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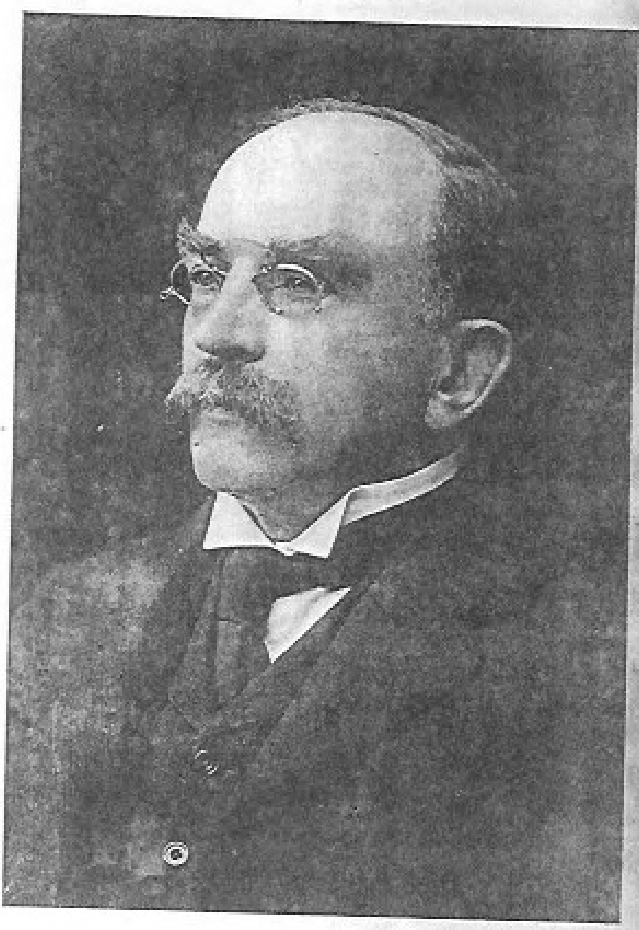

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JOSEPH LARMOR

1857–1942

The researches by which Sir Joseph Larmor will chiefly be remembered belong to the decade 1892–1901, which is now recognized as a transition period in physics. After half a century of rapid progress, the main wave of advance seemed to have spent its force; and it was beginning to be said that the possibilities of discovery were approaching exhaustion. Before the end of the decade X-rays, electrons and radio-activity had again set experimental physics in feverish progress, to be followed later by revolutionary changes in the foundations of physical theory. But at the time when Larmor started on his main work there was little to inspire new ideas. The ever-urgent problem of the ultimate relation of matter and electricity and aether, and the search for a unifying conception which would explain how they come to possess their fundamental properties, had occupied the greatest minds of the time; and it was hard to see any direction in which new light might be found. The ground had been gone over again and again, and impassable barriers seemed to have been reached. Classical physics was indeed near the end of its tether. Of those who yet contrived to make substantial progress at this difficult stage—who brought classical physics finally to the point where new methods became inevitable—two names stand out prominently, Lorentz and Larmor. Their work had much in common, so that it is sometimes difficult to assess their contributions separately. Larmor's reputation has perhaps been overshadowed by that of Lorentz. But on any estimate, Larmor's achievements rank high; and his place in science is secure as one who re-kindled the dying embers of the old physics to prepare the advent of the new.

Joseph Larmor was born at Magheragall in Co. Antrim on 11 July 1857. He was at school at the Royal Belfast Academical Institution, living at that time with an uncle in the city. He is described as a thin and delicate black-haired boy of most precocious ability both in mathematics and classics. He obtained a double first in the scholarship examination at Queen's College, Belfast, and ultimately graduated with the highest honours. From there he proceeded to St John's College, Cambridge. A severe illness made it necessary for him to lose a year, but he took the mathematical tripos in 1880, securing the first place in the list. Those were days when the senior wranglership was a matter of wide popular interest, and the achievement caused the greatest enthusiasm in Belfast, since it was the second year in succession that his school had triumphed in this way. There are stories of a torchlight procession, which must have been terribly embarrassing to the shy young mathematician. The tripos of 1880 is especially memorable because the name of Larmor was followed by that of J. J. Thomson as second wrangler—the strongest combination for the top two places in the history of the examination. Larmor was at once appointed Professor of Natural Philosophy in Queen's College, Galway. He was there from 1880 to 1885, and then returned to St John's College as lecturer. In 1903 the Lucasian professorship fell vacant through the death of Sir George Stokes; Larmor was the obvious successor, and thus came to fill the famous chair once held by Sir Isaac Newton. In 1932, at the age of seventy-five, he retired. His last years were spent at Holywood, near Belfast. He died on 19 May 1942.

