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LORD KELVIN

WITH the death of Lord Kelvin on December 17 there passes away the grandest figure of contemporary science, and with it closes an epoch in the history of physics. When William Thomson was born, in 1824, Ohm's law of the flow of electric currents had not been discovered, Oersted's discovery of the magnetic action of the current was but four years old, while Faraday's capital discovery of the induction of currents was not to come for seven years. The wave-theory of light had been but recently set on its feet by Young and Fresnel, and was not yet thoroughly believed, while the two laws of thermodynamics, perhaps the most important contribution of the nineteenth century, were unknown. All these things Lord Kelvin saw, and a great part of them he was. Probably no one, with the single exception of Helmholtz, born three years earlier, exercised a greater influence on the science of the nineteenth century, while to compare the influence of these two great physicists with that of Darwin is as bootless as to question whether the grass is greener than the sky is blue.

Whether William Thomson, born at Belfast, is to be classified as an Irishman, along with the great Sir William Rowan Hamilton, or by virtue of descent and almost lifelong residence in Glasgow, as a Scotchman, like that other genius Clerk Maxwell, we need not discuss, but that country in which, perhaps in all the world, intellect is most prized, may fairly claim him as her own. The fact that his father was professor of mathematics at the University of Glasgow, where his elder brother James became a distinguished professor of engineering, tends to show the hereditary nature of his talent. Brought up in the quadrangle of the university, Thomson as a boy must have enjoyed very unusual advantages of training, while he relates that the enthusiasm of J. P. Nichol, author of "The Architecture of the Heavens," first turned him in the direction of physics, while the good advice of the same master, encouraging him to read Fourier's "Théorie analytique de la Chaleur" bore quick fruit, which was renewed throughout his whole career. Precocious he certainly was, for his first paper, written at the age of seventeen, was on Fourier's expansion of functions in trigonometric series, followed by three others on the flow of heat, all written before he was eighteen. It is impossible to conceive of an American boy of seventeen to-day writing on such a subject, which still presents many difficulties even for the mature student, and at that time was understood only by the masters. The theory that precocity is a dangerous symptom receives a severe blow from Thomson's subsequent career.

After being educated at Glasgow University he went to Cambridge, and joined St. Peter's College, where he distinguished himself by becoming second wrangler in the Mathematical Tripos, and first Smiths Prizeman, a mathematical honor still more coveted, in 1845. On leaving Cambridge Thomson went to Paris, where in the laboratory of the distinguished physicist, Regnault, he had his first introduction to experimental methods of research. At this time he published the second of his papers on the laws of electrostatics, showing the analogy, never before noticed, between the distribution of what Faraday was calling electrical lines of force with the lines of flow of heat in a conductor. In this, as in most of his work then and later, we see the great influence that the work of Fourier had upon him, and the powers which he had obtained in the management of that analysis. In the same year he published his original method of spherical images, which has become of so great importance in all parts of mathematical physics.

In 1846, at the age of twenty-two, Thomson became professor of natural philosophy at Glasgow, where he remained fifty-three years, his jubilee being celebrated with great *éclat* in the presence of illustrious scientists from all over the world in 1896. Besides his powerful contributions to the theory of electricity and magnetism, which continued for many years, a new and no less important subject now began to engross him. The work of Sadi Carnot on the motive power of heat, though published in 1826, was but little understood, and belonged to the days when heat was supposed to be a substance. Almost simultaneously, Thomson in England, and Clausius in Germany brought out explanations of Carnot's principle that heat can do work only in falling in temperature, that is in passing from a hotter to a cooler body, each inventing a new axiom to take the place of Carnot's faulty analogy with the fall of water. The statement of this axiom by Clausius is easier to understand, and it led him to the important conception of entropy, but the line of argument of Thomson was no less original and compelling, and it led him to the idea of dissipation of energy, which amounts to the same thing. It is worthy of notice that when Thomson began to write on the subject of thermodynamics he still believed heat to be a substance, but he soon accepted the results of the reasoning of Helmholtz and the experiments of Joule on the nature of heat as work, or as we now call it, energy. The most important outcome of Thomson's thermodynamical work was the invention of the absolute scale of measurement of temperature, which is independent of the properties of any thermometric substance such as mercury or air. By a fortunate accident this scale (or one of the two proposed), coincides nearly with that of a thermometer using one of the more permanent gases like hydrogen or nitrogen. The question of how nearly it coincides could be decided only by experiment, and these experiments were carried out from 1852 to 1862 by Thomson and Joule in collaboration, the most important result obtained being that on being forced through a porous plug all gases except hydrogen were slightly cooled, this cooling being shown to be due to the slight attraction of the molecules of the gas for each other, in spite of the tendency of the gas to expand on account of the motion of the molecules. It is probably by these researches that Thomson as an experimental physicist will be chiefly remembered, for they furnish us, by the Joule-Thomson effect, with our only means of reducing the indications of an actual gas thermometer to the absolute scale.

