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EDWIN HERBERT HALL

1855-1938

BY

P. W. BRIDGMAN

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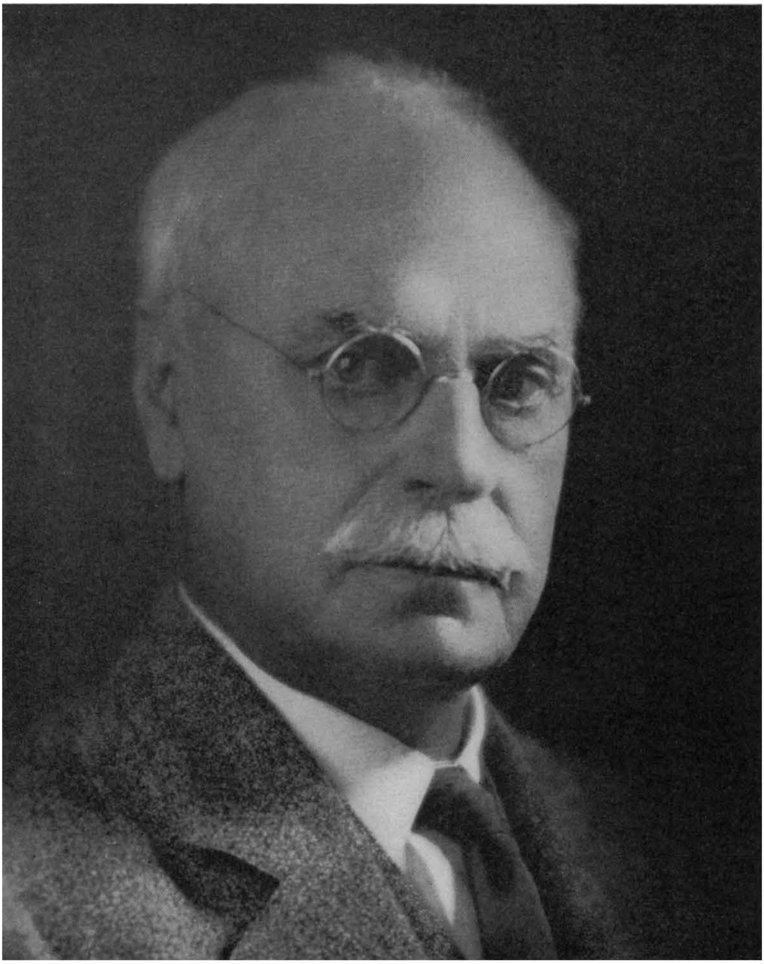

Edwin H. Hall

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Edwin Herbert Hall was born in North Gorham, then Great Falls, Maine, on November 7, 1855, the son of Joshua Emery Hall and Lucy Ann Hilborn Hall. On his father's side he was descended from John Hall, who came to this country from England early in the 17th century and settled at Dover, New Hampshire; from Anthony Emery who landed in Boston from England in 1635, the son of Jean Emery, a Frenchman who settled in England after the massacre of St. Bartholomew; and from Kenelson Winslow, who emigrated to this country probably in 1629 and settled in Marshfield, Massachusetts. He was of the ninth generation of each of these three lines. On his mother's side he was descended from Robert Hilborn, who was of Quaker stock and came to Maine probably from New Jersey about 1775. In spite of Robert Hilborn's Quaker stock, he enlisted twice for service in the American Revolution from Portland, Maine. Also on his mother's side his descent was probably from Nicholas NQyes, who came to Newburyport about 1635. For two generations back his ancestors were Maine country folk, engaged in the conventional occupations of the countryside. His father's father, Levi Hall, was born in Windham, Maine, in 1787, and moved to Great Falls. He was a farmer and probably also a stone mason, served as deputy sheriff with zeal, was an abolitionist, a "Washingtonian" teetotaler, and an officer in the war of 1812. His father's mother, Jane Emery, was born in Windham, Maine, in 1795. His mother's father, Samuel Hilborn, lived most of his life in West Minot, Maine, occupied as a farmer. His mother's mother was Nancy Noyes. His father, Joshua Emery Hall, was born in 1823 in Great Falls, now North Gorham, Maine, received a common school education with a little "academy" instruction, and was occupied with farming and lumbering. He served as selectman, representative in the Maine legislature, and justice of the peace. He died at the early age of 41, of some abdominal trouble, perhaps peritonitis. At the time of his death his old school teacher said of him in the local paper, "I never *knew* a better scholar. His grade and grasp of mind were remarkable; his attainments, for his advantages, rare; his qualifications for usefulness, uncommon." His mother, Lucy Ann Hilborn, was born in 1825 in West Minot, Maine, and lived in West Minot and North Gorham until she came to Cambridge to live soon after her son's marriage. In youth she taught in a district school and worked in a textile factory. She was very well-read, had discriminating literary taste and a talent for drawing. She died at the age of 86. A brother of his mother, Samuel Greeley Hilborn, was Congressman from California.

