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"*To the solid ground*
Of Nature trusts the mind which builds for aye."—WORDSWORTH.

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SCIENTIFIC WORTHIES.

XXXVI.—SIR WILLIAM CROOKES, F.R.S.

SIR WILLIAM CROOKES has the rare privilege of looking back upon a scientific activity extending already over more than fifty-five years. By numerous papers and by several volumes the results of his experimental researches in different departments of physics and chemistry have been spread all over the world. Though born in 1832, even his advanced age has not diminished his scientific productiveness.

All Sir William Crookes's researches, with the exception of the first, were made in his private laboratory in Kensington Park Gardens. Although the motion of the walls of this laboratory, as seen under the high magnifying power of the horizontal pendulum, gave rise, at first sight, to doubts as to the solidity of its construction (Philosophical Transactions, 1876, Crookes, "On Repulsion, &c.," § 134), it has stood the test of time. The perennial stability, however, of many of the stones joined by Crookes to the edifice of science never was questionable. Most of those who have risen to eminence in physics have done so by giving their exclusive attention to that science, and it is only rarely that the physicist can do pioneer work also in chemistry. Rarer still is the case of Sir William Crookes, whose series of physical papers is frequently interrupted by communications concerning his chemical discoveries.

In the *Philosophical Magazine* of April, 1861, Crookes tells us:

> "In the year 1850, Prof. Hofmann placed at my disposal upwards of 10 lb. of the seleniferous deposit from the sulphuric acid manufactory at Tilkerode, in the Hartz Mountains, for the purpose of extracting from it the selenium, which was afterwards employed in an investigation of the selenocyanides."

In the examination, by the spectroscope, of the residue left in the purification of the crude selenium, Crookes's attention was attracted by a bright green line, which he had never met with before. In following up its appearance, he succeeded in isolating a new metal, which he called thallium, after the emerald green line which has become now as familiar to chemists, even if not brought up in a spectroscopic atmosphere, as the lines of sodium and lithium; and the physicist again and again enjoys the homogeneity of thallium light when observing interference for large differences of path, either with his Rowland or his Michelson grating, or with his Fabry and Perot apparatus, or with his Lummer and Gehrcke plate.

The year 1861 brought the first great triumph to Crookes. During the next twelve years he carried out minute investigations of the many properties of the new element, culminating in his determination of its atomic weight—203·642, or when reduced with the now accepted values for the atomic weights of oxygen and nitrogen, 204·04. Extreme care was given to the necessary weighings, and the pains taken to start with pure substances were enormous. The international committee for the atomic weights and other authorities regard Crookes's determination of the atomic weight of thallium as the best we possess, though thirty-four years have elapsed since the date of its publication.

Crookes finished his determination not without tribulation, having been troubled with discouraging irregularities in his weighings. In order to improve his results, the weighings were made in a partial vacuum, but even under these conditions the balance behaved most capriciously. Sometimes the substance appeared to be heavier when cold than when in a heated condition; sometimes the action was opposite. Working further with indefatigable ardour he came to what he then called "repulsion resulting from radiation," and going on he invented in 1875 an apparatus in illustration of the thoroughly novel and striking phenomena he had observed, the radiometer. His researches in this new field, contained in 485 paragraphs, and published in the Philosophical Transactions of 1874, 1875, 1876, 1878, 1879, represent an immense amount

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of experimental work of the greatest interest and ingenuity.

Under the influence of the dynamical theory of gases the general nature of the perplexing phenomena was recognised and referred to the intervention of the residual gas. The genius of Schuster, Osborne Reynolds, Tait, Dewar, and Maxwell was associated with this explanation, but special mention should here be made of the more personal, yet beautiful and ennobling example of scientific cooperation given by Sir William Crookes and Sir George Stokes, the documents relating to which have just been published. The new and fascinating chapter in the dynamical theory of gases, relating to the stresses in rarefied gases arising from inequalities in temperature, which thus sprang up in connection with Crookes's experimental work, is, notwithstanding the 110 references to the literature of the radiometer in a modern German text-book, still unfinished. We may be sure that quantitative experiments concerning the radiometer actions under entirely new conditions will again prove the importance of the chapter, emblazoned on its cover by Crookes's light-mill.

