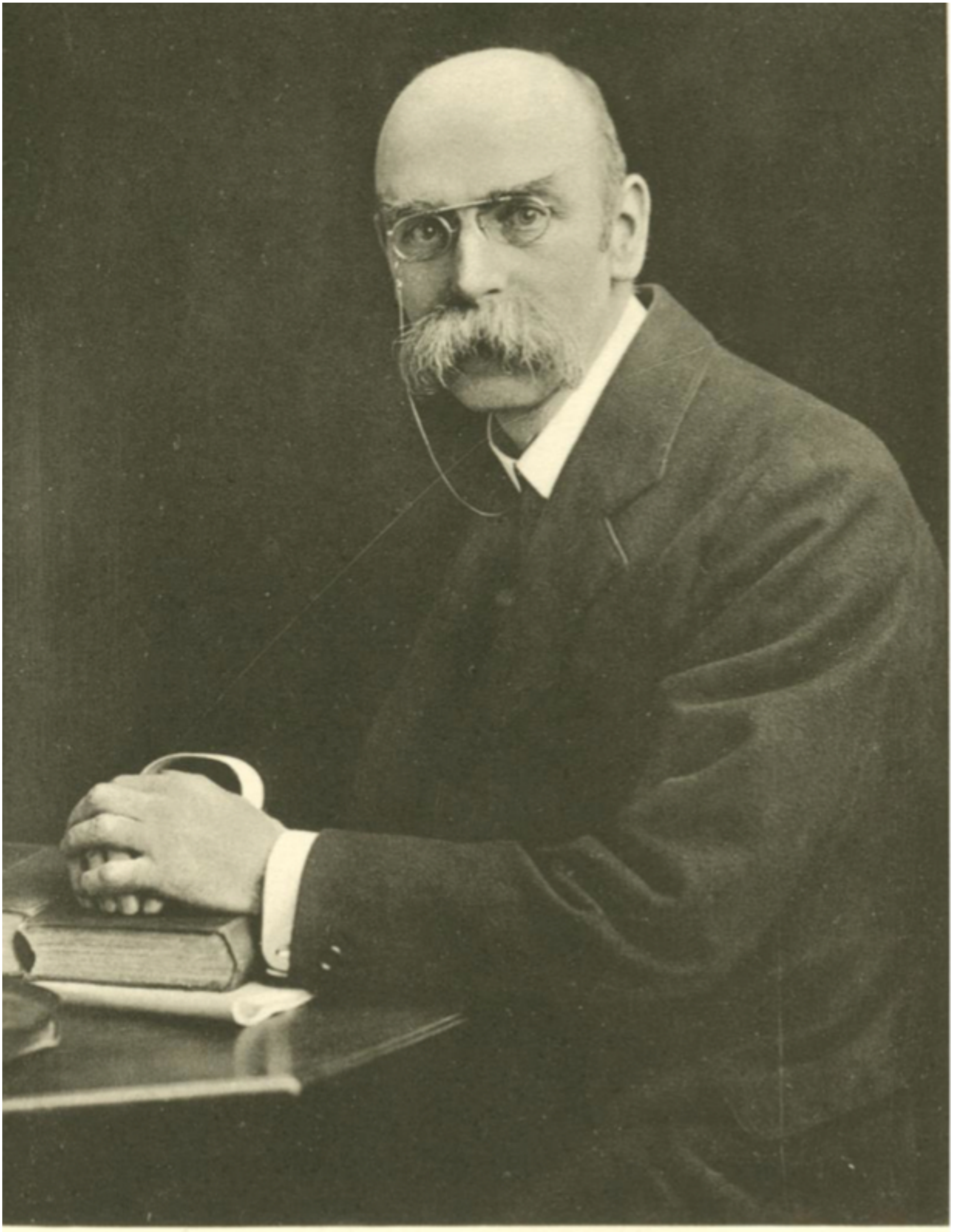

A. E. H. Love

AUGUSTUS EDWARD HOUGH LOVE

1863–1940

Professor A. E. H. Love, Sedleian Professor of Natural Philosophy in the University of Oxford and Fellow of the Queen's College, Oxford, died on 5 June 1940, following an operation. He was aged seventy-seven. Up to a very short time before his death he was fulfilling the full duties of his Chair, lecturing and attending meetings of the Sub-Faculty of Mathematics. For the last few years his health had been frail, but only to the extent that he took a taxi to go into Oxford for his lectures from St Margaret's Road where he resided. To the end he retained full use of all his faculties, and there was never any apparent dimming of the acuteness with which he would deal with a piece of University business, the precision of his lecturing, or the wisdom and judgment which he contributed to matters of current policy. Under the present statutes he was, at his age, ineligible for service on the Board of Faculty of the Physical Sciences, or the Board of Visitors of the University Observatory, but he never on that account forsook the society of his colleagues as they gathered at their informal lunch club before meetings of the Sub-Faculty. He last examined in the Final Honours School of Mathematics in 1936, at the age of seventy-three; I once heard an Oxford colleague say: 'We are none of us as good as Love at that game'. Certainly, if compulsory retirement from participation in formal University business is in general wise, the case of Love shows that it would be still wiser to provide for exceptional relaxation of the rule. Love's tenure of his chair, dating as it did from 1898, came under older statutes, and he was under no obligation to retire from that appointment; no breath of criticism

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was ever heard against him in that he occupied the chair for twelve years after the normal date of retirement.

Love was unmarried. He is survived by his sister Blanche, between whom and her brother there existed an unusually strong affection. Many of their friends have dwelt on Miss Love's devotion to her brother in every sisterly way; he was the entire centre of her life, and her loyalty to his welfare was touching. It is sad to relate that his death affected her health. This notice is the poorer by the omission of many sidelights on Love which she alone could have given.

Augustus Edward Hough Love was born on 17 April 1863 at Weston-super-Mare. The name Hough was in memory of some association with S. H. Hough, F.R.S., the Cape astronomer, the exact details of which, though once told to the writer by Miss Love, are not available. Augustus, or 'Gus' as his sister always called him, was the second of three brothers, the sons of John Henry Love, surgeon, a Somersetshire man. The father was later Police-surgeon