M. N. Saha

MEGHNAD SAHA*

1893-1956

Foundation Fellow 1935

THE name of PROFESSOR MEGHNAD SAHA would always remain associated with the theory of thermal ionization and its application to the interpretation of stellar spectra in terms of the physical conditions prevailing in the stellar atmospheres. The theory had all the simplicity and inevitableness which usually characterize a fundamental and epochal contribution. It was almost a direct consequence of the recognition that the laws of thermodynamics and the kinetic theory of gases can be extended to a gas of free electrons. Apart from astrophysics, the theory later found numerous other important applications, such as, to mention some of them, in the study of the ionosphere, conductivity of flames, electric arcs and explosion phenomena. Saha's researches in astrophysics and physics extended over a wide range of subjects. At one time or the other he worked on stellar spectra, thermal ionization, selective radiation pressure, spectroscopy, molecular dissociation, propagation of radio waves in the ionosphere, solar corona, radio emission from the sun, beta radioactivity, and the age of the rocks. Besides physics he took a keen interest, at times almost bordering on the professional, in ancient history and archaeology. He was a devoted and inspiring teacher, and he gave his time generously to his students. He organized active schools of research at Allahabad and Calcutta; and in establishing the Institute of Nuclear Physics at Calcutta, in building the laboratories of the Indian Association for the Cultivation of Science, and in founding academies of sciences in India, his role throughout was of the utmost importance. He, more than anyone else, was responsible in starting the monthly journal *Science and Culture*, and he was its editor for many years. He was from the beginning a member of the Council of Scientific and Industrial Research constituted by the Indian Government in 1942, and member (or chairman) of several of the research and other committees of the Council. He was the Chairman of the Council's Indian Calendar Reform Committee. He was an elected independent member of the Indian Parliament. He took the keenest interest in problems of national planning, particularly in relation to science and industry. He was an active member of the National Planning Committee appointed by the Indian National Congress in 1938 with Jawaharlal Nehru as chairman. In his criticism of things and men, Saha was fearless and trenchant, and he was motivated by a deep earnestness and sincerely, though often tenaciously,

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held convictions. His memory and versatility were amazing. He was extremely simple, almost austere, in his habits and personal needs. Outwardly, he sometimes gave the impression of being remote, matter of fact, and even harsh, but once the outer shell was broken, one invariably found in him a person of extreme warmth, deep humanity, sympathy and understanding; and though almost altogether unmindful of his own personal comforts, he was extremely solicitous in the case of others. It was not in his nature to placate others. He was a man of undaunted spirit, resolute determination, untiring energy and dedication. On 16 February 1956, on his way to the Office of the Planning Commission in New Delhi, he succumbed to a sudden heart-attack (some hundred yards from the Office of the Commission) and at the age of sixty-two, a career superb in science and great in its promotion and dissemination was tragically closed.

Meghnad Saha was born on 6 October 1893, in the village of Seoratali in the district of Dacca, now in East Pakistan. He was the fifth child of his parents, Jagannath Saha and Smt. Bhubaneswari Devi, who had five sons and three daughters. The family depended for its livelihood on the very meagre income from a petty shopkeeing business, and Saha's early education was beset with many hardships. In the village at that time there was no high school. Even the nearest middle school teaching English was in another village seven miles away, and Saha was able to join it due to the generosity of a local medical practitioner, Ananta Kumar Das, who agreed to provide him with free board and lodging in his house. In 1905 Saha joined the Government Collegiate School in Dacca after securing a Government scholarship for standing first, at the middle school examination, in the Dacca district. This was the year of great political unrest in Bengal caused by the partition of the province against popular opinion, and the school also was not without its share of trouble. The young Saha was drawn into a boycott of the visit of the Bengal Governor to his school, and as a sequel he forfeited the scholarship, and had to leave the Government School with many others. He now joined a private school—the Kishori Lal Jubilee School—and passed the Entrance Examination of the Calcutta University in 1909, standing first amongst the East Bengal candidates. He was a precocious student, and he was equally good in mathematics and the languages. He stood first in the all-Bengal competition examination in the Bible, open to school and college students, conducted by the Baptist Mission. In 1911 Saha passed from the Dacca College, Dacca, the Intermediate Science Examination of Calcutta University. He was first in mathematics and chemistry, but third in order of merit in the whole examination. One of his subjects at the examination was the German language which he studied privately—the college had no arrangement for its teaching.

