Physics and the Physicists of the Eighteen Seventies*

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IN 1874 the Physical Society of London was founded by a well-known physicist, Prof. Frederick Guthrie. The first meeting of the Society was held on March 21, 1874, in Guthrie's lecture room in the Science Schools, South Kensington, and by his great kindness I had the privilege of reading the first paper to the members, the subject being "The New Contact Theory of the Galvanic Cell".

Let us then take a glance backward at the state of physics in the years 1870–1880, and the men who were foremost in advancing it. We may divide them into two broad classes. There were first a few who were highly competent mathematicians and conformed to the model of Newton in being able not only to wield the powerful weapon of mathematical analysis but also were competent experimentalists. In Great Britain at that time this class was chiefly represented by Sir George Stokes, Lucasian professor of mathematics in the University of Cambridge, by Sir William Thomson, who had held the chair of natural philosophy in the University of Glasgow since the time when he was twenty-two years of age, and by his enormous knowledge, brilliant experimental researches and practical inventions held a foremost place in universal opinion as a physicist. Then next by James Clerk Maxwell, who, even as an undergraduate, had made notable contributions to mathematics and physics. He had translated Faraday's physical conceptions into mathematical language, explored the phenomena of colour, laid firm the foundations of the kinetic theory of gases and made important measurements of the viscosity of air. He had held professorships of natural philosophy at Aberdeen and King's College, London. In 1865 he had resigned this latter appointment and retired to his Scottish estate at Glenlair to engage in writing his great treatise on "Electricity and Magnetism".

Peter Guthrie Tait was then professor of physics in the University of Edinburgh. As a mathematician he had inherited the mantle of Sir W. R. Hamilton, the inventor of quaternians, but Tait also made many very important contributions to experimental physics. Then in the same rank of great mathematical physicists, we had in Germany Helmholtz and Kirchhoff; in France, Cornu, and in the United States, Willard Gibbs. On the other hand, there were many eminent physicists who, like Faraday, had not much mathematical knowledge, but attained their results purely by experimental work. Among these in the eighteen seventies, John Tyndall was one of the most popular. He had very great abilities as an exponent of science. J. P. Joule had made the most valuable contributions to physical measurements by his proof of the so-called Joule's law in electricity and in his determinations of the mechanical equivalent of heat. A reprint of Joule's scientific papers was issued by the Physical Society in 1884.

Very prominent in this group was William Crookes. He had, like many of the experimental physicists, begun as a chemist. Crookes discovered by spectrum analysis the element thallium, and had isolated the metal and determined its atomic weight. Crookes had then turned to research on electrical discharge in high vacua. He had improved methods of vacuum technique and had rediscovered many important facts concerning electric discharge in high vacua noticed by Hittorf, Puluj and others. Finally he devised the light-mill or radiometer.

Another of this group was J. H. Gladstone, the first president of the Physical Society, and he also was first of all a chemist and latterly an experimental physicist. His work on refractive indices was of special importance. Neither must we omit to mention in this group the name of Frederick Guthrie, who made several very important additions to physical knowledge. Other experimental physicists of that date were R. B. Clifton at Oxford, W. Grylls Adams and G. Carey Foster in London, Balfour Stewart in Manchester. Prior to about 1866, there were in Great Britain scarcely any laboratories properly equipped for research or teaching in physics.

The necessity for quantitative work, especially in electricity, had been emphasized by the technical advances in telegraphy. In 1856, a far-seeing man, Cyrus Field, had conceived the idea of a trans-Atlantic submarine cable to unite Great Britain and the United States, and had formed a company in 1856 to undertake it. But the question at once presented itself whether signals could be sent through such a long cable quickly enough to enable a sufficient income to be earned to pay the interest on capital and also the working expenses. Faraday had been consulted, and pointed out that such a submarine cable was a large condenser or Leyden jar, but he thought signals might be sent through it sufficiently quickly to make it pay.