to the Borough of Wolverhampton, and the family lived there, at a house at the corner of Queen Street and Walsall Street. Later they lived in the Waterloo Road, until the death of the father in Love's later Cambridge days, when they settled down at Cambridge under Love's care. The three brothers attended Wolverhampton Grammar School, to which Love was admitted in 1874. They are said by a contemporary to have been very reserved, and to have taken little, if any, part in school life outside their work. The headmaster in Love's time was Thomas Beach, a man of great force of character and high reputation, who 'infused new life into the Grammar School and sent up a succession of good scholars to both Universities'. Amongst Love's contemporaries was W. A. S. Hewins, sometime Director of the London School of Economics. Love owed much to the mathematical master, the Rev. Henry Williams, who was second master and afterwards succeeded Beach in the headship; he was known as 'Daddy' Williams. Beyond his being very studious, Love is said to have given no indication whilst at school of the career he was to have. In after-life Love took a considerable interest in his old school, and for some years before his death he gave a prize annually for the best mathematician in the school.

In 1881 Love was awarded a sizarship at St John's College, Cambridge, on the results of the examination for Minor Scholarships, and with that and a school leaving scholarship (Warner Scholarship) he went up to St John's in the Michaelmas Term of 1882, when he matriculated. He was at first doubtful whether to read classics or mathematics, but chose the latter, and gradually came to the top of his year. It is said that 'no one with any personal acquaintance could fail to recognize his extraordinary cleverness', for he evidently matured rapidly after his school-days. He coached with R. R. Webb. He was elected Scholar of the College in 1884. He was Second Wrangler in Parts I and II of the Mathematical Tripos in 1885, being placed between Arthur Berry, of King's, who was Senior Wrangler, and H. W. Richmond, F.R.S., also of King's; Barnard was Fourth. He was placed in Division 1 in Part III in 1886, and obtained the First Smith's Prize in 1887. He had been elected Fellow of the College on 8 November 1886. This Fellowship he held until 1899. He took his B.A. in 1885, his M.A. in 1889. Soon after his B.A. degree he became College lecturer in mathematics, his colleagues being R. R. Webb, J. T. Ward and Sir J. Larmor, F.R.S., and later H. F. Baker, F.R.S. Later he was elected to one of the five newly-founded University lectureships. In those days, when great importance was attached to the order of merit in the Tripos, Love was much occupied with private coaching, but nevertheless found time for research. He was elected to the Fellowship of the Royal Society in 1894.