We now come to a new subject, and the one which made Thomson famous in the eyes of the public, and which eventually procured him his knighthood. At the beginning of the agitation of the project of the Atlantic telegraph cable, Thomson plunging with enthusiasm directly into the heart of the matter, took up the mathematical question of the mode of propagation of signals in a telegraph line laid under water. To this he again applied his favorite Fourier mathematics, and in 1855 he communicated to the Royal Society a paper in which the theory was completely worked out, in which it was shown that the current is propagated exactly as heat is conducted, and that instead of being propagated with a definite velocity, like sound, so that a short signal would arrive, pass over and cease, the current would arrive gradually, increase to a maximum, and die away, always leaving an undesirable residue to trouble the next signal. The longer the cable the longer would it take for the current to rise to its maximum, but not in proportion. The vital question was, how long would it take, and how much current could be got through, and this he solved in the most convincing fashion, with the announcement of the possibility of the prediction of the action of one cable by the behavior of another. If K is the capacity per unit of length, R the corresponding resistance, the time at which a signal reaches its maximum value at a distance d away is proportional to the product KRd^2. This is the famous KR-law, and then follows the remarkable prediction, "We may be sure beforehand that the American telegraph will succeed, with a battery sufficient to give a sensible current at the remote end, when kept long enough in action, but the time required for each deflection will be sixteen times as long as would be with a wire a quarter of the length, such, for instance, as the French submarine telegraph to Sardinia and Africa." The mastery of the principles of the telegraph thus shown led to the appointment of Professor Thomson as electrician of the first cable laid in 1858, a position which he held many times for later cables. Not content with showing the conditions necessary for success of working, Thomson had invented an instrument to make possible the reception of the weak signals to be transmitted, and his mirror galvanometer was ready when the shore end of the cable was laid. The important principle of this galvanometer was not merely the long weightless index consisting of a beam of light, the mirror principle having been invented by Poggendorf, but the reduction of the moving magnet to a very small light affair weighing less than a small sewing needle, and giving wonderful sensibility. Thomson was the first to insist on the advantage of small size in magnetic and other measuring instruments, and his galvanometer became the model of all delicate galvanometers from that time to this, each increase in lightness having been attended with an increase of sensitiveness. It is interesting to recall, in connection with the first cable, which lived to transmit only 732 messages, that it was ruined by the practical, that is non-theoretical, electrician, Mr. Whitehouse, who applied to it currents from huge induction coils, probably giving potentials of two thousand volts. By the advice of Thomson, thus dearly paid for, this was reduced, on the 1865 cable, to a few volts, this being amply sufficient to work his delicate instruments. The mirror galvanometer, together with the electrometers invented before the cable was talked of, were the first of Thomson's many electrical measuring instruments, by which he will perhaps best be remembered by practical people. Later he invented the siphon recorder, still in use for *recording* cable signals. Thus Thomson became the first, as he was the greatest, of electrical engineers, telegraph engineers then, but now embracing the many fields of telegraph and telephone, wireless, and transmission of power. In this connection may be mentioned his connection with the establishment of practical units for all electrical measurements, first made imperatively necessary by the cable, and lying at the basis not only of all exact measurement, but of all practical engineering. A committee of the British Association for the Advancement of Science was appointed, with Thomson as chairman, to consider the question of units in general, and in 1863 they made the determination of a practical unit of resistance, now known as the *ohm*, the method of experimentation being devised by Thomson. Finally the efforts of this committee culminated in the proposition of what is known as the C.G.S. system of absolute measurements for every sort of physical quantity, this system being now in use by every scientist and electrical engineer in all parts of the globe.

