# Some Modern Aspects of Physical Research.[1]

By Sir ALFRED EWING, K.C.B., F.R.S.

IN this ancient and honourable Royal Society, we have an association of persons with a common motive, namely, to assist the advance of natural knowledge. The chief functions of such a society are (1) to provide facilities for intercourse, personal and formal; (2) to provide a library—and we have a great library of ever-increasing value; (3) to provide the means of publication. Records of scientific research are not a readily marketable commodity. They would fare badly if left to the mercy of the ordinary laws of supply and demand. So we meet the cost of publication, and they go out, after some winnowing of chaff from wheat, with our imprimatur. The published volumes of our Proceedings and Transactions contain papers by Kelvin and other fellows which may be said without exaggeration to mark epochs in the development of scientific thought.

The urge which we feel towards research—that urge which is our bond of fellowship—is not mainly utilitarian; it arises rather from a special type of intellectual curiosity. Often indeed the results of research undertaken with no utilitarian purpose have been found to possess a utility that was not in the mind of the discoverer. For example, Kelvin's theory of the oscillatory discharge of electricity, followed by Maxwell's recognition of electromagnetic waves in the ether, and by the detection of such waves by Hertz, though matters of purely scientific interest at the time, led in due course to wireless telegraphy and broadcasting. Again and again in the history of discovery an abstract research has turned out of quite unlooked-for practical value.

We may recognise, I think, two general types of research, both of which it is the business of a scientific society to foster. There is the inspired type—the flash of genius, of intuition, of imagination, which breaks new ground or brings the old into a new harmony by some far-reaching generalisation. There is also the plodding everyday systematic spade-work of research; a kind which goes on in a hundred laboratories; not inspired, not spectacular, not in the least intoxicating; but we should make a grave error if we were to underrate its importance.

Such a society as ours is, consciously or not, in some degree propagandist. One of its effects is to spread an interest in science beyond the bounds of the scientific workers. There is already a changed attitude on the part of the public towards scientific ideas and the scientific method. Formerly the voice of the specialist was that of one crying in the wilderness; now he commands the attention of the man in the street. In the training of engineers, in the carrying on of manufactures, in many different fields of social activity, we trace the permeating influence of science. Young men leaving the universities with a knowledge of scientific principles and able to manipulate scientific instruments are quickly absorbed into industry. One sees great industrial concerns setting up their own research laboratories, and finding that it pays them to do so. Research has found a place not only in manufacture and industry, but also in the budgets of the politician. The Government endows individual researchers and encourages corporate efforts in various administrative departments, notably through its Department of Scientific and Industrial Research. The activities of that department are perhaps not so well known as they ought to be. Such an organisation can successfully undertake researches of a kind impossible for isolated workers. I have some personal knowledge of its work, for I am at present chairman of two of its scientific committees. One of these deals with the effects of moving loads in producing stress in railway bridges. This is an investigation which no private individual could conceivably have carried out: it needed, and has in fact received, the active co-operation of the railway companies. It is a long and costly inquiry, but I am able to say with confidence that the results already secured are such as to justify the expenditure, by the influence they will have on the future design of bridges and locomotives.

Looking back, it is curious to note the progress in pure and applied science that has come about within the period of my personal recollection. I am old enough to recall the very beginnings of electrical engineering, the first use of electric lamps, the first transformers and storage batteries, the first attempt to produce and distribute electric power. In student days I exhibited at a bazaar the first telephones of Graham Bell's invention, which had been brought across the Atlantic by Lord Kelvin. It happened too that, guided by a brief description in the *Times*, I made the first Edison phonograph ever made on British soil, an invention which has given us the advantages (if you so regard them) of the gramophone. I remember too the earliest form of motion pictures, from which has come the ubiquitous cinema. My memory goes back to the most primitive type of internal-combustion engine, the development of which has given us motor cars, and has made flying possible. It goes back also to the earliest application of refrigeration, which is now playing so large a part in bringing our food from overseas.

It was my privilege while a young professor at Cambridge to test for Parsons his earliest condensing steam turbine, and a little later his first turbine-driven steamboat. The invention of the steam turbine, which we owe to Sir Charles Parsons, has been applied on a gigantic scale not only for ship propulsion, but also for the distribution of electric power from central stations. I recollect vividly hearing, in the early 'seventies, Lord Lister describe to this society his antiseptic method in surgery, and seeing him take from a sterilised flask its plug of cotton wool and drink down the milk it contained—milk which he had drawn from the cow three months before. Later came the two cardinal discoveries of radioactivity and the X-rays. Both of these soon became handmaids of surgery; but apart from that, they put novel instruments of unparalleled effectiveness into the hands of the physicist. Think of what all this discovery and invention has meant in making Nature more man's servant, in prolonging his life, in giving him more of comfort, of interest, of power.

[1] Presidential address delivered before the Royal Society of Edinburgh at the annual meeting on October 26.