Of the two rivals in the tripos of 1880, Thomson was the first to achieve wider eminence—originally as a mathematical physicist. Distinction came less rapidly to Larmor; but by 1892 he had published some thirty papers on a variety of subjects in applied mathematics, and he gained election into the Royal Society. Between 1894 and 1897 he published in the *Philosophical Transactions* his great memoir 'A dynamical theory of the electric and luminiferous medium' in three parts, amounting altogether to 250 pages. A year later the theory was re-cast, and submitted in an improved form for the Adams prize in the University of Cambridge. This successful prize essay was published in 1900 as a book *Aether and matter*, or—to give it its full title—'Aether and matter: a development of the dynamical relations of the aether to material systems on the basis of the atomic constitution of matter, including a discussion of the influence of the earth's motion on optical phenomena'.

As regards substance, *Aether and matter* ranks among the great scientific books. It is a difficult book—unnecessarily difficult, because Larmor was certainly not gifted with lucidity of style. But to the student of the period 1900–1905 it was the one gateway to new thought, revolutionary and inspiring.

It is scarcely possible to do justice to this work without some reference to the aether controversy which occurred many years later. To the modern ear 'aether and matter' sounds antiquated; and indeed forty years have carried us a long way beyond the ideas which Larmor set forth. That would not in itself diminish our appreciation of work which had in its time been a step in the progressive development. But it is probable that many have been taught to look on the elaboration of aether theory as an altogether sterile occupation of our model-minded predecessors—an aberration from the true line of progress. The nineteenth century is littered with the debris of abortive aethers—elastic solids, jellies, froths, vortex networks—but it is a mistake to think that nothing finally emerged from it all. Great advances were ultimately made. MacCullagh's aether (1836) was a medium endowed with 'rotational elasticity', a property simple to describe mathematically but quite unlike the kind of elasticity exhibited by any form of matter. The model-makers found that the property could be imitated by a collection of small studded spheres pressed in contact, each sphere containing a gyrostat; and this habilitated the theory in their eyes. It was MacCullagh's aether that Larmor adopted and extensively developed—developed, because meanwhile the electromagnetic theory of light had arisen, and the MacCullagh aether, originally only luminiferous, must now be the medium of all electrical and magnetic interaction. Larmor regarded rotational elasticity in the modern way. Aether was not a material medium,[1] and there was no object in pretending to 'explain' its properties as though it was. Its properties were *sui generis*, not analogous to anything known in matter, and only to be defined by mathematical equations. A model may illustrate these properties; but it associates them with irrelevancies which are likely to lead to erroneous inferences. In his own words:

'As to the intrinsic nature of the rotational elasticity of the free aether, although it is an important corroboration of our faith in the possibility of such a medium to have Lord Kelvin's gyrostatic scheme by which it might be theoretically built up out of ordinary matter, yet we ought not to infer that a rotational free aether is necessarily discrete or structural in its ultimate parts instead of being a continuum. There must be a final type of medium which we accept as fundamental without further analysis of its properties of elasticity or inertia; and there seems no reason why we should prefer for this medium the constitution of an elastic solid rather than a constitution which distortion does not affect—perhaps there is just the reverse.'

After Larmor's work the rotationally elastic aether was without question the only live aether theory; the others belonged to past history. It is alive to-day. What Larmor said about it remains true, though no doubt greater interest is taken in things, since discovered, which he did not say about it. In view of later developments, his warning that the discrete elements of structure shown in the model were not necessarily features of the aether theory itself is particularly important; for attempts to measure the velocity of objects relative to the aether implicitly assume that it is, like a material ocean, constructed of identifiable structural elements whose position can be traced from moment to moment. Larmor had made it clear that even if such identifiable elements existed—and there was no ground for such an assumption—these had no bearing on the propagation of light and electromagnetic force. At the time neither Larmor nor any one else drew the logical conclusion that it was very doubtful whether any definable meaning could be given to the term 'velocity relative to aether'. That was left for Einstein to realize. But when velocity relative to aether was finally abandoned, it left Larmor's aether theory quite unscathed.