We may now say a few words of Thomson's instruments. Of the galvanometer we have already spoken, this being the most easily understood of his instruments, and used for measuring current. For the measurement of potential he devised two electrometers, acting on the principle of the attraction and repulsion of statically electrified bodies. In one, the absolute electrometer, a horizontal plate was hung from the arm of a balance, which weighed the attraction due to a parallel fixed plate. This idea was again not invented by Thomson, but by Snow Harris, who, however, did not understand how to get correct results with it. The bright idea conceived by Thomson was to surround the disk with a so-called guard-ring, the idea being that as the calculation supposed an infinite plate, the suspended disk should be, as it were, a sample of a larger plane surrounding it, the disk alone being movable. Thus the demands of theory and practise were both met at once, and exact calculation became possible. In the quadrant electrometer a quite different, but equally original arrangement was adopted. The moving part was made in the shape of a horizontal figure of eight, and turned about a vertical axis, most delicately supported by a silk fiber, and attracted and repelled by a circular box enclosing it, cut into quarters, which alternately attracted and repelled, but so as to combine their action, giving a most delicate instrument. These instruments, like the galvanometer, have become classical. By his journeys on cable ships, and his practical experience as a yachtsman, Thomson devoted much thought to the needs of navigation, and invented a sounding apparatus using steel piano wire instead of rope, with a depth indicator depending on the pressure of the water, and a compass, both of which are to-day in universal use. The principle of the compass was again that of lightness for sensitiveness, the card being supported by silk strings. He also elaborated the method of correction of the compass for the ship's magnetism. Later on came instruments for the measurement of the large currents and potentials used in present-day practise.

The culmination of Thomson's application of Fourier mathematics, and perhaps his most sensational contribution to science, was his estimate of the age of the earth, based upon the time it has taken to cool, our knowledge being derived from the measurement of the rate of increase of temperature as we go below the surface of the earth. His conclusion was that the earth had required from one to two hundred million years to cool from its molten state to the present, a conclusion which was a violent shock to the geologists, who required a far greater period for the formation of the rocks.

None of the above-mentioned subjects was, however, Thomson's favorite subject of research, the place of which must undoubtedly be given to his speculations on the nature of the ether, and the constitution of matter. In fact, he stated at his jubilee that there had not been a day during the last forty years when he had not devoted some time to the consideration of these subjects, but that the total result must be summed up as failure, inasmuch as he knew no more of their true nature now than at the beginning. This discouraging admission must be taken with several pailfuls of salt, and attributed to that true scientific humility which is the characteristic of great minds, for there is no one who has contributed more to our knowledge of both ether and matter than Thomson. His fondness for this subject was a symptom of his devotion to and mastery of the principles of mechanics, whether in its applications to rigid bodies, to elasticity, or to hydrodynamics. In connection with his contributions to geology may be mentioned his powerful researches on the tides, of both fluid and solid spheroids, and his conclusion from the motion of the earth that it is nearly as rigid as a sphere of steel. Thomson and Tait's "Treatise on Natural Philosophy" (roguishly referred to by Clifford as $T + T'$) was an epoch-making work, conceived on a scale never before attempted, and destined to be completed only in the first instalment devoted to mechanics, on which subject it constituted a wonderfully inspiring guide. This work, which Helmholtz thought enough of to translate into German, is difficult of characterization, but we may mention its insistence on the value of Newton's ideas, and its exposition of the power of Lagrange's generalized methods in dynamics. The portion which perhaps best shows the originality of Thomson's genius is the chapter on systems containing rotating gyrostats, of whose peculiar action it gives the complete key. The recent application of these principles in the Brennan mono-rail railway and the Schlick gyrostat for preventing the rolling of ships is no more interesting than Thomson's use of them to construct from rigid materials a model of an elastic atom, in his "Steps toward a Kinetic Theory of Matter," read at the British Association meeting in Montreal in 1884, or his model of a gyrostatic ether whose elasticity was to be similarly explained.