Younger men, who have been born into a world where these things are already familiar, cannot realise the excitement and delight of an earlier generation in seeing them spring, new and strange, from the brains of their creators.

> Bliss was it in that dawn to be alive,
> But to be young was very heaven!

I was really in middle life when, in the last decade of the nineteenth century, the great physical renaissance began, of which radioactivity and X-rays were the two chief starting-points, opening up as they did new vistas of thought as well as furnishing new tools for research. J. J. Thomson had shown in 1881 that a charged body derives additional inertia from the existence of the charge, but it was not until after his discovery (in 1897) of the electron as a disembodied atom of electricity, an indivisibly small unit, that it became apparent that all mass is electrical in origin. We used in older days to aim at explaining electricity in terms of matter; now we have come to regard matter as one of the manifestations of electricity. We recognise that the atoms of all substances are complex structures, which are built up out of only two kinds of brickbats, positive and negative units of electricity, called respectively protons and electrons. The positive brickbats, the protons, contribute nearly the whole mass, and it comes from the concentration of electricity into a very minute space. We may perhaps think of the protons and electrons as being electrified holes in the ether, imagining the proton hole to be about eighteen hundred times smaller in diameter than the electron hole in order that it may have a sufficiently bigger mass. But I must admit that to suggest a definition of the ultimate particles of matter as electrified holes in a medium which perhaps does not exist, is more stimulating to the imagination than satisfying to the intelligence. Whatever the protons and electrons may be, they build up the atom in what Rutherford has taught us to regard as a sort of planetary system. There is a nucleus which contributes nearly all the mass. It is positively charged because it contains all the protons and only some of the electrons. The remainder of the electrons, in number equal to the positive charge, are disposed outside, much as the planets are disposed around the sun.

This conception of an atomic structure has led to the grouping of the elements in a systematic series, rising in regular steps by one unit of positive nuclear charge as we pass from one element to the next. The number of units of nuclear charge gives the atomic number of the element, and it goes progressively up from hydrogen = 1, helium = 2, lithium = 3, and so on, up to uranium = 92, forming a continuous series in which there are only two or three gaps still waiting to be filled. Towards this idea the way was paved by Barkla's discovery of the characteristic radiation of substances under bombardment by X-rays. The splendid generalisation of the atomic series was itself reached through the inspiration of Moseley. It justifies Prout's old hypothesis, the objection that the atomic weights of the elements do not come out as whole numbers having been completely removed by the discovery of isotopes, the discovery, namely, that some elements are mixtures of two or more substances having the same chemical properties, but with integral differences in their atomic weights.

More or less concurrently with these developments of atomic theory came the recognition of series in the lines of optical spectra, initiated in 1885 by Balmer, a teacher in a secondary school at Bâle. His work was followed up by Lyman and Rydberg, and is now interpreted, thanks to the genius of Bohr, in a manner which connects the spectral lines with the complex atomic architecture of Rutherford. In this interpretation the quantum theory, which had been framed by Planck in 1900 to account for other and quite different phenomena, has received so complete a confirmation that we are forced to accept it as a rule in Nature's operations, although at present it is a rule we cannot understand.

In the hands of the Braggs, father and son, X-rays have served to show exactly how the atoms take their places in the tactical groups which constitute crystals. The whole development of modern atomic theory is a chain of discovery connecting phenomena that were previously separate, stretching link by link into regions that had seemed hopelessly outside the pale of exact knowledge. No one surely foresaw that it would be possible to weigh and measure the constituent particles which make up an atom.

Other romances of science are to be found in the recent progress of astronomy. A new departure was taken by Michelson in 1920 in the success of his device for measuring the sizes of certain stars. He found, for example, that in Betelgeuse we have a celestial giant two hundred million miles in diameter, big enough to take in the whole orbit of the earth, and more. This diameter had been foreseen by theory. In particular, Eddington has applied his imagination and his mathematics to the question. He shows that the surface temperature of a star is no criterion of the fervent heat within, where a temperature of perhaps twenty million degrees may be reached. Under such conditions the energy of the star is about equally divided between the energy of waves of radiation and that of the motion of particles. The radiation causes a disruptive pressure which acts against gravitation so strongly that the balance between those two forces is the factor which determines how much mass is condensed to form a single star. This explains why it is that all stars are roughly of the same order of magnitude.