Crookes thus was brought into touch with the dynamical theory of gases and with experimental work in high vacua, and so came to his experiments concerning the electric discharge in gases. In this province we are indebted to him for some very striking discoveries relating to the now well-known kathode rays, then already associated with the names of Plücker (1859), Hittorf (1869), and Goldstein (1876). His brilliant experiments ("The Trajectory of Molecules," "Molecular Physics in High Vacua," "Phosphorogenic Properties of Molecular Discharge") were published in the Philosophical Transactions for 1879, but became generally known to the world—not to the scientific world alone—by his lecture on "Radiant Matter," delivered on Friday, August 22, 1879, at Sheffield, to the British Association for the Advancement of Science. Even now the reading of this lecture, though the facts in it have become familiar, brings one under its irresistible charm, and Lenard and Tesla, describing in eloquent terms the impression made by it on their young minds, certainly give utterance to a prevalent opinion. In the beautiful volumes on "Ions, Electrons, Corpuscules," for which physicists are indebted to the Société française de Physique, only one lecture has been inserted, that of Sir William.

There exists perhaps only one lecture given on a similar occasion which has become as popular and made on the hearers as deep an impression, both by its contents and its accomplished form; I mean the lecture delivered before the Association of German Naturalists at Stuttgart in 1889 by Hertz, in which his great discoveries were expounded.

All the wonderful and important properties of the constituents of the kathode rays or of radiant matter: its darting in a straight line from the negative pole, the position of the positive electrode being unimportant; its casting of a shadow when intercepted by solid matter; the strong mechanical action radiant matter seems to exert where it strikes; the change of direction by a neighbouring magnet; the heat produced when its motion is arrested; the remarkable power which the molecular rays possess of causing phosphorescence in preparations of calcium sulphide shining with blue-violet, yellow, orange or green light, in diamonds shining with nearly all colours of the rainbow, in rubies glowing with a rich full red; all these results Crookes tried to explain by the hypothesis that the kathode rays, or streams of radiant matter, or of matter in an ultra-gaseous state are particles or molecules negatively charged and projected with great velocity from the negative electrode. The inherent truth of Sir William Crookes's hypothesis concerning the nature of the kathode rays is, after much controversy for a space of nearly twenty years, now established, and the original hypothesis, with finer contents, is now accepted by all physicists.

In Crookes's experiments for the first time the majestic simplicity of the kathode rays became clearly apparent. In the irritating complexity of the other phenomena of the vacuum tube, appearances of great purity had been isolated, so that Crookes could risk the opinion "that we are here brought face to face with Matter in a Fourth state or condition," neither solid, liquid, nor gaseous.

Crookes alone among his contemporaries recognised the essential importance of the kathode rays, and with almost prophetic insight foresaw the part radiant matter would have to play in the development of physical science. In the splendid evolution of electronic theory we are now witnessing, we see how true Crookes's foreshadowing of the *rôle* of radiant matter was.

"In studying this Fourth state of Matter, we seem at length to have within our grasp and obedient to our control the little indivisible particles which, with good warrant, are supposed to constitute the physical basis of the universe. We have seen that in some of its properties Radiant Matter is as material as this table, whilst in other properties it almost assumes the character of Radiant Energy. We have actually touched the border land where Matter and Force seem to merge into one another, the shadowy realm between Known and Unknown, which for me has always had peculiar temptations. I venture to think that the greatest scientific problems of the future will find their solution in this Border Land, and even beyond; here, it seems to me, lie Ultimate realities, subtle, far-reaching, wonderful.

"Yet all these were, when no Man did them know,
 Yet have from wisest Ages hidden beene;
And later Times thinges more unknowne shall show.
 Why then should witlesse Man so much misweene,
That nothing is, but that which he hath seene?"

All the experiments in this lecture now have become classical, and several of them are repeated every year in every university of the world. The most familiar and representative of the group is perhaps that one with the Maltese cross in the pear-shaped Crookes's tube, in which the black shadow of the cross is projected on the hemispherical phosphorescent end

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of the tube, in such a manner that a permanent impression on the memory of the student is made.

As an outcome of work recorded in Crookes's various preceding papers, "On Repulsion resulting from Radiation," &c., and, therefore, with paragraphs numbered in continuation of his "Phosphorogenic Properties of Molecular Discharge," Crookes in 1881 published a research on "The Viscosity of Gases at High Exhaustion." Maxwell's great theoretical discovery that the viscosity of a gas is independent of the density, one of the most beautiful proofs for the reality of molecular motion, had already been the starting-point of experiments by Maxwell himself, Kundt and Warburg, using the method of rotating discs.