Saha now entered the Presidency College, Calcutta. Here he had amongst his contemporaries many who are familiar names in Indian Science, such as S. N. Bose (the author of the quantum statistics that goes by his name), N. R. Sen, J. N. Mukherjee and the late J. C. Ghosh. P. C. Mahalanobis, the distinguished statistician and planning expert, was his senior by a year; N. R. Dhar was senior by two years. Amongst his teachers Saha had Acharya P. C. Ray in chemistry, Jagadish Chandra Bose in physics, and D. N. Mallik and C. E. Cullis in mathematics. Both in the B. Sc. Examination (1913) with Honours in Mathematics and the M. Sc. (Applied Mathematics) Examination (1915), Saha had the second place, the first position going to S. N. Bose. He intended at one time to take the competitive examination for the Indian Finance Service, but was not granted permission by the Government. He resolved to devote himself to study and research in applied mathematics and physics. To support himself and his younger brother staying with him, he for a few months took two private tuitions of which at one time he was doing as many as three in different parts of Calcutta, covering the long distances on a bicycle. In 1916 the Calcutta University under the dynamic leadership of its Vice-Chancellor Asutosh Mukherjee, a Judge of the High Court, opened a new University College of Science for post-graduate studies and research—this was made possible because of the magnificent donations of two eminent lawyers of Calcutta, Tarak Nath Palit and Rash Behari Ghosh. Saha and S. N. Bose were appointed lecturers in the Department of Mathematics with Dr. Ganesh Prasad as Professor. He, however, found it irksome to get on with the Professor of Mathematics, and in 1917 he (with S. N. Bose) was transferred to the Department of Physics. About a year later C. V. Raman joined the Department as Palit Professor of Physics.

Saha's early lectures to the post-graduate classes covered diverse subjects such as hydrostatics, the figure of the Earth, spectroscopy, and thermodynamics; and he was in charge of the Heat Laboratory. Many of the subjects were new to him—he had taken physics in the undergraduate classes only—but this only served to stimulate his dauntless spirit all the more, and he studied the new subjects, specially thermodynamics and spectroscopy, with great avidity and zest. It was fortunate, as he often recalled in later life, that about a year earlier he had come across Miss Agnes Clarke's two popular books on the Sun and the stars. These books fascinated him greatly and gave him some idea of the main problems in astrophysics. He now read, amongst other books, Planck's *Thermodynamics* and Nernst's *Das Neue Warmesatz*, and he was familiar with the papers of Bohr and also Sommerfeld on the quantum theory of the atom. All this in a sense paved the way for his epochal work on the thermal ionization of elements. More will be said about this presently.

Shortly after the end of the First World War there was announced the momentous discovery of the deflexion of starlight by the gravitational field of the sun, confirming Einstein's theory of general relativity. Saha got deeply interested in the relativity theory. He, jointly with S. N. Bose, prepared an English translation of Einstein's papers, later published in the form of a book by the University of Calcutta. The study of relativity led Saha to some investigations in electromagnetic theory and his first original paper entitled 'On Maxwell's stresses' appeared in the *Philosophical Magazine* in 1917. This was followed by papers on the dynamics of the electron. He derived, on the basis of the special theory of relativity, the Lienard-Wiechert potential due to a point-charge. During these years he also worked on radiation pressure, and in 1918 (with S. Chakravarti) he published in the *Journal of the Royal Asiatic Society of Bengal* (Calcutta) a paper on the measurement of the pressure of light, using a resonance method. Though Saha had little real skill or aptitude for practical work, he always took the keenest interest in and gave every encouragement to experimental work going on in his laboratory, and often suggested fruitful problems for investigation. He held that in a progressive department of physics, research should be vigorously pursued in both theory and experiment, and a high place given to serious and good teaching. Saha's first work in astrophysics, and it was a very important one, was the formulation of the concept of *selective radiation pressure*, and the recognition of its role in the relative distribution of the elements in the solar atmosphere. (He had read in Agnes Clarke's book about the 'hypothetical levitative force' which apparently acted on atoms of some elements only, e.g. calcium.) A short note 'On radiation pressure and the quantum theory' appeared in the *Astrophysical Journal* in 1919. A detailed paper communicated to the same journal was for some reasons—partly the length of the paper—not accepted for publication, and it was published in the relatively little-known *Journal of the Department of Science, Calcutta University*. Saha did not pursue the subject of selective radiation pressure further. It was raised to an entirely new level by E. A. Milne. In 1918 on the basis of his work in the field of electromagnetic theory and radiation pressure, Saha was awarded the D.Sc. degree of the Calcutta University. His examiners were O. W. Richardson, N. R. Campbell and Porter.

