merely chemical importance, and suggesting a resemblance to scent or other volatilization from solid bodies. But Professor Rutherford, with great skill, succeeded in determining approximately the atomic weight of the utterly imperceptible amount of substance thrown off, as well as its speed, and found that it was not by any means the radio-active substance itself which was evaporating, but something quite different.

Plainly if an elementary form of matter is found to be throwing off another substance, it becomes imperative to inquire what that substance is, and what it is that is left behind. Now the atomic weight of radium, or of thorium or uranium, or of any known strongly radio-active substance, is very high—in each case over 200 times the atomic weight of hydrogen—whereas the atomic weight of the substance flung off appears to be more nearly of the order 1 or 2; in other words, the substance thrown off is more likely to be either hydrogen or helium than it is likely to be radium. (It is just possible, as Rutherford and Soddy suggest, that the inert chemical elements are all by-products of radio-activity.)

Now clearly here is a fact, if a fact it be, of prodigious importance. Undoubtedly the measurements require confirmation, but for myself I see no reason to doubt them, at least as regards their order of magnitude. The atomic weight of radium being say 225, and that of the projected portion being say 2, the residue must represent by its atomic weight the difference between the heavy atom of the original substance and that of the light atom or atoms which have been flung away: unless indeed it be assumed, as it will almost certainly be assumed by some sceptical chemists, those who derided argon and other chemical discoveries when made in a physical manner, that the substance flung away is some foreign ingredient or impurity—a hypothesis, I venture to say, already strongly against the weight of available evidence.

The substance left behind in the pores of the radio-active substance has been examined even more completely than the projected portion: it is volatile, it slowly diffuses away, and it behaves like a gas. It can be stored in gas-holders when mixed with air, for in amount it is quite imperceptible to all ordinary tests; and yet it can be passed through pipes and otherwise dealt with. It condenses not far above the temperature of liquid air, and it is itself radio-active, but in such a way that its power decays rapidly with time. Its radio-activity seems to consist likewise in throwing away part of itself and leaving yet another residue, likewise radio-active; and one of the residues so left, in its convulsion, flings away electrons as well as atoms of matter. It is not to be supposed that thorium and radium and uranium all behave alike in details. The emanation of one may lose its activity rapidly, and give rise to another substance which retains its power for some time; the emanation of another element may last some time and generate a substance whose activity rapidly decays; but into these details it is not now the place to go.

12. Assuming the truth of this strange string of laboratory facts, we appear to be face to face with a phenomenon quite new in the history of the world. No one has hitherto observed the transition from one form of matter to another: though throughout the Middle Ages such a transmutation was looked for. The transmutation of elements has been suspected in modern times, on evidence vaguely deducible by skilled observers from the spectroscopic details of solar and stellar appearances. The evolution of matter has likewise been

suspected by a few chemists of genius: it was perceived, on the strength of Mendelejeff's law, that the elements form a kind of family or related series, and it was surmised that possibly the barriers between one species and the next were not absolutely infrangible, but that temporary transitional forms might occur. All this was speculation; but here in radio-active matter the process appears to be going on before our eyes. Professor Rutherford and Mr. Soddy, who in Canada during the present year have worked hard and admirably at the subject, have adduced facts which point clearly in this direction; and they initially describe what appear to be the first links of a chain of substances, all produced in hopelessly minute quantities reckoned by ordinary tests, but which yet by electrical means can easily be detected, and their boiling-points and other properties investigated. Moreover the investigators of these strange substances are able to dissolve and precipitate, and perform ordinary chemical operations on, these utterly imponderable and hopelessly minute deposits of radio-active substances, because of the powerful means of detection which their ionizing power puts into our hands—even a few projected atoms being able by their ionizing power to discharge an electroscope appreciably.

