Franz Ernst Neumann was born on September 11, 1798, at Joachimsthal, a small town about forty miles to the north-east of Berlin. At the early age of seventeen he entered the army as a volunteer to fight against Napoleon in the campaign of 1815. A serious wound, received in the battle of Ligny, kept him to his bed for many weeks; but, on recovery, he once more joined the army. At the end of the war he returned to his lessons at the "Gymnasium" of Berlin, and subsequently entered the University as a student of theology. Soon afterwards he migrated to Jena, where he came under the influence of C. S. Weiss, the Professor of Mineralogy, and turned his attention to that subject. His papers, published between 1823 and 1830, all referred to crystallography, and even his earliest work attracted attention, and left a lasting impression on the science of mineralogy. It secured him a call to the University of Königsberg as "Privat-docent," where Bessel, Jacobi, and Dove became his colleagues. Under their influence he gradually drifted more and more towards the study of physics. His knowledge of mathematics was acquired by private study, for although the University of Berlin nominally possessed a teacher of mathematics, no lectures were given. If the circumstances of Neumann's early education are considered, it is remarkable that he obtained such a command of mathematical physics, and this seems to have been ascribed by himself to the careful study of Fourier's writings, which he admired to such an extent that he made a manuscript copy of the great treatise on the 'Conduction of Heat.' In the year 1828 Neumann was appointed Professor Extraordinarius at a salary of 200 thalers (£30). Bessel, who had formed a high opinion of his powers, wrote in the same year a letter to the Minister of Education pressing Neumann's claim to a better position. The letter had the desired effect, and Neumann was nominated, in 1829, Professor Ordinarius, and his salary raised to £75. He never left Königsberg, continuing his professorial duties until 1876, and died on May 23, 1895.

Among his earlier papers on physical subjects, attention must be drawn to one on the specific heat of minerals (*Pogg. Ann.*, 1831). It contains an extension of Dulong and Petit's law of specific heats to compound bodies having a similar chemical constitution, but is chiefly valuable for the improvement, both in the methods employed and in the theoretical discussion of the experimental results. It is shown how the method of mixture may be applied to the case of badly conducting substances. The second paper treats of the specific heat of water. The older observers had stated that when hot water is poured into cold water, the resulting temperature of the mixture is lower than that calculated, on the assumption that the specific heat of water is constant. Neumann showed that this result is due to errors of experimentation, and demonstrated with

improved apparatus, that the specific heat of water increases with rising temperature. On the assumption that the rate of change is uniform, Neumann calculated the ratio of the specific heats at 100° and 0° to be 1·0176. The assumption made is now known to be incorrect, but it cannot be said that Neumann's experimental result has been much improved upon by later investigators. Although nearly all fields of physical science have at different times been successfully treated by Neumann, his fame chiefly rests on his theoretical investigations in optics and electricity. After Fresnel's fundamental researches, which had shown the possibility of explaining the most complicated optical phenomena by the undulatory theory, it became necessary to connect that theory more closely with the conditions of wave-propagation in ordinary elastic bodies. In other words, an elastic solid theory of the ether formed the next step to be taken, and the name of Neumann will always remain associated together with that of Cauchy, McCullagh, and Green in the early efforts to found a truly dynamical theory of light. In the first paper, "Theorie der doppelten Strahlenbrechung abgeleitet aus den Gleichungen der Mechanik," Neumann obtains a wave-surface identical with that deduced somewhat earlier by Cauchy. In the case of biaxal crystals it does not agree with that of Fresnel. It consists of three sheets, one of them being due to the longitudinal wave. The difference of the two other sheets with Fresnel's surface is, however, more nominal than real, for as Stokes pointed out, in his Report on Double Refraction, the difference may, by proper adjustment of the constants, be made to show itself only in the tenth place of decimals. The same report gives full details on the comparison between the theories of Cauchy, Neumann and Green. A further important contribution to optics was made in the year 1835 under the title "Theoretische Untersuchungen der Gesetze, nach welchen das Licht an der Grenze zweier vollkommen durchsichtigen Medien reflectirt und gebrochen wird." This paper raises the difficult question of the mathematical expression for the conditions which must hold at the surface separating two crystalline media. For well considered reasons Neumann adopts the view that the density of the ether is the same in all media, and follows out this hypothesis to its logical consequences. The same problem was treated at the same time by McCullagh by very different and simpler methods, but the results of both investigators were identical. Neumann further confirmed his equations by experiment. The general acceptance of the electromagnetic theory has now considerably changed our point of view, but the historical importance of Neumann's work must be conceded in spite of certain defects which may, with justice, be urged against it.