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Here we see the immense power of mathematical analysis guided by correct physical ideas. In 1855 William Thomson, then a young professor, sent a paper on the theory of the electric telegraph to the Royal Society. Assuming the cable to have certain resistance and also electrostatic capacity per mile, he proved that when a steady electromotive force was applied at one end the outcoming current at the other rose up gradually according to a certain curve of arrival. The time taken to reach a certain current strength was directly proportional to the square of the length of the cable and directly as the product of the resistance and capacity per mile of the cable. This showed that the right method for signalling was to have as sensitive a detector as possible at the receiving end and to use the lowest possible applied electromotive force at the sending end. Thomson had meanwhile invented and made his sensitive mirror galvanometer for cable signalling.

By 1865, three Atlantic cables had been laid and lost. But in 1866 success finally crowned the efforts of the promoters and a fourth cable was made and laid and the 1865 cable raised and repaired. Thus two complete Atlantic cables effected communication between England and the United States, which were worked with Thomson's instruments. In 1870, Thomson invented his remarkable syphon recorder to receive and print cable messages, and this has remained to this day the standard instrument for all cable reception.

Thus the year 1870 saw the practical achievement of submarine telegraphy accomplished and the invention of the instruments needed for working. From that time the making and laying of submarine cables became a particularly British industry.

But the same year (1870) witnessed another event of great importance with regard to physical research, namely, the founding of the Cavendish Laboratory at Cambridge. Although some attempts had been made to foster physical research there, the University was without means to provide for it. In October 1870, the seventh Duke of Devonshire, then Chancellor of the University of Cambridge, sent a letter to the Vice-Chancellor offering to defray the cost of erecting and equipping a physical laboratory in the University. This munificent offer was gratefully accepted. In March 1871, Maxwell was elected as the first Cavendish professor of physics. The building of the Laboratory was completed early in 1874. A year before, in 1873, Maxwell had published his great treatise on "Electricity and Magnetism", and physicists everywhere were trying to master the new ideas he had introduced into the subject. He had embodied in it his earlier work of expressing in mathematical language Faraday's ideas of lines of electric and magnetic force and of the dielectric as the true seat of the energy involved. He had also included in the second volume a reproduction and exposition of his great paper sent to the Royal Society in 1864 on "A Dynamical Theory of the Electromagnetic Field". In this paper he had shown that electric and magnetic effects are propagated through space with a velocity equal to that of light in the medium and had foretold the existence of the electromagnetic waves now utilized to give us radio-telegraphy and telephony.

After Maxwell's death in 1879, I remember that an eminent mathematician, Sir W. D. Niven, said to me that he regarded this paper with its wonderful originality and power to be one of the greatest productions of the human mind.

In his introductory lecture given by Maxwell in October 1871 on his installation as Cavendish professor, he had expressed his ideas of the aim and functions of the Laboratory. He did not contemplate its main use to be that of training undergraduate students in the repetition of experiments described in text-books, but that its principal object should be quantitative measurements and the production of new knowledge by research by post-graduate or other students. Very magnificently has this ideal been held in view by Maxwell's successors in the chair.

Another event in the year 1870 which had an influence on physical research was the taking over by the State of the telegraph system in Great Britain. Up to that time, land telegraphy had been conducted by several public companies each with its special area of operations. This of course greatly limited the use of the electric telegraph.

The Government of that day passed Acts of Parliament in 1868 and 1869 entitling it to buy out, take over, and place under the General Post Office all telegraphic work in Great Britain. At the same time, it was greatly extended and the country overlaid with a network of telegraphic wires enabling communications to be made between all places where there was a post office. This called for the production of practical standards of the electrical units such as the ohm, the volt, the ampere, the farad, and accurate methods of electrical measurement. A British Association Committee had constructed a number of coils of wire of various alloys the resistance of each of which was asserted to be at certain marked temperatures equal to 10^9 absolute units of resistance on the electromagnetic system. These had been deposited in the Cavendish Laboratory.

When I went up to Cambridge in October 1877 to work in the Cavendish Laboratory, Maxwell suggested to me to undertake the work of comparing these coils and ascertaining from them their resistances at certain temperatures and hence the most probable value of the B.A. Unit.

For this purpose I devised a special form of Wheatstone's bridge which was described to the Physical Society in 1880. I prepared, as the result of about two years work, a chart showing the variation of resistance with temperature of each of the coils. The true absolute values of these were determined later on (after Maxwell's early lamented death in November 1879) by Lord Rayleigh, who was Cavendish professor until 1884. This B.A. Unit proved to have an electrical resistance of $0 \cdot 9867 \times 10^9$ centimetres per second or less than a true ohm of 10^9 cm./sec.

