honour by which he was guided in all the relations of life. A most charming and genial companion, an affectionate and constant friend, he delighted those who enjoyed the privilege of his society and his generous hospitality by his musical accomplishments, which were of a very high order.

G. J.

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Gustav Robert Kirchhoff was born on March 12, 1824, at Königsberg. He began his studies in his native town under the direction of F. E. Neumann, and no one who has studied the writings of both these eminent men can fail to notice the great influence which Neumann's teaching must have had in forming the character of Kirchhoff's scientific ideas.

In 1850 Kirchhoff went as Professor Extraordinarius to Breslau, and in 1854 as Professor of Physics to Heidelberg, where he stayed till 1875. In that year he accepted a chair of Physics in Berlin. Gradually failing in health he had to give up his lectures, and died on October 17, 1887.

His writings, the first of which he published at the age of twenty-one, cover nearly the whole range of physics, and there is hardly one of them which has not marked a decided progress in the subject to which it refers.

His first paper (1845), treating of plane current sheets, was the first of a series in which he deduced and applied the now well-known equations for the distribution of electric currents in conductors which are not linear. In 1849 an important communication appeared in Poggendorff's 'Annalen,' in which, for the first time, the resistance of a wire was measured in what is now known as electromagnetic measure. A paper of considerable interest, "Ueber die Bewegung der Elektricität in Leitern," appeared in the year 1857. The propagation of electric effects in wires is discussed in this paper, the principal result being: "that the rate of propagation of electric waves is found to be $c/\sqrt{2}$—that is, independent of the cross section, the coefficient of conductivity of the wire, and the electric density; the rate is 41,950 (German) miles per second, or very nearly the same as that of the propagation of light." In view of the important conclusions to which modern researches in electricity have led, considerable historical interest will always attach to the above statement. The remaining electrical papers treat of the oscillating discharge of the Leyden jar, the distribution of electricity on two conducting spheres, and of the capacity of a condenser formed of two parallel circular plates.

We have next two papers on Magnetism; one (1853) treats of the magnetism induced in an infinitely long cylinder, and the other solves the problem of the magnetisation of an iron ring under the influence

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of electric currents. A suggestion made in the latter paper to use closed rings of iron for the determination of the coefficient of induction has led, at the hands of Stoletow and Rowland, to important practical results.

Kirchhoff's name is most generally known in connexion with his researches on the relation between the absorptive and the emissive properties of bodies. The explanation of the Fraunhofer lines which are derived from these researches, and the work done jointly with Bunsen on the discontinuous spectra of gaseous bodies, gave such an impulse to the study of radiation that a whole science—that of spectrum analysis—developed as a historical sequence to Kirchhoff's work. It is a curious instance of an abstruse calculation giving rise to extended experimental investigations which have in reality very little connexion with it; for it is only a small fraction of spectrum analysis in which the connexion between radiation and absorption is made use of at all. There is really no *à priori* reason why we could not have known as much as we do now of the spectra of different bodies without being acquainted with the important law proved by Kirchhoff.

A discussion has arisen as to how far Kirchhoff's work was anticipated by that of Balfour Stewart. The latter had experimented on the radiation and absorption of heat, and had drawn some important conclusions from his experiments. Stewart's work is conclusive in showing that if we assume the ratio of the emissive to the absorptive power to be the same for all bodies and only a function of the temperature and wave-length, all facts can be satisfactorily accounted for. Kirchhoff, without being acquainted with Stewart's researches, went further, and proved that the law just stated is the only one consistent with thermodynamical equilibrium. Kirchhoff's paper has been objected to as being too elaborate in the method of its proof, but no simpler proof has ever been given, and it would be difficult to lay a finger on a single sentence of this classical paper which could be removed or shortened without detriment to the logical sequence of the argument.

In connexion with these theoretical researches and in order to trace the existence of terrestrial elements in the sun, Kirchhoff prepared a drawing of the solar spectrum. Unfortunately an arbitrary scale was used, and the prisms were occasionally shifted, so that the map was soon superseded by Ångström's, in which the lines were directly referred to wave-lengths. It seems of interest, however, to point out as a proof of the acuteness of Kirchhoff's observing power and the perfection of the optical adjustments, that the amount of detail given in his map is exactly that given by calculation as possible with the resolving power which he used. No work could be more trying than that of drawing a map of the solar spectrum reaching the limits of the instrumental powers; Kirchhoff's eyes suffered in consequence, and he had to leave the completion of the map to K. Hofmann.