This occasion of Thomson's first visit to the United States was otherwise signalized by the deliverance at the Johns Hopkins University of a remarkable series of lectures on "Molecular Dynamics and the Wave Theory of Light," before a very unusual auditory from both sides of the ocean. These lectures, first published twenty years later, were characteristically Thomsonian, and represented his long attempt to make the elastic theory of the ether work successfully. Constructing a model of a molecule by means of concentric hollow shells with springs between to give many modes of vibration, he was led to an explanation of anomalous dispersion, without knowing of its experimental discovery by Kundt and Christiansen, or its explanation by Helmholtz ten years before. This ignoring of the work of others was characteristic of both Thomson and Helmholtz, and perhaps constitutes the strength of great thinkers. Possibly in this way is to be explained Thomson's cold attitude toward the electromagnetic theory of light, which he maintained until after the world in general was convinced of its truth. He was determined at all hazards to make the elastic ether do, probably because he saw that even if light is to be explained as electromagnetic waves, we have still to give a dynamical explanation of electricity and magnetism. Of late years the pendulum has swung the other way, and there is now an attempt to explain all dynamics on an electromagnetic basis, but with this Lord Kelvin would probably have had no sympathy. In these Baltimore lectures we find a remarkable description of a probable way to make electric waves, which was almost exactly realized by the method of Hertz three years later, coupled with the erroneous opinion, from which Thomson could hardly rid himself, that they would be waves of compression, and would travel much faster than light. In order to explain elasticity, he had a penchant for the ideas of Father Boscovich, of forces emanating from centers, from which he built up atoms, ether, and even made application to radioactivity. One of his last papers is on a "Plan of an Atom to be capable of storing an Electrion with Enormous Energy for Radioactivity," and in a paper with the characteristic title of "Æpinus Atomized" he put forth the model of an atom consisting of a globe of positive electricity permeated by a multitude of minute negative *electrions*, as he persisted in calling them, ignoring the general use of the word electron.

Lord Kelvin devoted a considerable portion of his energies to tilting at windmills and championing lost causes. Of this his treatment of the elastic and electric theories is an example. Another *bête noire* in late years was the Maxwell-Boltzmann theorem of the partition of energy, which he characterized as a cloud upon the kinetic theory of gases. The writer once enjoyed the good fortune of spending several days in the company of Lord Kelvin, and of hearing him frequently training his guns on that target. At last he plucked up courage to ask, "Lord Kelvin, what do you consider to be the fundamental error in the argument of Maxwell and Boltzmann?" "I don't think there is a single thing about it that is right," was the instant comprehensive answer, to which there appeared no obvious reply.

Lord Kelvin's personality was a most attractive and original one. To see him and hear him talk was to be lost in admiration of his vigor, his quickness and his enthusiasm. Nothing was lost to him, and he was never idle. In the railway carriage on the return to London on the occasion mentioned he soon pulled out his note-book, and was figuring on the ether flowing through an atom, the result of which figuring was apparent the week after at the Paris congress. Helmholtz, on a visit to Thomson on his yacht, the *Lalla Rookh*, writes to his wife, after admiring the skill with which Thomson managed the yacht, "It was very pleasant and informal. W. Thomson has carried the freedom of intercourse so far that he always carries a mathematical note-book about with him, and as soon as an idea occurs to him, begins to reckon right in the midst of the company, which is generally regarded with a certain awe. How would it be if I should accustom the Berliners to that?" On the occasion of a visit in Glasgow he writes, "He has no vacation at Easter, but his brother James, professor of engineering at Belfast, and a nephew, are there. The former is a very clever head with good ideas, but hears and knows nothing but engineering, and speaks of it continuously at all times of the day and night, so that hardly any conversation can take place when he is there. It is funny, too, how each of the brothers explains something to the other, and neither listens to the other, and each talks of totally different subjects. But the engineer is the most obstinate of the two and generally puts his piece through." The friendship between these two great physicists, Helmholtz and Thomson, both without other peers, was most interesting from the fact that they many times almost simultaneously treated the same subjects, and that they were both examples of Helmholtz's statement that "in physical science he only can fruitfully experiment who has a penetrating knowledge of theory and according thereto can ask the right questions, and on the other hand, as is most brilliantly shown in the discovery of spectrum analysis, he only can fruitfully theorize who has a broad practical experience in experimentation." Would that these words and these examples might be carved in letters of gold in every laboratory in this land!