Several further papers treated of optical subjects, amongst which,

perhaps, the most important refers to double refraction in strained uncrystalline bodies.

Neumann* next turned his attention to electricity, and in two important papers, published in 1845 and 1847, established the laws of induction of electrical currents. We meet here, for the first time, with the "electrodynamic potential." It is shown how currents, induced in one circuit either by the motion of conductors carrying electric currents, or by a change in the intensity of the current, may be deduced from one function depending on the relative position of the conductors, and that this function will also determine the mechanical forces acting between the conductors. To appreciate fully the great advance which was made by these two memoirs, it is necessary to realise that the papers were published before it had been shown, by Helmholtz and Lord Kelvin, how the principle of the conservation of energy may be utilised in the treatment of the problem. It may also be pointed out that Neumann's investigations are deduced from Lenz' laws, which are direct consequences of the principle of energy; so that Neumann's treatment may, indirectly, be said to depend on that principle.

Neumann was the first to solve the problem of the magnetisation induced in an ellipsoid of revolution under the action of any magnetic forces. Other important contributions relate to the functions known as spherical harmonics. It is a matter for regret that his first paper on that subject ('Astronomische Nachrichten,' 1838) was completely overlooked by magneticians until Ad. Schmidt recently drew attention to it. The method which might with great advantage have been employed in the treatment of terrestrial magnetism, may be explained by reference to the simpler problem of expanding a function of one variable by means of Fourier's series. For instance, if the daily changes of temperature are to be expressed in such a series from hourly readings of the thermometers, a very simple and well-known process leads to the determination of the constants. Neumann's investigations led him to an analogous process for the expansion of a function in a series of spherical harmonics, the functions having known values at the points of intersection of certain latitude and longitude circles on a sphere.†

Neumann's last publication was a memoir (edited by his son, C. Neumann), 'Beiträge zur Theorie der Kugelfunctionen,' which contains many interesting theoretical researches on that subject.

* Neumann's initials are often incorrectly given; thus, in the text of Maxwell's 'Electricity and Magnetism' (second edition) he is uniformly quoted as J. Neumann.

† In both the problems mentioned the values of the constants are really indeterminate, but the solution gives, under certain assumptions, their most probable values. Care should be taken that in any actual problem the assumptions are really justified.

Neumann's publications are not sufficient to give an adequate idea of his life's work. As a teacher he exerted a wide-spread influence, and the progress of physical science in Germany is largely indebted to the stimulating influence which he exercised, especially with the help of the 'Mathematisch-Physikalisches Seminar,' founded by him in conjunction with Jacobi and Sohnke. The object of this institution was to supplement the teaching given in lectures, and to introduce students into the methods of original research. Exercises were set to the students by the directors of the seminar, and, as Neumann himself explained, "In the choice of problems I laid stress on their referring to points of practical importance, such as the application of Gauss' theory of principal points and planes in a system of lenses; or that the selected exercise should lead students to an experimental investigation of a problem which they had treated in a theoretical manner."

There was never, probably, a school of original research conducted in so systematic a manner as this seminar, in which Neumann was the leading spirit. Annual reports of the work done by each student were sent in to the Prussian Minister of Education, and, occasionally, money prizes were given for a research of special merit. An interesting account of the history of this seminar is contained in a notice of Neumann's life by P. Volkmann.* Its importance may be recognised by the fact that Kirchhoff's first papers on the distribution of electric conductors, and H. Wild's construction of his photometer and polarimeter, figure amongst the direct results of the teaching given in the seminar. Kirchhoff's great powers were soon recognised by Neumann, and when, in the year 1846, Neumann had set as a special prize problem "The determination of the constants on which the intensity of induced currents depends," the prize was awarded to him for a research which contained the first measurement of a resistance in electro-magnetic measure. Neumann's success as a teacher will be appreciated by reference, in Volkmann's publication, to the doctor dissertations of his pupils, which were carried out under his guidance. Amongst the students who flocked to hear his lectures at Königsberg, we find Borchardt, Durège, Lipschitz, Kirchhoff, Wild, C. Neumann, Clebsch, Auwers, Quincke, and Voigt.

Neumann was elected a Foreign Member of the Royal Society in 1862, a Corresponding Member of the French Academy in 1863, and received the Copley Medal in the year 1887.

(?) awarded 1886

A. S.

* Leipzig (G. Teubner), 1896. I owe to this publication and to Mr. Voigt's notice in 'Göttingen, Nachrichten,' 1895, p. 248, nearly all the information given in the above obituary notice.