Saha's greatest contribution is, undoubtedly, the theory of high-temperature ionization and its application to stellar atmospheres. The equation that goes by his name was first given in the paper 'On ionization in the solar chromosphere', published in the *Philosophical Magazine* for October 1920. Using the language of physical chemistry he called it the 'equation of the reaction-isobar for ionization'. Discussing the case of the ionization of calcium, he wrote:

'We may regard the ionization of calcium atom as taking place according to the following scheme, familiar in physical chemistry,

$$Ca \rightleftharpoons Ca_{+} + e - U$$

where Ca is the normal atom of calcium (in the vapour state), Ca_{+} is an atom which has lost one electron, U is the quantity of energy liberated in the process. The quantity considered, is 1 g atom. . . To calculate the "Reaction-isobar" K, let us assume that P is the total pressure, and a fraction x of the Ca-atom is ionized.

Then we have

$$\log K = \log \frac{x^2}{1-x^2} P = \frac{U}{4{\cdot}571\ T} + 2{\cdot}5 \log T - 6{\cdot}5$$

This is the equation of the "reaction-isobar" which is throughout employed for calculating the "electron-affinity" of the ionized atom.' The value 6·5 in the above expression is the value of the chemical constant obtained from the Sackur-Tetrode-Stern relation.

It is pertinent to remark that the ionization theory was formulated by Saha working by himself in Calcutta, and the paper quoted above was communicated by him from Calcutta to the *Philosophical Magazine*—incorrect, statements to the contrary have sometimes been made. (Saha's first visit to Europe was made a couple of months later.) Further papers soon followed. It is not too much to say that the theory of thermal ionization introduced a new epoch in astrophysics by providing for the first time, on the basis of simple thermodynamic considerations and elementary concepts of the quantum theory, a straightforward interpretation of the different classes of stellar spectra in terms of the physical conditions (temperature and to a lesser extent pressure) prevailing in the stellar atomospheres. S. Rosseland in the Introduction to his well-known *Theoretical astrophysics* (Oxford University Press, 1936) has observed: 'Although Bohr must thus be considered the pioneer in the field, it was the Indian physicist Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory. Saha's work is in fact the theoretical formulation of Lockyer's view along modern lines, and from that time the idea that the spectral sequence indicates a progressive transmutation of the elements has been definitely abandoned. From that time dates the hope that a thorough analysis of stellar spectra will afford complete information about the state of the stellar atmospheres, not only as regards the chemical composition, but also as regards the temperature and various deviations from a state of thermal equilibrium, the density distribution of the various elements, the value of gravity in the atmosphere and its state of motion. The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas.'

It may be of some interest to relate how Saha was led to the ionization theory. In his own words*: 'It was while pondering over the problems of astrophysics, and teaching thermodynamics and spectroscopy to the M.Sc. classes that the theory of thermal ionization took a definite shape in my mind in 1919. I was a regular reader of German journals, which had just started coming after four years of First World War, and in course of these studies, I came across a paper by J. Eggert in the *Physikalische Zeitschrift* (p. 573), Dec. 1919, "Über den Dissoziationzustand der Fixsterngase" in which he applied Nernst's Heat Theorem to explain the high ionization in stars due to high temperatures, postulated by Eddington in course of his studies on stellar structures.†

* Extract (taken from a copy in the possession of Dr A. K. Saha, son of Professor Saha) from a letter dated 18 December 1946, to Professor H. H. Plaskett, University Observatory, Oxford.