13. Thus then it would appear that our theoretical conclusion concerning the inevitable radiation and loss of energy from electrically constituted atoms of matter, a loss which must involve them in necessary change and dissolution, meets with quite unexpectedly rapid confirmation; and it is for that reason that I feel willing to accept, tentatively and as a working hypothesis, this explanation of radio-activity. For how is radio-activity to be explained? It looks as if the massive and extremely complex atoms of a radio-active substance were liable to get into an unstable condition—probably reaching this condition whenever any part of it attempts, or is urged, to move with the velocity of light. I have shown elsewhere[1] that the mere fact of radiation will act as

[1] See *Nature* for June 11, 1903.

a resisting medium and increase the speed of the particles automatically, on the same principle that a comet would be accelerated if it met with resistance; since the inverse square law applies to electrical central forces. Electrical mass is not strictly constant: it is a function of speed, but in such a way that it is practically constant until the velocity of light is very nearly attained. That is a critical velocity, which apparently cannot be surpassed. When this critical speed is reached, any electrified body becomes suddenly of infinite mass, and something is bound to happen. What that something is, it is not easy theoretically to say; but the partial or incipient disintegration or dissociation of the atom, and the flying away of a portion with a speed comparable to that of light, is no unlikely result.

Out of the whole multitude of atoms, even of the atoms of a conspicuously radio-active substance, it is probable that only a very few get into this unstable or critical condition at any one time; perhaps not more than one in a million million; nevertheless, just as occasional though rare encounters take place in the heavens, followed by the blaze of a new and temporary star, so, though probably not by the same mechanism, here and there a few out of the billions of atoms in any perceptible speck of radium arrive in due time at the unstable condition, and break down into something else, with energetic radio-activity during the sudden collapsing process; emitting, in the process of collapse, not only the main projected substance, but likewise also a few electrons, and those X-rays which always accompany a sudden electric jerk or recoil. And the X-rays so emitted are of the most penetrating kind known, being able to pass through an inch of solid iron in perceptible quantity.

14. The hypothesis concerning radio-activity which is now in the field, then, is that a very small number, an almost infinitesimal proportion, of the atoms are constantly breaking up; throwing away a small portion, say one per cent. of themselves, with immense violence, at

about one-tenth of the speed of light; the remainder constituting a slightly different substance, which however is still extremely unstable, and therefore radioactive, going through its stages with much greater rapidity than the radium itself, because practically the whole of it is in the unstable condition, and so giving rise to fresh and fresh products of its own decay, till a comparatively stable state is reached, or till the process passes beyond our means of detection.

Roughly, the process may be likened in some respects to the condensation or contraction of a nebula. The particles constituting a whirling nebula fall together until the centrifugal force of the peripheral portions exceeds the gravitative pull of the central mass, and then they are shrunk off and left behind, afterwards agglomerating into a planet; while the residue goes on shrinking and evolving fresh bodies and generating heat. A nebula is not hot, but it has an immense store of potential energy, some of which it can turn into heat, and so form a hot central nucleus or sun. A radium atom is not hot, but it too has a great store of potential energy, immense in proportion to its mass, for it is controlled by electrical, not by gravitational forces; and just as the falling together of the solar materials generates heat, so that a shrinkage of a few yards per annum can account for all its tremendous emission, so it has been calculated that the collapsing of the electrical constituents of a radium atom, by so little as one per cent. of their distance apart, can supply the whole of the energy of the observed radiation—large though that is—for something like 30,000 years.

15. It does not follow that the life of a piece of radium is as great as that; the data are uncertain at present, but there is absolutely no ground for the popular and gratuitous surmise that it emits energy without loss or waste of any kind, and that it is competent to go on for ever. The idea, at one time irresponsibly mooted, that it contradicted the principle of the conservation of energy, and was troubling Physicists with the idea that they

must overhaul their theories—a thing which they ought always to be delighted to do on good evidence—this idea was a gratuitous absurdity, and never had the slightest foundation; but the notion that radium was perhaps able to draw upon some unknown source or store of energy, without itself suffering loss, was a possibility which has not yet wholly disappeared from some minds. Sir W. Crookes, for instance, suggested that it might somehow utilize the most quickly moving atoms of air, after the fashion of a Maxwell demon—a possibility that should always be borne in mind as a conceivable explanation of the power of some living organisms. It is much more reasonable to suppose, however, that radium and the other like substances are drawing upon their own stores of internal atomic energy, and thereby gradually disintegrating and falling into other, and ultimately into more stable, forms of matter.