When relativity theory and quantum theory were comparatively novel it began to be said that the aether had been abolished. This was not a very happy way of expressing things, and it does not seem to have been favoured by the leading authorities; but the idea gained so much currency that the course of least resistance was to avoid using a word sure to provoke distracting controversy. Both the aether and the matter of Larmor's time have now given place to a profoundly modified conception of the structure of things, the matter being even more unrecognizable than the aether. But we still talk of 'particles', although a particle in anything like the old classical sense is no longer admitted. There was no justification for the special animosity against the term 'aether'.

[1] On p. 336 of *Aether and matter* Larmor contrasts his own theory with the view which 'virtually identifies aether with a species of matter'.

It was said that the term had too material a connotation. If indeed the student in 1915 associated material ideas with the aether, it is a strong argument against those who advocate the teaching of science historically. But very largely the view that the aether must be given up was a speculation which in a few years proved incorrect; and the aether has since been reinstated in all but name. 'Particles in negative energy levels' now pack the space which the aether occupied; and a cosmical energy tensor permeates every part of the universe, whether matter is present or not, just as the aether used to do. If there had been no interregnum these developments would have been reached much more naturally as a modernization of the aether parallel with the modernization of matter. It is therefore an arbitrariness of language which obscures the continuity between Larmor's aether theory and present-day developments. Like modern writers he could have made shift to do without the term, if there had been any reason for avoiding it.

Part I of Larmor's memoir completed the theory of the rotationally elastic aether, extending its original optical application to embrace all electromagnetic field phenomena, but it was not very successful in explaining the relation of aether to matter. At the end of Part I there is a postscript, dated August 1894, headed 'Introduction of free electrons'. Thereafter electrons became the main subject of the theory; and in 'Aether and matter' the emphasis is especially on the 'matter'. It was already known, from an investigation by J. J. Thomson, that an electric charge effectively increases the mass or inertia of the body which carries it. In Part II of the memoir Larmor suggested that the mass of an electron might arise *wholly* from its electric charge. Further, all inertia might be of this nature, ponderable matter being composed of systems of electrons. This appears to have been the first suggestion of a purely electrical theory of matter.[2]

It should be remembered that at this time electrons had not been discovered, though the date of discovery of the negative electron (1897) was drawing near. They were, however, not new to theory. Faraday's law of electrolysis had made it clear that, at least in certain conditions, discrete units of electric charge must occur; and electrons or their equivalent had appeared in various earlier investigations, including especially those of Lorentz. The experimental isolation of an electron might almost be described as a casual incident in the progress of electron theory, just as the experimental isolation of an atom was a casual (and very late) incident in the long history of atomic theory. At first it had little effect on the theory, more especially as the nature of positive electricity was not elucidated until long afterwards. As Whittaker has pointed out, it would make very little difference to celestial mechanics if it were discovered that the masses of the planets were all equal; and the position of electron theory was very much analogous. The observational background of Larmor's theory is illustrated by the following passage in which he is arguing for a purely electrical theory of inertia:

'Bearing in mind the phenomena of the solar corona and comet's tails, and

[2] E. T. Whittaker, *History of the theories of aether and electricity*, p. 343.

certain electric phenomena in vacuum tubes, where some modification of the aether which affects light by reflexion or otherwise is projected with velocities of that order. . . .'

The one contemporary discovery which both Larmor and Lorentz seized on as pertinent to their theories was the Zeeman effect (1896). Otherwise the wave of experimental progress, which began about that time, had little immediate effect on fundamental theory.