In Crookes's experiments the method of observation consisted in noticing the subsidence of the vibrations of a delicately suspended lamina oscillating within a bulb containing the gas. By these simple yet adequate means, very careful measurements were made, and the falling off of the viscosity of different gases from atmospheric pressure to very high exhaustions downwards observed, especial attention being paid to the highest vacua and definite measurements made of the degree of exhaustion employed. At these high exhaustions Maxwell's law completely breaks down, as Maxwell himself foresaw. His observations were discussed in a splendid "note" by Sir George Stokes, another example of the cooperation between these physicists.

Crookes's apparatus afforded at the same time many other data and measurements. The apparent attraction by heat was only found in air of greater than one-thousandth part of ordinary density; while there is repulsion when the density is further increased, the repulsion increasing to a maximum, and thence fading away towards zero as the rarefaction is continued.

In 1881 Crookes's paper on radiant matter spectroscopy appeared. An entirely new method of spectrum analysis is given, based on the well-known fact that under the influence of the kathode rays a large number of substances emit phosphorescent light, some faintly and others with great intensity. Most bodies give a faint continuous spectrum, but more rarely the spectrum of the phosphorescent light is discontinuous, and to bodies manifesting it his attention has been specially directed. This characteristic spectrum is given by the group of elements known as the rare earths, especially yttria in some of its compounds; and in the study of this group the method is of very great importance, and has given, in the hands of Sir William Crookes, at an immense amount of trouble and time, very valuable results. To give, however, an adequate survey of these investigations would demand much space, and uncommon chemical knowledge of the rare earths. We mention only that not long ago Crookes isolated from yttria a new earth, characterised by an isolated strong group of lines high up in the ultra-violet, ascribed by Sir William to a new element named by him victorium.

In connection with his work on the photographed spectra of the elements, of which it seems only a small portion has been published, we record one of his smaller papers, relating to "the slit of a spectroscope," that narrow, but extremely important, gate to a large domain. Crookes makes the very ingenious suggestion to use quartz jaws, cut in the same manner as metal ones. The prismatic edges refracting away all the light which falls on them, their transparency offers no objection, while only the light passing between the jaws comes into operation. As the quartz jaws can be worked to a finer edge, they give better definition.

"With a pair of jaws in the spectroscope at present in use, I can take excellent photographs when they are only 0·0001 inch apart. For eye observation the width can easily be less than that."

Another small paper of date 1879 is also characteristic of Crookes's experimental skill, and illustrates at the same time, if I may say so, the purity of his work. The exceedingly small rate of leak of electricity in a high vacuum is illustrated by Crookes's observation that a pair of gold leaves in a vacuum bulb retains an electrical charge for months.

Of Crookes's recent work, we mention his experimental work on radium. In 1900 Crookes first effected the separation from uranium by two distinct chemical methods of the one direct transformation product, called uranium X. He discovered in 1903 that the alpha rays from radium produce, probably by their bombardment, phosphorescence on a target of crystalline zinc sulphide. This wonderful phenomenon, perhaps the most direct proof of the discontinuous structure of matter, was popularised in his spintharoscope.

These examples must suffice to impart an idea of Crookes's work. "The best history," it has been verily said, "is but like the art of Rembrandt; it casts a vivid light on certain selected causes, on those which were best and greatest; it leaves all the rest in shadow and unseen." What is true in the science of history cannot become untrue in the history of science. It would be desirable to follow a similar precept in trying to picture before our mind the origin of the gratitude and admiration physicists feel for a philosopher, who by his experimental skill, his acute observation, and the continuity of his endeavours, combined with his daring intuition, has impressed indelible marks in different branches of physics and chemistry. This involves, however, more than we can attempt here.

Sir William Crookes is a member or corresponding member of a number of scientific societies in his own country and abroad. At one time or another he has occupied the presidential chair of many of the leading learned and scientific societies of Great Britain. The Royal Society awarded him a Royal Medal in 1875, the Davy Medal in 1888, the Copley Medal in 1904; the French Académie des Sciences, a gold medal and a prize in 1880; the Society of Arts, the Albert Medal in 1899; and he was knighted by the late Queen Victoria in 1897.

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