The Permanence of Substance.

By Sir JOSEPH LARMOR, F.R.S.

IN Victorian times the atoms of matter were described by Clerk Maxwell, in picturesque and weighty phrase, as the "foundation stones of the material universe." It was believed that an æthereal medium for physical intercommunication in the cosmos was essential: and if so, material systems could not arise as other than mobile structures inhering in that universal medium. The standard illustration (for that was its true function) which went far by visual experiment to give vitality as well as precision to this general doctrine, was the Kelvin formulation of vortex atoms, based on Helmholtz's advances in the exact hydrodynamics of ideal perfect fluid, and lying in the natural succession to the brilliant but often fantastic gropings after vortical imagery by Descartes. The force of the illustration lay in the certainty that in the ideal pervading medium such vortex structures could not be wiped out, must be indestructible for ever. The ultimate atoms of matter, which stimulated the investigation of these vortical ring structures by way of analogy, have now been pushed back, first in theory and afterwards far more precisely by experimental discovery, to the electronic constituents of the chemical atoms.

If there is an æther, matter must be of necessity atomic, the possible variety of atoms being restricted to the limited number of types of suitable structure that are dynamically stable: and conversely, if matter is found to consist actually of self-contained atomic structures, this central fact is either evidence for a universal æther in which all matter subsists, or else must remain wholly inexplicable, perhaps even inscrutable. Such would be the modern version of the great argument of Democritus, on atoms and the void.

On the other hand, in extreme modern developments of the idea of relativity, the material universe seems to have no "foundation stones." An ultimate atom of matter is not there describable as an essential structure at all, such as can be explored, of course only partially, yet to an increasing degree which becomes adequate for more and more scientific purposes. It usually appears as nothing but a local aggregation of electric charge, held together by unknown internal constraint which is assumed not to disturb other relations. It can thus be liable to dissolve itself into pure motional energy by fusion with opposite charges; and the fact that the measures of mass and energy are modified in the same way by change of the frame of reference lends plausibility. The end of the cosmos would be the vanishing of matter: its beginnings must be on every scheme inscrutable.

It seems to be mainly with a view to elegance and completeness in the algebra that the electronic nucleus is thus introduced merely as a local aggregation of electric charge with some permanent law of volume-density. At a later stage it became recognised that internal forces are needed to hold it together; and whatever they may be they must not interfere with its necessary relativity as a whole as regards uniform translatory motion. They seem to be disposed of by being classed in the exposition as an unknown part of the stress-tensor of the field. Thus this procedure can be in no respect an improvement on the classical method which it claims to supersede, of regarding an electron as a structural singularity unknown except so far as it is defined by increasing knowledge of the field that is physically attached to it by its very constitution. Even in pure spatial analysis of differential geometry a singular pole is approached through the influence it sheds around: the algebra never gets into the inside of it, so to say. That is the classical way, and can be held to be the correct scientific method, of approach to the properties of the unknown permanent electron or atom. The occasional denial of it seems possibly to be linked up with a metaphysical doctrine[1] that all natural law is nothing more than a manifestation of the *quasi*-geometric qualities of a fourway continuum named space-time; so that a complete exploration throughout it, by continuous spatial analysis without inherent unexplored poles, must be the aim of physical theory. The alternative view is that the infinitely little transcends human grasp by involving just as great inherent complexity as does the infinitely large; though both can be approached and annexed, with increasing completeness, to our scientific schemes, by virtue of transcendental relations of mind to matter which lie at the root of all possibility of knowledge or scientific formulations.

In further illustration of the contrast of methods, these hypothetical internal stress-forms the rôle of which is to hold a local distribution of electric density together, and so constitute an electron, may be more closely considered. They are now often referred to as the "forces of Poincaré," because he found out that for a shell model of the electron they can be formulated simply as an isotropic pressure, and without doing any violence to the relativity postulate for the structure. But, on the illustrative analogy of a rotational æther, it had been familiar that, for any static model, all that was required was to bring into play in the theory just this hydrostatic pressure that obviously can subsist in such an æther. Yet, viewed from this more concrete or physical point of view, that was not sufficient; for it was immediately recognisable that such a shell model is an unstable structure, much as is actually an electrified soap-bubble, thus requiring that analogies along that line had to remain in abeyance pending possible formulation of plausible slight constraints such as might protect the illustrative structure from destruction. But without assuming any definite internal structure for the electron at all—all such models are suggestive and valuable for consolidation of knowledge, none can be complete or final—we can postulate merely that it is permanent and is mobile, and explore, by mixed observation and theory, the nature of the field around it with continually increasing precision, and also the mutual influences of neighbouring electrons which arise from the superposition of their fields. This tentative procedure runs parallel to the course of actual progress: while any postulate of reduction of physical science to a self-contained

[1] An alternative form of the postulate, that nothing may be the subject of reasoning that cannot be observed, seems to imply a sense of humour.

geometric analysis in space-time may savour of reproducing the infinite with finite appliances.