Not that it is to be supposed that even these are finally and absolutely stable: these too are subject to radiation loss, and so must be liable to decay; but at a vastly slower rate, perhaps not more than a few hundred atoms changing and diffusing away each second—a process utterly imperceptible to the most delicate weighing until after the lapse of millions of years; so that for all practical purposes, and for times such as are dealt with in cosmic history, they are permanent, even as the solar system and stellar aggregates appear to us to be permanent. Yet we know that all these systems are in reality transitory, as terrestrial structures like the Pyramids or as the mountains and the continents themselves are transitory: of all these things it may be said that in any given form they have their day and cease to be. But whereas geological and astronomical configurations pass through their phases in a time to be reckoned in millions of years—the active life of a solar system covering perhaps no very long period—it is probable that the changes we have begun to suspect in the foundation-stones of the universe, the more stable elemental atoms themselves, must require a period to be expressed only by millions of millions of centuries. For in such a time as this, at the rate of a hundred atoms per second, a bare kilogramme—a couple of pounds only—of matter, even of heavy matter, would have drifted away. And yet this period is a million times the estimated age of the earth.

16. If we allow ourselves to speculate, on the strength of the slender experimental evidence as yet forthcoming, instead of waiting, as to be wise we must wait, for confirmation and thorough examination of the facts, we should say that the whole of existing matter appears liable to processes of change, and in that sense to be a transient phenomenon.

Somehow, we might conjecture, by some means at present unknown, it takes its rise: electrons of opposite sign crystallizing or falling together, perhaps at first into a manifestly unstable form; these forms then pass on from one into another, going through a series of transitional states, and abiding for a long time in those configurations which are most stable; giving a process of evolution inconceivably slow in its later stages, comparatively rapid in its early ones: and yet not so rapid, even in a substance like radium, but that its life as such may be reckoned by thousands of years.

If such a transitory existence is ever established for the forms of matter as we know them, it by no means follows that the process goes on in one direction only, or that the total amount of matter in the universe is subject to diminution. There may be regeneration as well as degeneration.

The total amount of radio-activity in a substance is singularly constant. If the radio-active portion is removed, a fresh supply makes its appearance at a measured rate: that rate being expressible by a decreasing geometrical progression, and being precisely equal to the rate at which the power of the removed portion decays.

Whether the total amount of matter in the universe is constant likewise, as much disappearing at one end by resolution into electrons as is formed at the other end by their aggregating together, is at present quite unknown; and indeed it is clear that we have now become far immersed in the region of speculation. Nevertheless it is speculation not of an illegitimate character, for it is very consistent with all that we know about the rest of the material universe.

Astronomy tells us that the cosmic scheme, though it looks permanent, is subject to constant flux. In the sky we see solar systems and suns in process of formation by aggregation out of nebulae; we see them rise in brilliancy, maintaining a number of planets in health and activity for a time, and then slowly become subject to decay and death. What happens after that is not certainly known; it may be that by collision a nebula may be reconstituted, and the process started again; though so long as there is only a force of one sign at work (gravitation only) it would seem that ultimately the regenerative process must come to an end. The repellent force exerted by light upon small particles, however, must not be forgotten: it can overpower gravitation when it acts on small enough bodies; and there are other possibilities. Among the parts of an atom certainly the forces are conspicuously not of one sign; inside an atom there exist both attractive and repulsive forces; the resolution of an atom into its electron constituents, and the aggregation of these constituents into fresh atoms, are both perfectly thinkable. All we have to do is to ascertain by careful and patient investigation what really happens; and my experience has led me to feel sure of this, that whatever hypotheses and speculations we may frame, we cannot exceed the reality in genuine wonder. And I believe that the simplicity and beauty of the truth concerning even the material universe, when we know it, will be such as to elicit feelings of reverent awe and adoration.