In these Cambridge days began his long association with the London Mathematical Society. He was elected to its Council in 1890, and served continuously till 1920, serving again in 1922–25. For fifteen years (1890–1910) he was an energetic Honorary Secretary, and occupied the Presidential Chair for the customary two years in 1912 and 1913, besides being a Vice-President on several occasions. During his Secretaryship (in 1900) he published a complete index of the *L.M.S. Proceedings*, volumes 1–30, occupying 112 pages, including a subject index under fifty-four headings. (Of this, the first and third parts, authors' names and contents of volumes, were compiled by Mr Robert Tucker, his fellow-secretary; the second, most laborious part, owed a good deal to E. B. Elliott, F.R.S., of Oxford.) This was an example of the way in which Love was chiefly satisfied with himself if he could find something to do, intrinsically useful, which others accounted too laborious to undertake.

In 1898 a vacancy occurred in the Sedleian Chair of Natural Philosophy at Oxford and Love was elected at the age of thirty-five. He came to Oxford in 1899 and resided there continuously until his death, mainly at 34 St Margaret's Road. He was made a member of Common Room at the Queen's College, Oxford, on his election as professor; he was elected Fellow of Queen's in 1927, when the University Commission assigned fellowships to all chairs. He was also elected an Honorary Fellow of St John's College, Cambridge, in 1927. A story of his first appearance in the Common Room at Queen's is so pleasant that, whether true or not, it deserves record. It is said that the first time he entered the room, a then stranger to his college colleagues, he remarked by way of self-introduction: 'I'm Love'. 'Oh, indeed,' said one of the Fellows present, '᾿Έρως or ᾿Αγάπη?' Though puns on surnames are poor affairs, another that was made to the writer's knowledge is indicative of the fame of Love in the provinces: at a mathematical students' party at Manchester, when a game of questioning was being played, one the questions was: 'What famous mathematician's famous work suggests a tragedy?' The answer was intended to be Jacobi's Theorem of the Last Multiplier, but the actual answer supplied was better: 'Love's Elasticity'.

The greater leisure afforded by his Oxford chair gave Love opportunities of writing both student's textbooks and more serious work besides increasing his output of original papers. In 1911 he was awarded the Adams Prize of the University of Cambridge for an essay on 'Some Problems of Geodynamics'.

He was awarded the Society's Royal Medal in 1909, the London Mathematical Society's De Morgan Medal in 1926, and, as a fitting recognition of his lifetime's devotion to mathematical research, the Royal Society's Sylvester Medal in 1937. He became an Associate of the Italian Society of the Lincei, and a corresponding member of the Institute of France.

Love's standards in all matters was of the highest. No trouble was too much for him to take, in the matter of the preparation of lectures or examination papers, and he never indicated whether some of his self-allotted tasks might have been personally distasteful to him. Though his interests were in the fields of mechanics, elasticity, geodynamics and electrodynamics, he prepared advanced courses of lectures on tensor calculus and general relativity. His lectures, given largely in the Electrical Laboratory at Oxford, were extremely popular with students for their clarity, intelligibility and real efforts to enter into the students' point of view; his problem classes were always well attended. In the writer's time at Oxford Love had no research students in the modern sense; but he could rapidly size up any piece of research that came before him, in thesis or other form, and his judgment on a mathematical matter was rarely at fault. Love was a man whose striking candour and honesty as to his own aims and achievements were very noticeable—of great modesty in regard to his personal achievements—of great generosity and kindliness, especially to younger men.

He had interests in travel and in music. When he and the late Professor Hobson drove across Norway on one occasion he used to delight to relate how they entertained one another by singing. This is perhaps the occasion to mention his hobby of croquet, at which his prowess was considerable: as regularly as the swallows brought the summer, Love was to be seen wielding a mallet in the Parks, with doughty energy and evident enjoyment. It is not least here that his characteristic figure will be missed.

Love's mind was essentially that of an analyst—not in the modern sense of that word, but in the sense that he rejoiced in algebra rather than in geometry. G. T. Bennett, F.R.S., who knew him well, tells the following story of Love by way of illustration. They were out on a country walk and after a while drifted on to something technical of a geometrical kind. Bennett expounded the thing as it seemed to shape itself for him. Presently Love shook his head, saying that he did not follow. Bennett protested that he *must*, inasmuch as such-and-such a chapter of the *Treatise on Elasticity* was about just the same details of curvature and torsion as the figures he was discussing. 'Yes,' said Love, 'but you see it is all x, y, z for me, and not your pictures at all: I don't *see* them.' For Love, analysis was basic and the space-configuration derivative.