The scope of Larmor's theory and its place in the history of progress may perhaps be understood from the following summary (expressed largely in his own words). Starting with the conception of a rotationally elastic medium, which had been originally evolved from consideration of optical phenomena alone, he had shown that it was capable of natural development so as to pass into line with the much wider and more recent electrodynamic theory which was constructed by Maxwell on the basis of purely electrical phenomena. It was then found, reasoning entirely from abstract principles, that the only possible way of representing electrification was as a system of discrete or isolated charges constituting singular points, involving intrinsic strain, in the structure of the medium.[3] The fact that the structure of an elementary electric charge could be definitely described by a rotational strain, removed what had hitherto been a main obstacle in the development of electromagnetic theory, namely, an entire vagueness as to how electrification should be mathematically specified. These discrete charges, or electrons (positive and negative), might be attached to material atoms; or they might in a deeper sense be the material of the atoms, accounting not only for their distinctively electrical properties, but for their inertia, and ultimately for gravitational and all other physical characteristics. Larmor strongly inclined to the latter view, and adopted it in his detailed developments. 'The question must, of course, remain open as to whether other forms of activity besides this electrical one can be recognized in the constitution of the atom of matter: as yet nothing seems to have been found which demands a further amplification, so that any advance in that direction would at present be premature if not gratuitous.' Finally, not the least important feature of the theory was that it was purely 'dynamical', the governing condition being that aether and matter must be represented together as a generalized dynamical system obeying Hamilton's Principle of Stationary Action.

In certain stages of scientific progress the most successful theory is the shortest-lived; for a fertile conception stimulates and facilitates the advance which ultimately leads to its supersession. Nevertheless it is worth while to consider how much of Larmor's theory has survived the later revolutions of physics. Reference will be made later to some particular results which are still widely quoted, and are indeed used by modern writers in a way which must have greatly shocked the conservative mind of their originator. Of the broad features of the theory I think the most permanent is the nature of the distinction between positive and negative electric charge. The distinction is *chiral*, positive and negative charges being related to one another like right-handed and left-

[3] Larmor's 'freely mobile intrinsic strains' became for a time famous as a catch-phrase.

handed screws. This kind of distinction can be formulated mathematically with the widest generality; so that it is preserved both in relativity theory and in the group theory or symbolic algebra employed in wave mechanics. The distinction of opposite chirality enables us to construct two systems, which are intrinsically similar, and yet are not relativistically equivalent in the way that systems connected by a Lorentz transformation are equivalent. By recognizing opposite chirality Einstein's mechanical theory of relativity is extended to include distinctively electrical characteristics; and the same concept is used and amplified in the spin characteristics which appear in the wave-mechanical theory of atoms and nuclei. In Larmor's theory this conception of the difference between positive and negative charges was entirely novel. He was led to it because in a rotationally elastic medium the singularities must correspond to rotational strains, and such strains have a chirality which is not exemplified in the elastic strains of ordinary matter. I think that this result alone would have justified Larmor's great investigation, because it is a principle of supreme importance in fundamental theory which even yet has not been adequately followed up.[4]

The idea of a purely electromagnetic origin of inertia, and of all material characteristics, was for many years a fruitful source of progress; but it can scarcely be said to be literally true, unless we stretch the definition of 'electromagnetic' in a way not contemplated at the time. For it to be true, as Larmor formulated it, it would be necessary to identify his positive electrons with the protons discovered later. He himself considered this to be inconsistent with his theory; and, commenting in 1929 on his early papers, he wrote: 'The positive electron, which ought to exist as the optical image of the negative, unless some fundamental feature has not yet come to light, has not yet been discovered.' Three years later the positive electron (positron) was discovered.

The outstanding problem of the time—towards which electrodynamical theories were especially directed—was the effect of the motion of bodies through the aether. These researches culminated in the Lorentz transformation. The relation between Larmor's and Lorentz's contributions is indicated clearly in Whittaker's *History of the Theories of Aether and Electricity* (p. 439). The transformation was first given by Lorentz as a first-order approximation, neglecting the square of the velocity. In *Aether and Matter* Larmor showed that it was correct to the second order. Finally it was shown by Lorentz to be exact to all orders. It is the exactness of the transformation which has given it a fundamental position in physical theory, and has led to the new conceptions associated with relativity theory; and it is fitting that it should bear Lorentz's name as the originator and perfecter of it. But inasmuch as all the crucial experiments (Michelson-Morley experiment, FitzGerald and Trouton's condenser experiment, Rayleigh and Brace's double-refraction experiment) were concerned with second-order terms, the step contributed by Larmor was at the time much the most important. In particular the contraction of lengths of moving objects,

[4] Antisymmetry and chirality are closely connected; but chirality (which is the form employed by Larmor) is the more general concept and gives a more fundamental insight.

suggested speculatively by FitzGerald, is a second-order effect. We shall perhaps do justice between Holland and Ireland if we speak of the 'Lorentz transformation' and the 'FitzGerald-Larmor contraction'.