Eddington pictures the radiant energy within the star as trying to escape into surrounding space but caged in by the material. It is tossed to and fro from atom to atom as the ball is tossed in a Rugby match, and only little by little does it reach the surface and find itself free. He shows how at the enormous temperature of the interior the atoms are stripped of their outer electrons, which then mingle in the throng as free particles. Deprived in this way of the crinoline or fender of electrons that would normally keep them apart, the nuclei may approach one another far more closely than they could otherwise do, and the star may therefore contract to a density which vastly exceeds that of any substance known in our laboratories. But in contracting from a giant to a dwarf, the substance of the star preserves the essential features of a gas, for the particles have still a relatively large mean free path of movement in the intervals between their encounters. Owing to the removal of their crinoline, stellar atoms have only something like one-hundred thousandth the bulk of ordinary atoms, and so may be brought immensely closer to one another before the properties of a nearly perfect gas are lost. Finally, Eddington gives us reasons for imagining that in the course of its life history the star maintains its power of emitting radiation not simply by virtue of its contraction, but by converting into energy a portion of its own mass. His remarkable prediction as to the density of dwarf "white" stars has, during the past summer, been verified by Adams at Mount Wilson, who, by measuring the "relativity" displacement of lines in the spectrum of the companion of Sirius, has proved that star to have a density some two thousand times greater than that of platinum, and has directly confirmed the validity of the spectral shift as a test of Einstein's general theory of relativity.

Yet another romance is the story of helium, first inferred as an element in the sun by Lockyer in 1868 from observations of the spectrum of a solar prominence. It was not known to be a constituent of the earth until Ramsay found it in 1895 as a gas in the mineral cleveite. It takes an important place as the second member of the atomic series, the lightest of the group of inert elements which includes neon, argon, krypton, and xenon. It is found in small quantity in the atmosphere and in nearly all natural gases and spring waters. We now recognise it as a product of the disintegration of radioactive substances. Each alpha particle they shoot out is essentially an atom of helium. It is the nucleus of such an atom, which only requires to associate itself (as it can readily do) with two planetary electrons in order to become a complete electrically neutral atom of helium. The lightness and inertness of helium make it an ideal substance for the filling of airships, for it has a lifting power in the atmosphere not far short of that of hydrogen, along with the immense advantage of being completely uninflammable. Helium is now assiduously collected from its natural sources for this practical purpose. From the point of view of theory it is also particularly interesting. As an agent for producing the extremest degree of cold it has been used by Onnes, who, by vaporising liquefied helium, has reached a temperature only about two degrees short of absolute zero. One may remark in passing that the absolute zero of temperature is almost the only absolute thing that is left to us in a universe given over to relativity.

Rutherford has put helium to another scientific use. He employs the alpha particle, which is the nucleus of helium, projected from a heavy radioactive substance with a velocity of ten or twelve thousand miles per second, as a projectile with which to knock chips off the nuclei of nitrogen and certain other elements. In this way he produces hydrogen, for the chips which are knocked off are single protons, each of which forms the nucleus of a hydrogen atom. Thus in the hands of Rutherford the alpha particle is a veritable philosopher's stone by which the transmutation of elements, so long the dream of the alchemist, has become an accomplished fact. Quite lately we were told of laboratory experiments in which gold was reported to have been made by the removal of part of the nucleus of the element next above it in the list, namely mercury. The news was received with perfect calm by the scientific world, and even, I fancy, by the Governor of the Bank of England. For if you want gold it will doubtless be cheaper to find it by digging than to make it in that way.

There have been so many surprises in physics that the faculty of wonder is almost exhausted. Things have happened which a little while ago would have seemed to be miracles. We may think of Kelvin or of Tait as turning in his grave when an occupant of this chair speaks of there being no strict conservation either of matter or of energy, and accepts the possibility of transforming the one into the other. The foundations of the older physics have been rudely shaken, and the effect of such upheavals has been to alter the temper of the scientific mind. The old positiveness has gone. No longer are we positive about anything. The complacency, the facile dogmatism, which here and there showed itself in the last century, is now a rather absurd memory.

We are confronted by dilemmas and find no way out. We are obliged, one may say, to take the dilemma by the horns, boldly grasping both. The electromagnetic theory of light, established as we believed by Maxwell, is confronted with the view that there is no ether, nothing which will serve, in the words of the late Lord Salisbury, as a nominative to the verb to undulate; and, worse still, while the wave theory is amply supported by the facts of interference and diffraction, it is apparently inconsistent with the equally well-established facts of absorption and photo-electricity. How to reconcile these seeming contradictions we simply do not know. So while we may justly feel pride in all this progress and achievement, it is mingled with a consciousness of mystery, with a spirit of question. In a special sense is it true to-day that the widening of the circle of light has widened the circumference of darkness, and for the moment at least the darkness seems strangely impenetrable.

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## The Science and Art of Map-making.[1]

By A. R. HINKS, C.B.E., F.R.S.

THE progress of invention has placed in the hands of surveyors a number of beautiful new methods, and some we have not yet scientifically explored. Would you measure a base? So far from painfully seeking a dead-level plain and clearing it of every petty obstruction, you will gaily take the suspended invar tapes across country, and by preference run them up a hill at each end to get a better view for the base extension. Would you equip a party for primary triangulation? Look thankfully at Ramsden's 36-inch theodolite reposing in the museum of the Ordnance Survey; look doubtfully at the fashionable 10-inch: and before you take it any more into the field, examine whether the instrument of the future is not a 5-inch

[1] From the presidential address delivered at Southampton on August 27 before Section E (Geography) of the British Association.