† Saha in his paper 'On ionization in the solar chromosphere' makes a handsome acknowledgement to Eggert's work.

'Eggert, who was a pupil of Nernst and was at the time his assistant, had given a formula for thermal ionization, but it is rather strange that he missed the significance of ionization potential of atoms, importance of which was apparent from the theoretical work of Bohr, and practical work of Franck and Hertz which was attracting a good deal of attention in those days. ... Eggert used Sackur's formula of the chemical constant for calculating that of the electron, but in trying to account for multiple ionization of iron atoms in the interior of stars on this basis, he used very artificial values of ionization potential.

'While reading Eggert's paper I saw at once the importance of introducing the value of "ionization potential" in the formula of Eggert, for calculating accurately the ionization, single or multiple, of any particular element under any combination of temperature and pressure.

'I thus arrived at the formula which now goes by my name. Owing to my previous acquaintance with chromospheric and stellar problems, I could at once see its application. I prepared in the course of six months of 1919 (February to September) four papers and communicated them for publication in the *Philosophical Magazine* from India within August to September.'

One of the four papers above referred to was 'On the Harvard classification of stellar spectra'. When shortly after communicating the paper Saha went to London, he withdrew it from the *Philosophical Magazine*, and completely rewrote it in Professor A. Fowler's spectroscopy laboratory in the Imperial College of Science and Technology, London. The revised (and, no doubt, considerably expanded and improved) paper was published in the *Proceedings of the Royal Society* (1921) under the title, suggested by Fowler, 'On a physical theory of stellar spectra'. Saha had the greatest regard for Professor Fowler, and always spoke with warmth and gratefulness of the encouragement and help he had received from him in London. Years afterwards he wrote:* 'I took about four months in rewriting this paper, and all the time I had the advantage of Professor Fowler's criticism, and access to his unrivalled stock of knowledge of spectroscopy and astrophysics. Though the main ideas and working of the paper remained unchanged, the substance matter was greatly improved on account of Fowler's kindness in placing at my disposal fresh data, and offering criticism wherever I went a little astray, out of mere enthusiasm.'† This paper and the one on the 'Ionization of the solar chromosphere' are by far the most significant and original of Saha's many scientific contributions.

As one of the interesting and immediate results following from the ionization theory, Saha not only was able to explain the absence in the solar spectrum of the lines of Rb and Cs because of the low ionization potential of these elements, but also to predict that their resonance lines were likely to be

* Letter to Professor H. H. Plaskett referred to in the preceding footnote.

† Professor H. Dingle once observed: 'On thinking back to the relation which existed between Saha and Fowler I am tempted to compare it with that between Maxwell and Faraday.' (*The Observatory*, **66**, 22 (1945).

observed in the relatively cooler regions of the sunspots. H. N. Russell, following Saha's prediction, looked for and found the infra-red pair of Rb-lines, but no Cs-lines, in the Mount Wilson photographs of the spot spectra which, incidentally, had been taken before the publication of Saha's theory.

We may recall at this place that, apart from J. Eggert's paper referred to earlier, a definite suggestion about high-temperature ionization, prior to Saha's papers, was also made by the Oxford physicist F. A. Lindemann (later Lord Cherwell) in connexion with his controversy with S. Chapman about the origin of magnetic storms (*Philosophical Magazine*, December 1919). He gave the ionization formula for hydrogen, and discussed the possibility of the complete ionization of hydrogen in the solar chromosphere. Lindemann, however, did not further develop or generalize the formula; and above all he failed to notice that the theory of thermal ionization (with accurate values of ionization potentials obtained from spectroscopic data or otherwise) constitutes the key to the interpretation of stellar spectra with their almost bewildering complexity. It was Saha who first recognized this, and worked out the consequences in considerable detail, and he did this independently of Lindemann's suggestion about the high-temperature ionization of hydrogen.

In 1919 Saha was awarded the Premchand Roychand Scholarship of the Calcutta University, and this made it possible for him to spend some two years in Europe. He first went to London and spent about five months in the laboratory of Professor A. Fowler. Later he moved to W. Nernst's laboratory in Berlin, and did some experimental work on the conductivity of heated caesium vapour to seek an experimental verification of the theory of thermal ionization. The results were inconclusive. Some years later, when at Allahabad, Saha again returned to this problem, and an account of the investigation, jointly with K. Majumdar and N. K. Sur, was published in the *Zeitschrift für Physik* (1926).