Besides Edwin Herbert his father and mother had two other sons and two daughters. The daughters and one of the sons died in infancy or childhood. The surviving son, Frederic Winslow Hall, was born in 1860 and moved to California at the age of 20, where he is still living (February 1939), having retired from his practice of law.

Edwin Herbert describes himself as not living on a farm after 1867, when he was 12 years old, but continuing to work often as a farm hand during his boyhood and youth. He attended the usual district school, and prepared for college in two years at "Gorham Seminary". He entered Bowdoin in the fall before he was 16, and graduated at the head of his class four years later in 1875 with the A.B. degree. During college he taught two terms in the same district school which he had attended as a boy. He described himself as "an industrious, rather than a brilliant scholar, doing all my work fairly well, if not very easily.—The only real talent that I showed in college, if I showed any, was for writing. I was, perhaps, the most prolific editor of the college paper during my editorial year."

He did not decide on his life work immediately after graduation, but served during 1875-76 as principal of Gould's Academy, Bethel, Maine, and during 1876-77 as principal of the high school in Brunswick, Maine. It was not until after these two years of teaching that he decided to enter physics. He writes: "I should perhaps have studied law, if I had not felt myself unfitted to advocate a cause in which I did not believe. I turned to science, after two years of school teaching, because it was progressive and satisfied my standards of intellectual and moral integrity, not because I had any passionate love of it or felt myself especially gifted for scientific undertakings." In the fall of 1877 he entered the Johns Hopkins University as a graduate student in physics, working under Rowland. Before entering the Johns Hopkins he explored the possibilities of study at Harvard, but was advised with engaging candor by John Trowbridge, the Director of the Harvard Physics Laboratory, to go to the Johns Hopkins because Harvard did not possess adequate facilities. In 1879 he discovered the "Hall" effect, which will presently be discussed in greater detail. He received the Ph.D. degree in 1880, and continued at the Johns Hopkins during 1880-81 as assistant in physics. In December 1880 he was appointed to a Tyndall Scholarship by the Johns Hopkins for study and travel abroad during the following year, but he later resigned this scholarship because in the spring of 1881 he was appointed to an instructorship at Harvard for 1881-82. During the summer of 1881 he travelled in Europe and was a visitor in Helmholtz's laboratory in Berlin long enough to complete measurements of the Hall effect in some new metals, which he reported to the York meeting of the British Association in the summer of the same year. In the fall of 1881 he returned to this country to begin his instructorship at Harvard. Here he served as instructor from 1881 to 1888, as assistant professor from 1888 to 1895, professor from 1895 to 1914, Rumford Professor from 1914 to 1921, and Emeritus Professor from 1921 until his death. In addition to the A.B. degree from Bowdoin and the Ph.D. degree from the Johns Hopkins, he received from Bowdoin the A.M. degree in 1878, probably the conventional degree awarded automatically at that time to all graduates of three years' standing, and in 1905 the honorary LL.D., also from Bowdoin. He was a member of the American Association for the Advancement of Science (vice president of the section of physics in 1904), of the American Physical Society, the National Academy of Sciences (elected in 1911), corresponding member of the British Association for the Advancement of Science, and foreign member of the Société Hollandaise des Sciences. He was a member of the Solvay Congress at Brussels in 1924, and of the Volta

Congress at Como in 1927. In 1937 he received the award and medal of the American Association of Physics Teachers for Notable Contributions to the Teaching of Physics, and was made the first honorary member of the Association.