The problem to which Larmor made this vital contribution goes back to the discovery of astronomical aberration by Bradley. Aberration occurs just as though light were being propagated in a uniform medium everywhere at rest, and the earth carrying the observer's telescope were moving through the medium without disturbing it. On the other hand laboratory experiment by Fizeau indicated that transparent bodies imparted part of their velocity to the light-bearing medium, the 'dragging coefficient' depending on the refractive index. How then could the earth avoid dragging the light-bearing medium? And if the earth dragged it, how could astronomical aberration remain unaffected? There was the same kind of flat contradiction as that which later arose between the undulatory and the quantum theories of light. The Michelson-Morley experiment was designed as a crucial second-order experiment to test directly whether the aether at the earth's surface was being carried along with the earth in its revolution round the sun, or whether it remained stagnant, slipping through the interstices of the earth's substance. Apparently it decided that the aether was carried along with the earth. But although the theorist is glad to appeal to a crucial experiment to decide between two possibilities, he is not so satisfied when the decision is between two *impossibilities*. The elementary facts of astronomical aberration still remained opposed to a convected aether, the only serious attempt to reconcile them (proposed by Stokes) having broken down. In these conditions FitzGerald made his suggestion that motion through the aether might have an effect on the dimensions of material bodies, causing them to contract in just such a way as to conceal the optical effects expected from the motion. Considering the extraordinary nature of this hypothesis, and that it was an *ad hoc* explanation unsupported by anything hitherto known in theory or experiment, it was surprisingly well received. Larmor's investigation gave it a new status altogether. What would be the effect of motion through the aether on the dimensions of material systems was no longer a matter for speculation, but a theoretical problem capable of definite solution. The mathematical machinery for investigating aether and matter together as one system had been developed. The freely mobile intrinsic strains in a rotationally elastic medium, representing the ultimate particles of matter embedded in the aether, form a system in equilibrium. The problem was to correlate the conditions of equilibrium for one state of motion of the strains to those of another state of motion. The correlation was found to be the Lorentz transformation extended by Larmor to the second order—far enough to demonstrate that the material system must contract in the direction of its motion in order to preserve equilibrium. Both qualitatively and quantitatively the FitzGerald contraction was shown by Larmor to be a necessary result of an electrical constitution of matter.

The formula $\frac{2}{3}e^2\Gamma/c$, for the radiation from a charge e having an acceleration Γ, was first given by Larmor (1897). Few results have had so wide an application both in classical theory and in quantum theory, in terrestrial physics and in astrophysics. Since it is the basis of Kramers' theory of the absorption coefficient, and also of the theory of radiation damping, the astrophysicist is dependent on it whether he is dealing with the inside or the outside of a star. A more recondite discovery was the 'Larmor precession'. He showed that in a magnetic field the electron orbits are unchanged in form and in inclination to the field, but the plane of the orbit precesses with angular velocity $\frac{1}{2}eH/mc$. The modern theory of the magnetic splitting of the eigen states of an atom is based directly on this result.

Larmor had an intense, almost mystical, devotion to the principle of least action. Owing to its invariant form, this is a compact and often the most convenient way of formulating physical laws; though one would not necessarily choose it as physically the most illuminating. But to Larmor it was the ultimate natural principle—the mainspring of the universe. His first paper (1884) was 'On least action as the fundamental formulation in dynamics and physics', and numerous subsequent papers and addresses were devoted to this subject. I had never been able to persuade him of the truth of general relativity theory, but (about 1924, I think) he said to me reproachfully: 'I have been reading the continental writers on relativity, and I find it is all least action. I begin to see it now'. Much as Lord Kelvin required a theory to be put in the form of a mechanical model before he would admit to understanding it, so Larmor required it to be put in the form of an action principle.