Soon after the mathematical development by Clausius and Sir William Thomson of the mechanical theory of heat, Kirchhoff was the first to carry the application of that fruitful theory into the domain of Chemical Physics. The thermal phenomena connected with the absorption of gases and the dissolution of salts in liquids as well as their relationship with the vapour-pressures of the solvent, were treated in two papers of great interest and importance.

A few words must be said on Kirchhoff's papers on elasticity.

There are few problems which have occupied so many eminent mathematicians, and our author's investigations contributed very materially to the progress of that important branch of theoretical physics. Before Kirchhoff's time Sophia Germain had made an attempt which was only partially successful to establish the equations which regulate the vibrations of thin plates. Poisson had gone a good deal further, especially as regards the treatment of rectangular plates. Kirchhoff points out that Poisson's boundary conditions cannot in general be satisfied, and deduces from the general theory of elasticity a solution which can be applied to circular plates. With the help of measurements made by M. Strehlke, the theoretical results were checked and verified by experiment. In some later papers the elastic deformations of rods were treated in a more general way than had previously been done, and especially in 1879 the solution of the problem was extended to prismatic and conical rods.

The science of hydrodynamics also is indebted to Kirchhoff for several beautiful investigations, amongst which special attention may be drawn to the paper "Zur Theorie freier Flüssigkeitsstrahlen," and to one in which it is shown that two rigid rings in a fluid moving irrotationally exert apparent forces on each other which are identical with those which the rings would show if electric currents were to circulate round them.

Kirchhoff's papers have been collected into a volume of moderate size. He has also published a series of lectures on mechanics, in which we are especially struck with the precision with which the subject is treated, and with the way all metaphysical difficulties in the first definitions are avoided. "For this reason," he says in the introduction, "I take it to be the object of mechanics to *describe* the phenomena of nature, to describe them completely and in the simplest manner. I mean that it will be our task to state what the phenomena are, but not to find out the *causes*." None of those who have attended Kirchhoff's lectures on mathematical physics are ever likely to forget them. Each lecture was complete in itself, and the student felt on leaving the room that he had learnt

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something which it would be difficult or impossible for him to find in the published books. He was in consequence a popular and successful teacher, and nearly all the younger German physicists are his pupils.

In Kirchhoff science has lost a man who combined, to an exceptional degree, mathematical talent with observational skill and experimental knowledge.

A. S.

Dr. Balfour Stewart was born in Edinburgh on November 1st, 1828, and died in Ireland on December 18th, 1887, having just entered his sixtieth year. He was educated for a mercantile profession, and in fact spent some time in Leith, and afterwards in Australia, as a man of business. But the bent of his mind towards physical science was so strong that he resumed his studies in Edinburgh University, and soon became assistant to Professor J. D. Forbes, of whose class he had been a distinguished member. This association with one of the ablest experimenters of the day seems to have had much influence on his career; for Forbes's researches (other than his Glacier work) were mainly in the department of Heat, Meteorology, and Terrestrial Magnetism, and it was to these subjects that Stewart devoted the greater part of his life. In the classes of Professor Kelland, Stewart had a brilliant career; and gave evidence that he might have become a mathematician, had he not confined himself almost exclusively to experimental science.

In 1858, while he was still with Forbes, Stewart completed the first set of his investigations on Radiant Heat, and arrived at a remarkable extension of Prévost's "Law of Exchanges." His paper (which was published in the 'Transactions of the Royal Society of Edinburgh') contained the greatest step which had been taken in the subject since the early days of Melloni and Forbes. The fact that radiation is not a mere surface phenomenon, but takes place like absorption throughout the interior of bodies, was seen to be an immediate consequence of the new mode in which Stewart viewed the subject. Stewart's reasoning is, throughout, of an extremely simple character, and is based entirely upon the assumption (taken as an experimentally ascertained fact) that in an enclosure, impervious to heat and containing no source of heat, not only will the contents acquire the same temperature, but the radiation at all points and in all directions will ultimately become the same, in character and in intensity alike. It follows that the radiation is, throughout, that of a black body at the temperature of the enclosure. From this, by the simplest reasoning, it follows that the radiating and absorbing powers of any substance must be exactly proportional to one another (equal, in fact, if measured in proper units), not merely for the radiation as

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