He married, on August 31, 1882, Caroline Eliza Bottum of New Haven, Vermont, who had been his assistant at the Brunswick High School. She was descended on both her father's and her mother's (Hoyt) side from Simon Huntington who, tradition says, died at sea in 1633 while on his way from England to America with his family. A woman much beloved for her qualities of heart and mind, she died, after a brief illness, on June 1, 1921, just as his lectures ended before his retirement, and as he was looking forward to the cultivation of his leisure. There were two children, Constance Huntington Hall, who is now living in Cambridge, and Frederic Hilborn Hall, who died while a senior at Harvard. In January 1907 he suffered a severe nervous breakdown, probably associated with a physiological condition for which it was subsequently necessary to operate, and from which he did not recover sufficiently to resume his college work until the fall of 1908. In the spring of 1912 he was again subjected to a similar operation, made a rapid recovery, and was able to sail for England in July to attend the 250th anniversary celebration of the Royal Society of London as delegate of the American Academy of Arts and Sciences. During the summer he attended various scientific meetings, including the British Association meeting in Dundee. In 1914-15 he was again abroad, on sabbatical leave, and was in Italy when the World War broke out. Here he remained until early 1915, when he went with his family to France and gave lectures on the system of American education at Grenoble, Montpellier, Toulouse, and Bordeaux, under the auspices of the "Fondation Harvard".

Except for the illnesses mentioned above, he described himself as having been remarkably free from ordinary ailments. During college he was athletic, rowed on the college crew, and was always interested in sports, serving at one time on the Harvard Athletic Committee and writing an article on Athletic Professionalism and its Remedies. He played golf for fifteen years after his retirement. His death on November 20, 1938, was due to heart failure, when he was apparently on the road to convalescence after an operation.

He always had a strong sense of civic duty, and in addition to his scientific activities engaged in many community enterprises. He was unobtrusively religious, and although never a regular church member, was a constant attendant at the First Congregational Church in Cambridge. From 1917-18 through 1927-28 he was president of the Family Welfare Society of Cambridge; in the autumn of 1919 he served as special police officer during the Boston police strike, being the first man to volunteer for service; in 1931 and 1932 he was chairman of the Cambridge Unemployment Relief Committee which raised through contributions from citizens over $200,000 which was largely spent on relief projects, the most important of which was the construction of a nine-hole municipal golf course at Fresh Pond, Cambridge; from 1933 he was president of the Charles William Eliot Memorial Association, founded to commemorate, in 1934, the hundredth anniversary of Mr. Eliot's birth, and to work for a permanent Eliot memorial; and at the time of his death he was a member of the executive committee of the Cambridge Republican Council and a member of the Cambridge Community Federation.

Writing always remained a source of satisfaction to him. His prose style was perspicuous, and graced with a felicity that made it a pleasure to read. On occasion he was capable of effective verse. His scientific writings were not confined to technical expositions of his own research, but he wrote articles of popular appeal, and also on matters of education, in which he was always interested. During the later years of his life he was a frequent contributor to the "letter box" of the Boston Herald on current topics. After his retirement he found leisure to read classics in French, Italian, and Spanish; he was an omnivorous reader of the newspapers and popular weeklies. He was interested in paintings, and enjoyed informal music of his family and friends; he liked to go to movies but cared little for the modern theatre.