Another story of G. T. Bennett's is also related to Love's primary interest in elasticity. Bennett was visiting Oxford at a time when those coiled-up self-straightening steel measuring ribbons were novelties. Bennett had one with him and the present writer recollects Bennett's exhibiting it in a café in the Cornmarket, stretching it out with a great sweep of the arm and then flexing it. Amongst others Bennett showed it to Love, and pointed out that the ribbon had a natural lateral curvature which was annulled when it lay coiled up within its spool; but Bennett had noticed that when unspooled and flexed through say 180 degrees by hand, in an enforced fashion, it assumed a free curvature (now longitudinal) which seemed exactly to match the unstressed transverse curvature. Love promptly quoted Gauss, but withdrew against the objection that $R \times 0 = 0 \times R'$ does not give $R = R'$! So Bennett left the spool on Love's mantelpiece, with the suggestion that he should return it and an explanation at the same time. But it never came! Love's massive mind was perhaps averse to the ingenious discoveries of the geometer.

Love had contacts with Karl Pearson and with G. F. Stout, the philosopher and logician. These must have had an influence on his own philosophic attitude, and his attempts in his *Theoretical Mechanics* to give a philosophic treatment of the entities of dynamics. This work and his *Calculus* are, of course, little other than students' textbooks, but it is right to mention the influence they have had on the teaching of mathematics in England. That

Love, the applied mathematician and natural philosopher, should have written a work on the calculus illustrates his versatility. Professor Baker has written that whilst Love was writing the first edition of his *Elasticity* in the afternoons at Cambridge, he could turn aside to elliptic functions and even set questions in the theory of functions and geometry.

Love will be remembered by his two major works, *Some Problems of Geodynamics* (1911) and *A Treatise on the Mathematical Theory of Elasticity* (first published in two volumes in 1892 and 1893; second edition, largely re-written, 1906; third edition, 1920). The one is a research essay, consisting almost entirely of original work; the other is the standard mathematical work on elasticity.

Of the main branches into which classical mathematical physics may be divided, the subject of elasticity is the one which offers superficially the least attraction, in that it is the least provided with sensational experimental phenomena challenging investigation. It possesses neither the ancient mysteries of magnetism, nor the glamours of electrostatics, nor the more immediately appealing stage-effects of current electricity and electro-chemistry; nor the alluring simplicity, or what should have been the simplicity, in a mathematically ordered universe, of hydrodynamics; nor the massive grandeurs, the broad unexpected sweeps of generalization, of thermodynamics. It appears at first sight prosaic, utilitarian, devoid of romance. Yet it has attracted the attention of the greatest minds in mathematical science. The enquiries of Galileo, the physical investigations of Hooke and Young, the as-it-were pastimes of an Euler or a Bernoulli, the main research subject of Navier, Saint Venant or Mdlle Sophie Germain, a front-rank objective, amongst many others of the researches of Poisson, Cauchy, Kirchhof, Lamé, the generalizations of Green and Lord Kelvin, the papers of Stokes, of Lord Rayleigh—all these classical contributions demonstrate the hold which the subject has ever had on investigators of the front rank; and it continues to-day to employ the energies of a host of gifted mathematicians. The answer to the query which this circumstance raises is contained in Love's fine 'Historical Introduction' to his *Treatise*, from which the following may be quoted:

'The history of the mathematical theory of Elasticity shows clearly that the development of the theory has not been guided exclusively by consideration of its utility for technical mechanics. Most of the men by whose researches it has been founded and shaped have been more interested in Natural Philosophy than in material progress, in trying to understand the world than in trying to make it more comfortable. From this attitude of mind it may possibly have resulted that the theory has contributed less to the material advance of mankind than it otherwise might have done. Be this as it may, the intellectual gain which has accrued from the work of these men must be estimated very highly. The discussions . . . concerning the number and meaning of the elastic constants have thrown light on . . . the nature of molecules and the mode of their interaction . . . the nature of the aether and the nature of luminous vibrations. The methods that have been devised for solving the equations of equilibrium of an isotropic solid body form part of an analytical theory of great importance in pure mathematics. The application of these methods to the problem of the internal constitution of the Earth has led to results which must influence profoundly the course of speculative thought both in Geology and in cosmical Physics. To get insight into what goes on in impact, to bring the theory of the behaviour of thin bars and plates into accord with the general equations—these and such-like aims have been more attractive to most of the men to whom we owe the theory than endeavours to devise means for effecting economies in engineering constructions or to ascertain the conditions in which structures become unsafe.' May we not take this as an autobiographical confession of the source of the attraction of the subject to Love himself? Love goes on to point out that whilst most great advances in natural philosophy have been made by men who had a first-hand acquaintance with practical needs and experimental methods, yet in the subject he was discussing the names of Green, Poisson, Cauchy were important exceptions. It is to this latter class that Love himself belonged.