Part of Maxwell's work during the last years of his life comprised the editing for publication of the unpublished electrical researches of the Hon. Henry Cavendish (1731–1810). Cavendish was an experimentalist of great ingenuity, and with the most rudimentary apparatus carried out important researches. Maxwell repeated with similar apparatus all Cavendish's results. Among other things, Cavendish anticipated Faraday's discovery of specific inductive capacity and made researches to find out if the law of electrical attractions or repulsions varies in any sensible degree from the inverse square of the distance. Maxwell carefully repeated these with improved apparatus and found that the index deviated from 2 by not more than $\frac{1}{21{,}600}$ either way. Cavendish made measurements of the comparative electrical resistance of various materials by taking the shock of a Leyden jar through a certain length of each material and adjusting the lengths until the shocks were estimated to be about equally painful. Most of the workers in the laboratory were called upon at various times to act as 'shock meters' in Maxwell's repetition of Cavendish's experiments.

Maxwell's lecture experiments were always marked by great ingenuity, and he could give copious new information on even the most familiar scientific facts or discoveries. In conversation he was often difficult to understand by reason of a certain paradoxical and humorous mode of speech.

No mention of Maxwell's work would be complete without a brief reference to his other writings, written in the eighteen seventies. He published a treatise on the "Theory of Heat" which had all the characteristics of lucidity and novelty which marked his authorship. In it he gave the elements of the science of thermodynamics and the contributions to it made by Carnot, Clausius, Willard Gibbs, Rankine and W. Thomson. His other small book "Matter and Motion" was a delightfully interesting small treatise on dynamics. It was re-edited with some additions after Maxwell's death by Sir Joseph Larmor. In addition to this he wrote many articles for the ninth edition of the "Encyclopædia Britannica", and in 1873 gave a memorable lecture on "Molecules" to the British Association at Bradford, parts of which have been often quoted.

We must now return to consider the work of Sir W. Thomson (later Lord Kelvin) during the decade 1870–80 under consideration. He was at this time engaged in improving the mariner's compass. As a yachtsman and the owner of the *Lalla Rookh*, he took an extreme interest in all things connected with navigation, and left his improvements on everything. In 1874, he was asked to write an article on the magnetic compass for *Good Words* and at once took note of the defects of the then used type. Little by little he brought it to a state of perfection in which it was adopted all over the world. He gives a full account of it in the third volume of his popular "Lectures and Addresses". At the same time he vastly improved the method of deep-sea sounding by using steel pianoforte wire instead of hemp rope. The depth was measured by the degree to which the air in a glass tube open at the bottom but closed at the top was compressed when the sea floor was reached. In 1876 he made known his enormously ingenious machines for recording, analysing, and predicting the tides at any port, and in a lecture at Glasgow in 1875 he gave a most instructive account of methods of determining the position of a ship at sea by Sumner circles. His knowledge of everything connected with navigation, tides and waves was vast and accurate, and he touched nothing he did not elucidate and improve.

The decade we are considering was remarkable also for the completed invention of two important electrical appliances, namely, the speaking telephone and the incandescent electric lamp, the achievement of which had long been objects of physical research.

Without reference to early attempts, it is well known that Alexander Graham Bell was the first to produce a simple speaking telephone which was publicly exhibited in 1876 at the Philadelphia Exhibition. Sir W. Thomson saw and used it there and on return to England described it enthusiastically to an audience at the British Association meeting at Glasgow. Bell was actually engaged in trying to effect multiple telegraphy when he stumbled across the principle of his magneto-telephone.

The Bell telephone was a good receiver but poor transmitter. T. A. Edison had meanwhile invented his carbon button transmitter, in which the motions of a sound-actuated diaphragm compressed a button of lamp-black and varied its resistance and therefore the current in the circuit. D. E. Hughes, the inventor of a printing telegraph, then came into the field in 1878 with his discovery of the effects of slight pressure on a loose contact between two pieces of graphitic-carbon. This in time gave us the modern microphone transmitter. Bell had suggested meanwhile the idea of a telephone exchange, and the Edison and Bell interests in England had to unite to provide the most effective transmitter and receiver.