His technical contributions fall into two groups, of which the first is concerned with the teaching of elementary physics. When he began teaching at Harvard in the fall of 1881 the admission requirements and the preparation given in the secondary schools were both largely perfunctory; there was practically no laboratory work, and students could even go through a college course of physics without performing an elementary experiment. The initiative in setting the requirement of laboratory work in physics for admission to Harvard came from President Eliot, who had worked as a chemist with Professor J. P. Cooke, said to have been the first man in America to have a laboratory for the teaching of chemistry. At the suggestion, and with the encouragement, of President Eliot, the young Hall prepared a set of 40 experimental exercises to be used by the secondary schools in preparing candidates for admission. This was issued in 1886 as the well known "Harvard Descriptive List of Elementary Physical Experiments." It had the great merit that the apparatus required was so simple and so well thought out that the preparatory school teachers were able to meet the requirements on their meager budgets, sometimes even constructing the apparatus with their own hands. The effect of the new admission requirements rapidly spread beyond the Harvard sphere of influence to that of the National Educational Association. Within a decade or two the leading manufacturers of apparatus were turning out complete sets of equipment for the experiments of the Descriptive List, which they had renamed the National Physics Course. It would not be unfair to describe this work of Professor Hall as entirely remolding the scheme of secondary school physics, and as such exerting a most important influence.

The "list" was followed by a number of text books of elementary physics, given in the bibliography, of which perhaps the best known is the "Hall and Bergen," published in 1891. The importance of his contributions to the teaching of elementary physics was fittingly recognized by the American Association of Physics Teachers at the 1937 Christmas meeting of the American Association for the Advancement of Science at Indianapolis, as has already been mentioned. The matter has been dealt with at length in the February 1938 issue of the American Physics Teacher. The effectiveness of his personal teaching was not due to any characteristics of brilliancy, but rather to a very real concern that the student should grasp the situation, and to a meticulous setting forth of the difficulties.

The number of his research students was not large, perhaps not more than a dozen altogether. He took a keen personal interest in these, and there was a relation of genuine affection between them. In 1906, after 25 years' service at Harvard, he was presented with a silver loving cup, with the names of ten of his students, and the following inscription:

To Edwin Herbert Hall
From His Research Students
In Testimony
Of Their Esteem and Gratitude
In Appreciation
Of His Work in the Field of Discovery
Of His Quarter Century Service
In Behalf of Harvard University
His Life and Inspiration
1881–1906

Of course Professor Hall will always be best known for the "Hall" effect, and the major part of his scientific activity was connected either directly with this effect, or else with closely related phenomena. The effect was discovered during his graduate work at the Johns Hopkins, and was the subject of his thesis. The effect is usually described as a difference of potential which appears perpendicular both to the lines of flow of an electric current and a magnetic field, the magnetic field itself being perpendicular to the current. He states, in his description of his discovery, that he was stimulated to search for the effect by a passage in Maxwell's Electricity and Magnetism: "It must be carefully remembered that the mechanical force which urges a conductor carrying a current across the lines of magnetic force acts, not on the electric current, but on the conductor which carries it.—The only force which acts on electric currents is electromotive force." This statement seemed to Hall to be "contrary to the most natural suppositions in the case considered." He found an article by Professor Edlund on Unipolar Induction in Philosophic Magazine for October, 1878, which supported his feeling that there was trouble with Maxwell's conception, and he was encouraged to start his quest for the suspected effect by the remark of Rowland that he doubted the truth of Maxwell's statement, and had himself made a hasty experiment to detect some action of a magnetic field on a current, but with negative results. In the first experimental set-up, after "important changes in the proposed form and arrangement of the apparatus" had been made by Rowland, search was made for an increase of resistance in a wire carrying a current when a magnetic field was applied, which was thought would be the result of a suspected crowding together of the lines of current flow under the action of the field. The result of this first attempt was negative. Hall next searched for a transverse difference of potential, the arrangements being practically the same as in present arrangements for measuring the effect, and being also the same as had been previously tried by Rowland, but again with negative results. The reason for this failure we now know was merely lack of sensitivity, primarily due to too great thickness of the conductor. At Rowland's suggestion he tried again with gold leaf to carry the current, thus increasing the sensitivity by increasing the current density, and at once was rewarded with a positive result.