The honors heaped upon Thomson would fill a catalogue. Knighted in 1866, he is most familiarly known as Sir William Thomson, elected foreign associate of the Paris Academy of Sciences in 1877, he was raised to the peerage by Lord Salisbury in 1892, taking the title of Baron Kelvin, from the stream on which Glasgow is situated. He was president of the Royal Society, four times president of the Royal Society of Edinburgh, and member of nearly all the learned societies of the world. He was one of the twenty members of the recently instituted Order of Merit, of which the other scientific members are Lord Rayleigh, Sir William Huggins and Lord Lister. On his third visit to this country, in 1902, he was tendered by several scientific societies a great reception at Columbia University, where his praises were sung before a distinguished company. His visit to the American Physical Society was a memorable one for that society, of which he was the first honorary member. Kelvin's printed works comprise one volume of "Papers on Electrostatics and Magnetism," three volumes of "Mathematical and Physical Papers" (those not yet published will make another), Thomson and Tait's "Treatise in Natural Philosophy," in two volumes, and three volumes of Popular Lectures and Addresses. Of these many papers the majority are not of an experimental character, and Kelvin's experimental work that will be best remembered is probably comprised in his discovery of the Joule-Thomson cooling effect in gases and of the Thomson effect of the carriage of heat with or against the electric current.

Kelvin's great strength consisted in his mastery of the application of mathematical methods, and of mechanics in particular, combined with his rare physical intuition and his ability to construct models to make difficult phenomena tangibly realizable. Helmholtz says of him in his preface to his translation of Thomson and Tait, "William Thomson, one of the most penetrating and ingenious thinkers, deserves the thanks of the scientific world, in that he takes us into the workshop of his thoughts and unravels the guiding threads which have helped him to master and to set in order the most resisting and confused material." Again in his "Report on Sir William Thomson's Mathematical and Physical Papers" he sees the great merit of Thomson's scientific methods in the fact that, "following the example given by Faraday, he avoids as far as possible hypotheses about unknown subjects and endeavors to express by his mathematical treatment of problems simply the law of observable phenomena. By this circumscription of his field Thomson brought out the analogy between the different phenomena of nature much more clearly than would have been the case if it had been complicated by widely diverging ideas with reference to the inner mechanism of phenomena."

Though Kelvin is often mentioned as a mathematician, this is not correct in the strict sense, inasmuch as he did not add to the methods of mathematics proper. Indeed, it is very doubtful if he knew any more of mathematics at eighty than he did at twenty. He did not need to. For him a thorough familiarity with the methods of Lagrange, Fourier, Cauchy and Green amply sufficed. We never hear him mention a Riemann's surface or an existence-theorem. This we say not as a reproach, nor as an insinuation regarding the fertility of modern pure mathematics, but merely as an interesting fact. These methods may be taught, and in a reasonable time. Let us in America pray for teachers of this science which Helmholtz calls "die eigentliche Basis aller rechter Naturwissenschaft," of the inspiring quality of Lord Kelvin, the high priest of that most alluring goddess of the natural sciences, MATHEMATICAL PHYSICS.

ARTHUR GORDON WEBSTER

CLARK UNIVERSITY,
December 22, 1907

MEDICINE AND THE UNIVERSITY[1]

I BELIEVE that I make no mistake in assuming that the honor of the invitation to deliver this address came to me mainly through the official position which I chance to hold in the Association for the Advancement of Science and the desire to give prominence on this occasion to the sciences of nature in view of the approaching meeting of the association in this place. I must, however, disclaim any especial competence to speak for these sciences, and I know not where there is less need in our country of emphasizing the importance and significance of the natural and physical sciences, or where the representatives of these sciences have brought higher distinction to themselves and to their university, than here in the University of Chicago.

The past century is memorable above all others for the gigantic progress of the natural and physical sciences—a progress which has influenced more profoundly the lives and thought, the position and prospects of mankind, than all the political changes, all the conquests, all the codes and legislation. In this marvelous scientific advancement in all directions the sciences of living beings and their manifestations have progressed as rapidly and have influenced the material, intellectual and social conditions of mankind as much as the sciences of inanimate matter and its energies. So far as the happiness of human beings is concerned, there is no other gift of science comparable to the increased power acquired by medicine to annul or lessen physical suffering and to restrain the spread of pestilential diseases, although what has been accomplished in this direction is small indeed in comparison with what remains to be achieved. Man's power over disease advances with increased knowledge of the

[1] An address delivered at the convocation exercises of the University of Chicago, December 17, 1907.