We can only refer briefly to the numerous other subjects which he handled. A paper on the bending of radio waves round the earth (1924) gained a good deal of attention at the time. Two papers (1906 and 1915), written jointly with E. H. Hills, introduced a new kind of analysis of the irregular motion of the earth's axis of rotation as given by the determinations of latitude variation at the chain of International Latitude Observatories. The authors deduced directly the plane and magnitude of the couple acting on the earth, and its changes month by month. The diagrams showing the results of their analysis are of great interest, and give a different impression of what is happening from the usual analysis into 14-monthly and annual terms. Protection from lightning was dealt with in a Royal Society paper in 1914. In geomagnetism he was a leading authority. An intriguing (and perhaps typically Larmorish) title is 'Note on anthropomorphism and its quantification' contained in his collected papers', but the note scarcely fulfils the expectations aroused!

The writer attended Larmor's professorial lectures in 1905. They were ill-ordered and obscure; but they were well worth the effort to follow. Even the examination-obsessed student could perceive that here he was coming to an advance-post of thought, which made all his previous teaching seem behind the times. Besides his lectures, a main channel of his influence was his work as secretary of the Isaac Newton Electors from 1913 to 1932. A succession of Isaac Newton Students, many of whom afterwards became distinguished, benefited greatly from his oversight and counsel.

Larmor was decidedly conservative in his scientific views. It seems strange to say this of the man who must be counted the harbinger in England of the new ideas which mark the present century. He was the first really to recognize the immaterial nature of the aether and to throw off the obsession that an ultimate explanation of things must fill the universe with whirring machinery 'like the nightmare of a mad engineer'. No doubt many others had professed the same views as a matter of scientific philosophy, but to mould scientific practice to this outlook, as Larmor did, was another matter altogether. Yet most of those who remember him will find it hard to think of him as a sower of revolution! He seemed a man whose heart was in the nineteenth century, with the names of Faraday, Maxwell, Kelvin, Hamilton, Stokes ever on his lips—as though he mentally consulted their judgment on all the modern problems that arose. He would often say that all true scientific progress ceased about 1900—or even earlier, for his own *fin de siécle* effusion was only dubiously qualified. He admitted that modern work might have some kind of merit, if judged by the looser standards of these times; but that was about as far as he would go—except when he forgot his pose. There was, of course, a great deal of exaggeration in this pose; but he adopted it so systematically that perhaps he himself could scarcely distinguish it from his natural opinions. It was tempting after his conservative outbursts to chaff him as having been the moving spirit in the modern ideas which so much disturbed him, but it was plain that he did not like the accusation.

This habit of concealment of what was really passing in his mind made him a difficult colleague on syndicates and in examining dissertations. He was determined, but not persuasive. But, whatever may have been his sympathies, he kept abreast of current literature and was well able to give acute judgments in a wide variety of subjects. The trouble was that, if one happened to disagree with him, it was hard to bring the discussion down to essentials.

It is difficult to say how far he accepted relativity theory and quantum theory. He appears to have had no difficulty with the special-relativity theory, but he wavered very much over Einstein's theory of gravitation. His conversion (already mentioned) by finding that 'it is all least action' was followed by a relapse; but I think that in later years he was finally convinced. On quantum theory he had less occasion to form a definite decision. My impression is that he watched it in a detached way, more impressed by its immaturity than by its achievements, but by no means rejecting it. He read widely on both subjects; and, at certain periods at least, his writings on relativity theory were definitely constructive. More usually his references to modern theories give the impression of one who was conscientiously striving to keep open a mind which was not naturally open to the ideas they introduce.

He followed with keen interest the general advances in geophysics and astrophysics, and often contributed letters to *Nature* and *The Observatory* on the physical problems which they raise. But as he grew older, his style, never lucid, grew more and more involved. The letters often raised important points which might well have led to useful discussion; but they were seldom answered because no one could feel sure that he had rightly interpreted them. Indeed, communication of scientific ideas with Larmor, both orally and in print, was hedged with difficulty; as for writing—the illegibility of his letters was notorious. But he persevered in his efforts for mutual exchange of ideas, as a corrective to the increasing specialization of physics. He frequently attended the meetings of the British Association; and, when unable to be present himself, usually sent a written communication to be read. I recall one occasion when this practice proved unfortunate. The occasion was a discussion on quantum theory; and the opener had with much humour outlined the arguments likely to be advanced by an opponent who relied on the 'pint-pot' type of explanation. Quantum theory was then not so strongly entrenched but that such an opponent, warned in time, might have made a plausible defence of his position. The opening address was followed by a communication by Larmor read from the chair; and it was soon evident that the forecast was being fulfilled almost to the letter. One after another the arguments and the terms of expression, which we had been laughing at, were introduced. And as the absent contributor walked into the skilfully laid ambush, it became at last impossible to preserve seriousness.