The foregoing extract from Love's treatise gives a fair example of his massive, unhurried, literary style; his mathematical style was equally architectural, every detail set out in satisfying fullness, pleasant to read, pleasant to verify, comfortable, reassuring, inspiring confidence; savouring of a more leisurely age; and contrasting strangely with the modern mathematical-physical memoir with its omission of all but a bare mathematical skeleton and its irritating use of 'a simple calculation shows' or 'by the usual methods it follows'. Withal Love's mathematical style never concerns itself with trivialities; it is justly proportioned. Amongst the features of the *Elasticity* are its completeness in its field and its extreme scholarliness. The *Elasticity* is not a work to be read in a day or a week or even a month. It sets to work with great deliberation to build up a position on sure foundations. Love himself admits that his long preliminary discussion is somewhat forbidding, and it is true that it is not a work to put into the hands of an inexperienced student. But in a subject where strain and stress are fundamental, it is satisfying to have them treated in an exhaustive manner. After Love's strong meat, pre-digested food in this subject gives a feeling of emptiness. Love makes indeed a concession to human weakness in recapitulating his foundations after over a hundred pages have thus passed; the 500 which follow justify the thoroughness of the basic treatment.

The scope of the work can only be indicated here by an enumeration of some of the topics covered: the equilibrium of isotropic and aelotropic elastic solids, the transmission of force, the equilibrium and vibrations of spheres, the propagation of waves in elastic solid media, and then, curiously late but logically in their right position, chapters on torsion, the bending of beams, the bending and twisting of thin rods, plates and shells. Love's own contributions to the subject are modestly concealed throughout; but his sympathetic reproductions of the memoirs of his great predecessors and of many of his contemporaries owe much to his shaping. Love was a master in the use of spherical harmonic analysis, which he wielded, controlled and generalized (in the form of biharmonic analysis) with vigorous skill. But he never lets his preference for any particular type of analysis run himself into undue prolixity there. Throughout, the material is classical in texture, and the whole work, translated as it has been into several languages, stands as a great classic in the field of classical mathematical physics.

It is characteristic of Love's modesty that in the chapter of the *Elasticity* devoted to wave-motion in solid media, he makes no mention of his own fundamental contribution to that subject—his discovery of what are now known as 'Love waves'. This is one of the major researches embodied in the *Problems of Geodynamics*. It is a classical result that waves in any elastic medium can be analysed into two types, each propagated with its own velocity: the faster purely compressional waves and the slower purely distortional (equi-voluminal) waves; the former are longitudinal, the latter transverse, to the direction of propagation. Given any disturbance, the wave motion thereby originated ultimately separates itself out into these two types, in the absence of a boundary. These results are due to Poisson (1830) and Stokes (1849). When a boundary is present, either type of wave gives rise by reflection to both types of waves, but the analysis of the result of repeated reflections in the vicinity of a boundary, in terms of these two basic types, is difficult to follow. As Love remarks, 'it is not easy to see without mathematical analysis how such waves can combine to form a disturbance travelling with definite velocity (less than that of either type above) over the surface. Yet such is the case. Lord Rayleigh showed in 1885 that an irrotational displacement involving dilatation and an equi-voluminal displacement involving rotation can be such that (1) neither of them penetrates far beneath the surface, (2) when they are combined the surface is free from traction'. In Lord Rayleigh's work the surface is regarded as an unlimited plane, and the waves may be of any length. The wave-velocity is independent of the wave-length. Such waves are called 'Rayleigh waves'. In them the displacement is two-dimensional, consisting of a vertical component and a horizontal component parallel to the direction of propagation, the vertical component being the larger at the surface. The amplitudes of both decay exponentially with depth. Since they diverge from a source in two dimensions only, they ultimately preponderate over waves transmitted through the interior which diverge in three dimensions. It was originally attempted to identify such waves with the main shock of a seismic disturbance (which travels *over* the surface in contrast to the P and S waves, which travel through the interior) but difficulties arose, partly in that the relative size of the vertical and horizontal movements did not agree with that predicted for Rayleigh waves, partly because the greater part of the disturbances was transverse, perpendicular to the direction of propagation.