In the early twenties R. H. Fowler (in collaboration with C. G. Darwin) developed a very powerful method in statistical mechanics permitting a systematic exposition and working out of the equilibrium properties of matter. He used this to provide a (rigorous) derivation of the ionization formula which as described earlier Saha had obtained by extending (and justifiably) to ionization of atoms the theorem of van't Hoff, well known in physical chemistry for its application to molecular dissociation. Also, a significant improvement in the Saha equation introduced by Fowler was to include the effect of the excited states of atoms and ions. Further, it marked an important step forward when in 1923 E. A. Milne and R. H. Fowler in a paper in the *Monthly Notices of the Royal Astronomical Society* showed that the criterion of the *maximum intensity* of absorption lines (belonging to subordinate series of a neutral atom) was much more fruitful in giving information about physical parameters of stellar atmospheres than the criterion employed by Saha which consisted in the *marginal appearance or disappearance* of absorption lines. (The latter criterion requires some knowledge of the relevant pressures in the stellar atmospheres, and Saha following the generally accepted view at the time assumed a value of the order of 1 to 0·1 atmosphere.) To quote from E. A. Milne:* 'Saha had concentrated on the marginal appearances and disappearances of absorption lines in the stellar sequence, assuming an order of magnitude for the pressure in a stellar atmosphere and calculating the temperature where increasing ionization, for example, inhibited further absorption of the line in question owing to the loss of the series electron. As Fowler and I were one day stamping round my rooms in Trinity and discussing this, it suddenly occurred to me that the *maximum* intensity of the Balmer lines of hydrogen, for example, was readily explained by the consideration that at the lower temperatures there were too few excited atoms to give appreciable absorption, whilst at the higher temperatures there are too few neutral atoms left to give any absorption.... That evening I did a hasty order of magnitude calculation of the effect and found that to agree with a temperature of 10 000° for the stars of type AO, where the Balmer lines have their maximum, a pressure of the order of 10^{-4} atmosphere was required. This was very exciting, because standard determinations of pressures in stellar atmospheres from line shifts and line widths had been supposed to indicate a pressure of the order of one atmosphere or more, and I had begun on other grounds to disbelieve this.'

In November 1921 Saha returned from Europe and joined the University of Calcutta as Khaira Professor of Physics, a new chair created from the endowment of Kumar Gurprasad Singh of Khaira. In 1923 Saha left Calcutta to take up the appointment of Professor and Head of the Physics Department in the University of Allahabad. He held this appointment for 15 years. At Allahabad he gave a large part of his time to teaching—he regularly lectured to undergraduate and postgraduate classes. His lectures were systematically and carefully prepared, and a very large part of what he spoke, he wrote on the black board in his characteristically clear and bold handwriting. He made copious use of lantern slides, and was fond of demonstration experiments.†

He initiated and organized research in several subjects, such as statistical mechanics, atomic and molecular spectroscopy, experiments on thermal ionization and 'electron affinity' of electronegative elements, active modification of nitrogen, high-temperature dissociation of molecules, and ionospheric propagation of radio waves and physics of the upper atmosphere. In 1926 Saha presided at the Physics and Mathematics Section of the

* E. A. Milne, Obituary Notice of R. H. Fowler (1889-1944), *Obituary Notices of the Fellows of the Royal Society*, **5**, 61-78 (1945).

† Saha often quoted the following rather remarkable passage from the 9th century Sanskrit work, *Rasendra-Chintamani:*

'I have heard much from the lips of savants, I have seen many (formulae) well established in Scriptures, but I am not recording any which I have not done myself.

'I am only recording those fearlessly which I have carried out before my elders with my own hand. They are alone to be regarded as real teachers who can show by experiments what they teach. They are the deserving pupils, who, having learnt from their teachers can actually perform them and improve upon them. The rest are merely stage-actors.'