The effect appears to have been vaguely predicted by Kelvin, in 1851, who indicated the possibility of a term in his equations corresponding to the effect. There were at least three previous unsuccessful attempts to discover the effect: by Feilitzsch, Mach, and Gore. Wiedemann, in his "Galvanismus" described an experiment to prove that the effect does not exist, with apparatus practically identical with that used later apparently independently by Rowland, and with that with which the effect was eventually discovered.

Although an effect had been anticipated and searched for, and although the final discovery by Hall must be recognized to have been the reward of that persistence which was one of his most prominent characteristics, the effect actually found was essentially different from that anticipated. The effect anticipated was connected with the ponderomotive force acting on a conductor carrying a current. It seemed almost necessary that the primary action responsible for the ponderomotive force on a conductor carrying a current in a magnetic field should be between the current and the magnetic field, the action on the current then getting propagated to the material of the conductor by some sort of secondary action. In fact, this primary action is explicitly written down in the equations of the Lorentz electron theory as a force on an electron moving in a magnetic field. This simple picture was definitely present in the minds of many of the early experimenters, and led to serious misconceptions as to the nature of the effect. Thus there were many attempts to detect a distortion of the lines of current flow and a consequent change of the effective resistance, as in Hall's original unsuccessful attempt. The impossibility of maintaining the original simple picture was obvious to all when presently metals were found in which the sign of the effect was different from that to be expected from the simple picture. It is an interesting coincidence that most metals, including those first measured, do have the expected sign. It would appear that we have here another example, of which there are not a few in the history of physics, of an effect suspected, obstinately searched for, and presently discovered, on the basis of a picture which has proved not to be pertinent.

It is my personal opinion that the implications of this discovery have not even yet been adequately appraised, even in connection with the mere methodology of the concepts with which we describe electrical phenomena in conductors. Certainly the program envisaged by Rowland in commenting on the young discovery has not yet been fully carried out: "The recent discovery by Mr. Hall of an action of magnetism on electric currents opens a wide field for the mathematician, seeing that we must now regard most of the equations which we have hitherto used in electromagnetism as only approximate", and even as late as 1915 there were most serious misconceptions of the nature of the effect in the writings of physicists of very high rank.

Hall's thesis contained a quantitative measurement of the effect in gold for various current strengths and for different values of the magnetic field, from which an approximately constant coefficient could be calculated. Even at the time of the writing of his first papers he still hoped to be able to devise an experiment in which the lines of flow should be actually displaced in the magnetic field, but it was not long before he came to the accepted view of the current flowing obliquely to the equipotential surfaces under the action of the magnetic field. How little he realized the full implications of his discovery is suggested by the closing sentence of his first paper: "To make a more complete and accurate study of the phenomenon described in the preceding pages, availing myself of the advice and assistance of Professor Rowland, will probably occupy me for some months to come."

It has already been mentioned that in the summer of 1881 he travelled in Europe, and made a number of measurements of the new effect in Helmholtz's laboratory in Berlin. These measurements he reported in a paper read at the York meeting of the British Association in 1881. This paper was received with the greatest interest. Of it Kelvin said: "The subject of the communication is by far the greatest discovery that has been made in respect to the electrical properties of metals since the times of Faraday—a discovery comparable with the greatest made by Faraday." A large number of other investigators rushed into the field thus opened. The three other analogous transverse effects bearing the names of Ettingshausen, Nernst, and Righi-Leduc were speedily discovered, and a very extensive literature rapidly grew up.