The suggestion had been made that the disturbance in question was in some manner confined to the so-called 'crust' of the earth, and Love accordingly investigated the possibility of the propagation of purely distortional waves in a heterogeneous medium consisting of a layer with plane parallel boundaries, the one free, the other in contact with a subjacent medium of different density and rigidity. He was rewarded by discovering the existence of what are now known as 'Love waves'. They consist of a disturbance which does not penetrate deeply into the underlying medium, and in certain circumstances is practically confined to the upper layer; one of these circumstances is that the wave-length should be short compared with the thickness of the layer. The disturbance is *transverse* to the direction of propagation and parallel to the surface, unlike that in Rayleigh waves; and the wave-velocity is a function of the wave-length, increasing as the wave-length decreases. They therefore show dispersion. Love suggested that the oscillatory motion in the main shock of seismic waves was due to dispersion originating in this way, and adduces many observed circumstances in confirmation. The investigation, which is very brief and very clear, is contained in pp. 176–181 of the *Problems in Geodynamics*. It is clear that these waves propagate themselves by a kind of repeated reflection at the two surfaces of the upper layer. Love also investigated the effect of heterogeneity on Rayleigh waves, and showed that they, too, would under these conditions be subject to dispersion. This general occurrence of dispersion has led to the use of the period-group-velocity relation, as observed, to give important information about the thickness of the upper layers of the Earth, chiefly at the hands of Stoneley.

The *Problems of Geodynamics* deals with many other important problems, such as isostasy, earth tides, variation of latitude, compressibility and its effect on earth tides, the problem of gravitational instability and the vibrations of a compressible planet. Some of these investigations are very complex, but have throughout the massive stateliness of the *Elasticity*. Perhaps interest has now passed to other aspects of these problems, but the whole of this research essay may be read with avidity for its clear grasp, its display of technique and its setting out of its objectives. We rarely see research of this limpid character produced to-day; were it produced, experts would probably deny it publication on the ground of shortage of space. 'Spaciousness' best conveys the sense of Love's writings, and the world of science is the poorer that no more such will flow from his pen.

Two criticisms it seems fair to make of the notation of the *Elasticity*. One is, his use of the notation (X_x, Y_x, Z_x) for the components of stress across the plane perpendicular to the x-axis, etc. This obscures the symmetry expressed by $Y_x = X_y$, etc.—relations which hold in the absence of body-couples, and wholly prevent the recognition of *stress* as a tensor. The other is his omission of the factor $\frac{1}{2}$ in his definition of the skew components of strain, e_{yz}, etc. This likewise prevents the recognition of *strain* as a tensor. In turn this prevents the set of elastic constants of a general crystalline medium being recognized as the components of a tensor of the fourth rank subject to certain symmetry relations which reduce the number to 21. Hook's law is then expressed by the tensor equation $p_{\mu\nu} = \mathrm{T}_{\mu\nu\alpha\beta}\, e_{\alpha\beta}$, where p, e are the stress and strain tensors respectively. Perhaps this was a sign that Love belonged to an older generation of mathematicians.

The transformations and invariants associated with e and p would certainly be more intelligible if e and p were formally defined and introduced as tensors of the second rank.

In the war of 1914–18 Love made a contribution to ballistics which resulted in 'Love's method' for the calculation of high-angle trajectories by 'small arcs' being for some time in use at Woolwich.

Love was also interested in classical electro-dynamics and electric waves, and is the author of various papers thereon. The full bibliography of Love's writings is printed below. Here it may be sufficient to emphasize that Love was saturated with classical ideas on the subject; he once remarked to the writer, 'There is no such thing as a spinning electron'—as indeed there is not, *pace* the quantum mechanists. The slovenliness of many of the modern illogical extensions of that beautiful subject, classical electromagnetism, had no place in Love's logical and tidy mind.

It is given to few men of science to be at once fundamental discoverers and great expositors. Love was both. The *Elasticity* stands, with Lamb's *Hydrodynamics*, in a small, highly select class, and it challenges and survives the closest comparison with its fellows. And the discovery of the transverse surface waves in a heterogeneous medium shows that Love could be, in his mathematics as in his life, truly simple and so truly great.

E. A. MILNE

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