The problem of incandescent electric lighting had occupied attention for thirty years or more in the endeavour to provide a small unit of light for domestic illumination. J. W. Swan solved the problem early in 1880 of producing a carbon filament by carbonizing a cotton thread which had been parchmentized by sulphuric acid and mounting a loop of this carbon filament in a glass bulb exhausted of its air. Edison about the same time carbonized slender filaments of bamboo in horse-shoe shape and also produced an effective carbon filament lamp.

The early lamps gave a light of about sixteen candles at a power expenditure of about sixty-four watts. From that date electric illumination by incandescent lamps became practicable.

In conclusion, it may be useful to attempt to sum up briefly the achievements in physics during the decade 1870–1880. Broadly speaking, it was an age of practical invention in which well-ascertained scientific principles were applied in some way to create new industries or useful arts. In telegraphy there were many very important additions. Wheatstone automatic, quadruplex and high-speed printing telegraphs came into use. The speaking telephone and telephone exchanges added to the convenience of life. Electric incandescent lamps and the invention of the dynamo had made possible public electric supply stations and domestic electric illumination.

In 1873 the reversibility of the dynamo was discovered; that is, that it could act as a motor when current was put into it, and some degree of progress had been made in the use of electric motors and possible electric transmission of power.

In relation to physical theories, the period we are considering was essentially mechanistic and deterministic in ideas. The conception of a universal ether having elasticity and density was widely held and numerous mechanical ether theories proposed. Atoms in vibration were supposed to agitate the ether and produce waves in it, but no one had explained how the vibrating atoms got a grip on the ether seeing that the ether offers no resistance to the motion of the earth and planets through it.

Theories of atomic structure were in a very vague and nebulous state. Thomson's theory of atoms as vortex rings in the ether had not explained anything of importance. The science of thermodynamics had, however, been well developed and much progress made by the writings of Clausius, Rankine, W. Thomson and Willard Gibbs. The foundation stone of the science of thermodynamics was laid by the publication in 1824 of the remarkable essay by Sadi Carnot on the "Motive Power of Heat" in which he gave the Carnot cycle. This essay was, however, then known to very few. W. Thomson made acquaintance with it when as a young graduate he went for a year to Paris to work with the great experimentalist, Regnault. Thomson published in 1849 a paper in which he made known and expounded Carnot's work. Carnot's essay in French was republished in 1878, having been thus lost sight of for many years, but Thomson's paper in 1849 had by that time brought it to the notice of physicists of that day. Based on the Carnot cycle, Thomson afterwards suggested his absolute scale of temperature independent of any working substance. He also enunciated his Law of Dissipation of Energy. The fact that heat is the kinetic energy of atoms was fully understood and that the whole of any amount of mass kinetic energy could be converted into heat at a certain rate fully appreciated. But it was not so generally realized that the whole of any quantity of heat energy cannot be converted into mass kinetic energy. There was a widely diffused belief in that day that the physical theories corresponded closely to reality and that such words as size, time, mass and energy denoted actualities independent of any observer. Not every physicist, however, shared this view. Maxwell once said in my hearing, "Because we can imagine a mechanism which can achieve some result we find in Nature, it does not in the least follow that it is done in that way."

The physical theories of 1870–1880 were looked upon as well-established explanations of facts. Not ten years later, however, the first of the events occurred, namely, the Michelson and Morley experiment, which was to undermine and destroy this confidence and show that our interpretation of physical phenomena involves the observer as well as the thing observed.

When we come to look back then on the work of physicists during the eighteen seventies, what we find is that their inventions, discoveries of fact, and ascertained principles remain with us to-day of permanent value, forming part of our useful knowledge. But their theories and speculations as to underlying causes and nature have nearly all passed away. Perhaps it will also be the same with our present-day work. If some sixty years hence a fellow of the Physical Society gives a talk on the physics of the nineteen thirties, he will have to record the great additions then made to knowledge of physical facts. But he may also have to say that our explanations and theories concerning them have all vanished, or at least been replaced by others also destined in turn to pass away.