It was already implicit in the Maxwellian æther-theory of half a century ago that a loss of energy δE from a material system, if it occurs by radiation, involves proportionate loss of inertial mass, of amount $\delta E/c^2$, where c is the speed of radiation: and vice versa. Such loss would have to fall on the internal relative potential and kinetic energies of the constituents of the radiating atom. There appears to be some astronomical knowledge now available, following on the lines of an idea recently introduced and explored by Dr. Jeans (Monthly Notices R.A.S., November 1924, just now to hand), to estimate extreme superior limits restricting the amount and duration of radiation from the sun or a star that could be conceivable from this source of supply. This new type of limit, doubtless, however, quite unapproachable, and uncertain as depending on an estimate of the internal mutual energies of the atom that may be available for running away into radiation, would stand in contrast, for example, with the famous historical estimate, enormously smaller, afforded by the running down into radiation of energy located outside the atoms, that of the mutual gravitation of the parts of the system in bulk; which was put forward in the early days of the conservation of energy by Kelvin and independently in more searching and complete manner by Helmholtz to explain the solar heat, but is now regarded on cogent grounds as inadequate for the facts of cosmic evolution when taken by itself.

Data are perhaps not entirely wanting for an estimate of the kind here described, along two ways of approach. The total energy of relative positions and motions of electrons and other ultimate nuclei in the atom, such as might by the hypothesis possibly escape into energy of radiation, can on the lines of present general ideas of atomic structure be roughly set out. Indeed, the maximum possible transfer into radiant energy for all time would be measured by the total mutual energy of the initially disgregated elements, electrons and nuclei, that first fall into chemical atoms, of orbital type, and then ultimately on their destruction lapse together into closest contact. It is conceded that if atomic nuclei are regarded as finite electric charges concentrated almost into mere points, thus involving practically infinite space-density and so allowing the charges to approach infinitely near, this amount of possible radiation could tend to increase beyond measure. But that would introduce infinities in all directions, for example, infinite inertia of an atom, and is perhaps not contemplated on any kind of theory. (As the complete transformation, vice versa, of the gases from 1 c.c. of radium releases heat to the order of 10^7 calories, an easy computation shows that the preponderant nuclear energies of the atoms must there be very deeply drawn upon, as, of course, is now familiar, though not so much as to involve recognisable diminution of mass. Cf. Rutherford and his coadjutors, as reported in his treatise.)

There seems to be another corroborating mode of approach, which must indeed be obvious; one which also affords some confirmation of our postulate of indestructibility of the primordial atoms. It lies in the cardinal discovery of Aston that the standard relative atomic masses of all the chemical elements are expressible in high approximation by integers, with only one challenging exception. When in the cosmic process two atoms are imagined to combine, forming an atom of a more complex kind of matter, there would thus be no room for much conversion of mass into energy: the mutual energy, residing in the local fields, that can become free to run away into radiation, must correspond to the equivalent of a very small portion, perhaps on the experimental results not more than one-tenth per cent., of the total mass, however intimate be the consolidation that is required into one central nucleus for the new atom.

For astronomical purposes Dr. Jeans has made an estimate of the course of evolution for the universe, if all the matter in it were classed as a form of energy convertible into radiation. He finds, on Eddington's hypotheses, that durations of the present cosmic order ranging around two hundred millions of millions of years would become conceivable. Perhaps if only the mutual positional and motional energies of the ultimate discrete constituents of atoms could at the very most run into radiation, the energy thus assumed to be available (which is no measure of the duration of the system) must be reduced on the first estimate above by a factor which might be as small as 10^{-8} or as great as 10^{-5}, and on the other by a factor which could not exceed 10^{-3}.

Apart from such interesting change in formulation of an ultimate cosmic problem, the object of the present discussion is to concentrate on one fundamental question, which has become conspicuous in much recent ultra-physical speculation. Is matter to be regarded as consisting irrevocably of primordial atomic structures absolutely permanent: or alternatively, discarding all structural analogies based on classical dynamical principles, are the atoms, if such then really are retained, to be considered as mere concretions or aggregations liable to dissipate entirely into energy of radiation and so vanish?

Biographical Byways.[1]

By Sir ARTHUR SCHUSTER, F.R.S.

7. OSBORNE REYNOLDS (1842–1912).

WHENEVER I hear of a man who is described as being lovable, the figure of Osborne Reynolds rises up before me; and yet I doubt whether on a casual acquaintance or in official intercourse that adjective would have suggested itself. In ordinary conversation he often took a cynical view of things; he was obstinate in adhering to his own opinion, absolutely uncompromising, and sometimes a little hasty in imputing selfish motives to his opponents. But the discordant elements of his character were fused together by an almost primitive simplicity of mind, and after closer acquaintance few could resist the charm of his strong personality.

His loyalty to friends and colleagues knew no bounds.

[1] Continued from p. 199.