Larmor had a strong attachment to his native country, and generally spent part of his summer vacation in Ireland. It is no accident that *Aether and matter* is so largely a development of the work of his countrymen MacCullagh, Hamilton, FitzGerald. It was doubtless his intense feeling over the Irish question which persuaded him to enter parliament. He represented Cambridge University as a unionist from 1911 to 1922. One of his characteristic reminiscences was the defeat of the alternative vote, which he claimed to have secured by a long speech, leading the bewildered House deeper and deeper into mathematics until the whip gave him the signal that the wanted absentees had arrived. He was fond of telling (though the dates do not bear him out) that he had obediently voted for the abolition of the carrying of a red flag in front of motor-cars, and had been haunted by remorse ever since. But it should be added that if his mathematical powers ever rendered less equivocal service to parliament he would be the last to drop a hint of it. It is difficult to believe that he found the position congenial; and it is unlikely that many of his colleagues would discover the valuable critical judgment he possessed. His most important work outside the university was as secretary of the Royal Society from 1901 to 1912. In this responsible and influential position, filled at a time when his powers were at their strongest, much of his finest service to science was rendered. And behind the mask of the cynical observer of a degenerate age of science, there was a genuine enthusiast promoting new developments, and giving generous encouragement where it was most needed and most deserved.

It is difficult to add to this record of his scientific activity any intimate details of his ordinary life. He was unassuming and easily approachable; but acquaintance with him never seemed to grow beyond a certain point. His ready conversation was a screen which seldom betrayed his real thoughts and interests. In some respects he had settled down to be a typical bachelor don. He was often seen walking alone in the Backs and in St John's wilderness; and he evidently loved the charm and quiet of the scene. But he was by no means a recluse. Though naturally diffident and retiring, he was too conscientious to evade duties which forced him into prominence and social activity. Much lies hidden, for he shunned the possibility of any publicity of his acts of kindness and generosity. In his later years an attempt was made in the university to hold a celebration in his honour; but his objection was so determined that it was impossible to proceed. Naturally such a baffling personality was often misunderstood. He guarded more than most men in secret fastness; and it is likely that there will always remain obscurity in our estimate of his outlook and personality.

Larmor received a Royal medal in 1915 and the Copley medal in 1921. He was president of the London Mathematical Society in 1914–1915. He was knighted in 1909.

A. S. Eddington

PUBLICATIONS

Larmor's *Collected Papers*, edited by himself with many notes and appendices, were published by the Cambridge University Press in two volumes in 1927 and 1929. The following short list contains only papers alluded to in the Obituary.

On least action as the fundamental formulation in dynamics and physics. *Proc. Lond. Math. Soc.* 15, 158 (1884).

A dynamical theory of the electric and luminiferous medium.
Part I. *Phil. Trans.* 185, 719–822 (1894).
Part II. *Phil. Trans.* 186, 695–743 (1895).
Part III. *Phil. Trans.* 190, 205–300 (1897).

On the theory of the magnetic influence on spectra: and on the radiation from moving ions. *Phil. Mag.* December 1897.

The methods of mathematical physics. Presidential address to Section A. *Brit. Assoc. Report*, Bradford, 1900.

On the period of the earth's free Eulerian precession. *Proc. Camb. Phil. Soc.* 9, 183 (1896).

(With E. H. Hills.) The irregular movement of the earth's axis of rotation. *Mon. Not. R. Astr. Soc.* 67, 22 (1906); 75, 518 (1915).

Protection from lightning and the range of protection afforded by lightning rods. *Proc. Roy. Soc. A*, 90, 312 (1914).

Why wireless waves can bend round the earth. *Phil. Mag.* (6) 48, 1025 (1924).