Indian Science Congress Association. His address was on thermal ionization. Within less than a decade of Saha's arrival the Physics Department of the Allahabad University became one of the most active centres of research in the country, particularly in the field of spectroscopy. Amongst his earliest associates in research mention may be made of P. K. Kichlu (now Professor of Physics in the Delhi University), K. Majumdar and N. K. Sur. The Department attracted students from all over India. R. C. Majumdar, now Professor of Physics in the Delhi University, S. Basu, retired Director-General of the Department of Meteorology, and D. S. Kothari were Saha's students at Allahabad. It was in 1927 that at the age of thirty-four Saha was elected to the Royal Society. The United Provinces Government sanctioned a personal annual grant of Rs. 5000 for his research work.

In 1927, at the invitation of the Indian Government, Saha attended the Volta Centenary Celebration held at Como, and presented a paper 'On the explanation of complicated spectra of elements.' He later joined a total solar eclipse expedition to Ringebu (68°N) led by L. Vegard of Oslo University. In 1936 he was elected to an overseas fellowship of the Carnegie Trust of the British Empire, and he visited Germany, England, and the United States and spent about two months with H. Shapley at the Harvard College Observatory. (Saha took keen interest in archaeology and ancient history, and on his way to Europe he visited the ruins of Ur of the Chaldees then recently excavated by Sir Leonard Woolley.) In a paper 'On a stratospheric astrophysical observatory' which appeared in the *Records of Harvard College Observatory*, Saha made what at the time (1936) was a very ambitious plea of photographing the solar spectrum at a height of some 50 kilometres, well above the ozone layer; and he pointed out the enormous gain that would accrue for astrophysics. In this paper, as also in that on the action of ultra-violet sunlight upon the upper atmosphere published in the *Proceedings of the Royal Society* (1937) and in his Presidential Address to the National Institute of Sciences of India given at Lahore in 1938, he discussed the possibility that the ultra-violet radiation from the sun may be several orders of magnitude above that corresponding to a black-body at about 6500°K. He wrote: 'This may possibly be due to the fact that the ultra-violet spectrum of the sun may consist of a continuous background of faint light on which are superposed emission lines of H, He, He^+, Fe^+, and other elements which are represented in the visible range by lines of subordinate series, or by patches of ultra-violet continuous light (near about λ500) leaking through the solar atmosphere from a much hotter region inside the photosphere, as suggested by Professor H. N. Russell.'*

In December 1937, Sir Arthur Eddington visited India as a member of the delegation of the British Association for the Advancement of Science to the Jubilee Session (1938) of the Indian Science Congress Association held in Calcutta. (Lord Rutherford was to preside at the session but he died a few

* M. N. Saha. *Proc. R. Soc.*, A, **160,** 55 (1937).

months before, and his place was taken by Sir James Jeans.) At Saha's invitation Eddington paid a short but memorable visit to Allahabad; he was presented a civic address by the Allahabad Municipality.

In 1938 Saha was offered the Palit Chair in Physics at the University of Calcutta, vacated some years earlier by C. V. Raman who had gone to Bangalore as Director of the Indian Institute of Science. (Raman was succeeded by D. M. Bose who was Palit Professor from 1932 to 1937.) Saha accepted the offer and left Allahabad after a stay of fifteen years there. He occupied the Palit Chair for fifteen years, retiring in 1953 at the age of 60. In Calcutta Saha could not give as much of his time to his research as was possible in the relatively quiet atmosphere of Allahabad. Here a large part of his time was taken up in the administration of the laboratories, in building a new Institute of Nuclear Physics, and the reorganization and expansion of the laboratories of the Indian Association for the Cultivation of Science. Apart from all this, after the partition of India in 1947, he gave a substantial part of his time and energy to the massive human and economic problem of the 'refugees' from East Bengal (Pakistan)—it was a call that a man, himself from East Bengal, of his temperament and intense sensibility could not resist.