Professor Hall himself for the next eight years continued to contribute papers dealing with measurements of the effect in various metals and with the proper way of conceptualizing the effect. From 1888 to 1891 there was a gap in his scientific publications. Except for a single paper on the temperature coefficient of the Hall effect in 1893 he did not return to the Hall effect until 1911. During this interval of 23 years his more serious papers were concerned with various thermal phenomena, such as thermal conductivity of metals, the thermodynamic behavior of liquids, and various thermo-electric effects, in particular, the Thomson effect. His principal graduate instruction was on kinetic theory and thermodynamics, and the direct connection between his lectures and his research activity is evident. He was particularly concerned to understand the mechanism of thermo-electric action; among other things he showed that the conventional thermo-electric diagram of Tate is really a temperature-entropy diagram. He made important use of analogies with ordinary mechanical action, and sought to understand a thermoelectric current as something similar to a convection current in an unequally heated hydraulic circulatory system in a gravitational field. His vice-presidential address to the section of physics of the American Association for the Advancement of Science in December, 1904, was on "A Tentative Theory of Thermo-Electric Action." This theory he later modified, completely discarding certain features of it. In fact, among his papers was found a copy of his address with this writing in his own hand: "This was a very unhappy performance. I am sorry it was ever published." He always insisted, however, on the similarity to convective action and on the importance of the analogy. In 1911, in his paper with L. L. Campbell, he returned to the measurement of not only the Hall effect, but of the three other transverse effects as well. He was depressed by the disagreement between the values of the coefficients as measured by different observers, and was convinced that satisfactory values could be obtained only from measurements all on the same material, and if possible all on the identical piece of metal and in the same apparatus. This paper with Campbell was the first attempt at a realization of this ambition. For the rest of his life his experimental program was devoted to the accurate measurement of the four transverse effects under identical conditions, so that the values might be confidently used in theoretical speculations. In 1925 he published values for the coefficients of gold, palladium, cobalt, and nickel. After the erection of the New Research Laboratory of Physics at Harvard in 1931 he again attacked this problem with a reconstructed and improved apparatus. He was at work on this within a few weeks of his death, and had completed measurements of the four transverse effects as a function of temperature in copper and palladium, which apparently satisfied his exacting requirements. The measurement of these coefficients is admittedly one of the most difficult tasks which an experimental physicist can set himself. The delicacy of the measurements is suggested by the fact that one of the effects which Professor Hall had to consider and eliminate in his last apparatus was convection currents in the air created by the magnetic field because of the slight paramagnetism of oxygen. The dauntlessness of his experimental attack on this problem was characteristic of the man.

From 1917 on Professor Hall was occupied even more by his attempts to attain a theoretical understanding of electrical phenomena in metals than by his measurements. It was early evident to him from his theoretical attacks on the problem of thermoelectric phenomena that the little considered transverse effects could not be neglected in understanding the mechanism in metals, and his theorizing may be broadly characterized as an attempt to create a single whole which should include the thermoelectric and the transverse phenomena as well as those more usually considered. In commenting on a paper which he had just written for the Solvay Congress in 1924 he wrote: "Thus far the various transverse effects mentioned have been little more than a puzzle in science—things or phenomena to be explained. My hope is that through the paper I have just written I shall make them contribute to a luminous theory of the mechanism of metallic conduction, electrical and thermal." Perhaps the one outstanding feature that distinguishes his theory from others was his constant insistence on the importance of the rôle of the positive ions in metallic conduction. The early electron theories were concerned almost entirely with the rôle of the free electrons. It was obvious enough that where there are free electrons there must be ions, but for some reason the rôle of these ions was not explored in the conventional theories, perhaps because of mathematical difficulties. In particular, Professor Hall saw and insisted on the importance of the positive ions in affording an explanation for the unexpected sign of the Hall effect in some metals, and it was a great gratification to him toward the end of his life that the wave theory of metallic conduction fits the positive ions naturally into the complete picture, and shows their importance under conditions which he had anticipated.

His theoretical work probably has not exerted the influence which it otherwise might because it was written in his own peculiar idiom. He was not a mathematician, but he had a very strong physical sense, which was most at home in a mechanistic medium very similar to that of the great English physicists. For him a theory consisted in a painstaking working out by native wits of all the consequences which he could see were inherent in the fundamental physical picture. The quantitative relations, whose existence he discovered in this way, were then thrown into mathematical form through the medium of power series or other conventional mathematical functions, the coefficients of which had only an empirical significance. The result was a mathematical edifice which had no organic connection with the underlying physical ideas; it would have been impossible to reconstruct the physical picture from the mathematics. The more conventional and usual course in constructing a theory is to formulate in mathematical terms the underlying physical picture, and then to allow the consequences of this picture to develop themselves by the more or less automatic functioning of the mathematical machinery. Professor Hall's procedure was bound to appear strange and uncongenial to the conventionally schooled theoretical physicist, with the result that the real merits of his basic physical ideas were too easily overlooked.

Several times during the last ten years of his life Professor Hall was tempted to collect the substance of his papers dealing with different aspects of his theory into book form, and in fact at one time he had a manuscript ready for publication. Finally, in the summer of 1938, he published through the Murray Printing Company, of Cambridge, Massachusetts, "A Dual Theory of Conduction in Metals", a book of 170 pages, much shorter than he had at one time contemplated. This book is, I believe, much easier to read than the original papers, and is worthy of intensive study. It should not be too difficult to put into the language of wave mechanics the essential features of his theory, and in at least some cases it is obvious that if this were done the two theories would have identical aspects. Wave mechanics has not even yet worked out the details of all the complicated effects in metals, and in these cases the insight afforded by his point of view may well be most valuable. In particular, it is to be mentioned that by his theory he was able to calculate the Nernst and the Righi-Leduc coefficients for a couple of metals from other experimentally determined coefficients, an achievement which wave mechanics is hardly yet in a position to claim.

The mental characteristics to which he owed his success were probably first and foremost a certain obstinate methodicalness and clearness of apprehension. He writes of himself: "I am in some respects distinctly handicapped in all my scientific endeavors, being unskilful of hand and slow of apprehension. On the other hand, I am very persistent, and fond of wrestling with a difficult problem in my own slow way; any success I may have attained is to be attributed to these two qualities."

Those who knew him personally feel a loss greater than can be accounted for by any scientific eminence. It will be agreed, I believe, that his outstanding personal characteristic was his utter honesty and integrity, coupled with an independence and strength of character which enabled him to trust his own judgment, and steer his own course, once he had made his carefully reasoned decision. Combined with this was a very unusual reluctance to force his own views on others; he truly treated the opinions of others as equally worthy of respect with his own. Those who knew him more intimately knew that he had passed through dark times of discouragement or even despair, over which he triumphed by sheer force of character. Sometimes they were permitted glimpses of a depth and quality of sentiment rare and moving. His friends will not soon forget the erect vigor of his old age, or cease to be thankful that his last illness was not protracted.

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Key to Abbreviations

Amer. Assn. Adv. Sci. Proc.—American Association for the Advancement of Science Proceedings
Amer. Inst. Elec. Engrs.—American Institute of Electrical Engineers
Amer. Journ. Math.—American Journal of Mathematics
Amer. Journ. Sci.—American Journal of Science
Amer. Phys. Teacher—American Physics Teacher
British Assn. Adv. Sci.—British Association for the Advancement of Science
Bull. Amer. Math. Soc.—Bulletin, American Mathematical Society
Educ. Rev.—Educational Review
Harvard Grad. Mag.—Harvard Graduates Magazine
Journ. Phys. Chem.—Journal of Physical Chemistry
Nat. Acad. Sci. Biog. Mem.—National Academy of Sciences, Biographical Memoirs
Nuov. Cim.—Nuovo Cimento
Phil. Mag.—Philosophical Magazine
Phys. Rev.—Physical Review
Proc. Amer. Acad.—Proceedings, American Academy of Arts and Sciences
Proc. Nat. Acad. Sci.—Proceedings, National Academy of Sciences
Sch. Sci. and Math.—School Science and Mathematics
Sci.—Science
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