His researches in Calcutta were concerned largely with the systematics of atomic nuclei, particularly beta-activity; the propagation of electromagnetic waves in the ionosphere; and the problem of the solar corona. In the case of the corona an outstanding problem is that of the mechanism or source responsible for the high-degree ionization—loss of 9 to 13 electrons—of the iron atoms, and also nickel in the inner corona, as conclusively demonstrated by B. Edlen's remarkable work (1938) on the origin of the coronal bright spectral lines. D. Kundu working under Saha showed that some of the lines may be due to highly ionized cobalt atoms. The intense ionization, as also the excessive broadening of the Fraunhofer lines in the scattered radiation from the outer corona, and the strong coronal radio-emission in the region of wavelengths of the order of a few metres, all suggest coronal temperatures of the order of millions of degrees, but the origin of these temperatures which are comparable to those occurring in stellar interiors is largely still an unsolved problem. Saha found it difficult to accept the existence of such high temperatures. In fact, to account for the Edlen lines he advanced in a number of papers the somewhat quaint hypothesis that the highly charged ions necessary for the emission are produced as a result of some form of nuclear fission occurring in the sun's outer atmosphere—he suggested tri- or quadri-fission of U or Th. The problem of the emission of radio waves from the Sun and other stellar bodies also engaged his attention, and he discussed the likely role of the magnetic field and the hyperfine-structure level-splitting of the ground state of the H-atom (*Nature, Lond.*, **158,** 717 (1946)). He failed to recognize, at any rate explicity, the possibility of the occurrence as *line emission* of the 21-cm hydrogen line in radio spectra. (He was not aware at the time of the earlier prediction (1944) of H. C. van de Hulst.) In collaboration with B. D. Nag Chaudhuri* (the present Palit Professor of Physics) Saha investigated the problem of the geological age of some of the Indian rocks.

Saha early realized the growing importance of nuclear physics and the impact it was likely to make on the country's scientific and industrial progress. He felt that in the context of current developments there was a real and urgent need for a separate institution of nuclear physics devoted to post-graduate study and research. The result of his dedicated and untiring efforts was the Institute of Nuclear Physics in Calcutta, founded in April 1948 (and formally opened in 1950). The Institute is attached to the University. It runs a post-graduate course, and its research activities cover, amongst other subjects, beta-ray spectroscopy, nuclear resonance, and the use of radio-active isotopes in medicine. There is also an active theoretical group; a separate biophysics section and an instrument section. It has a 38-inch cyclotron—the magnet and some of the other critical parts were obtained from Lawrence's Laboratory in Berkeley. Saha was elected Honorary Director for the Institute for life. After his death, the Institute befittingly has been named after him.

Though the Institute of Nuclear Physics took much of Saha's energy and time, yet there was another institution, the Indian Association for the Cultivation of Science, which was always in his mind, and for its reorganization and expansion he worked hard and ceaselessly. The Association, the oldest institution devoted to science and its cultivation in modern India, was founded in 1876 by a private medical practitioner of Calcutta, Dr. Mahendra Lal Sircar. He intended it 'to combine the character, scope and objects of the Royal Institution of London and of the British Association for the Advancement of Science'. As is well known the Raman effect was discovered in the laboratories of this Association in 1928. At the time Raman was Palit Professor of the University and also the honorary head of the Laboratories of the Association.

Saha, shortly after his coming to Calcutta as Palit Professor in 1938 (Raman left Calcutta in 1932) began to take a keen interest in the activities of the Association. He was elected the Honorary Secretary in 1944, and in 1946 he was elected the President of the Association. He was succeeded by J. C. Ghosh in 1950. The large-scale expansion in the research activities of the Association which has taken place in recent years is almost entirely the result of Saha's initiative, resourcefulness and devoted work. The Association has now a new building in Jadavpur (Calcutta) where it moved in 1951 from 210 Bowbazar Street.

In 1952 the post of a full-time Director of the Laboratories of the Association was created and the choice of the first Director obviously fell on Saha. He accepted the appointment in 1953 on retirement from the Palit Chair of the University which he held for fifteen years. He was Director of the

* At presnt Secretary, National Institute of Sciences of India and Member (Science), Planning Commission.

Laboratories of the Association and Honorary Director of the Institute of Nuclear Physics at the time of his death in 1956.

Saha was the General President of the twenty-first annual session of the Indian Science Congress Association held in Bombay in January 1934. The first part of his address dealt with some of the current astrophysical problems, and in the second part he advocated the formation of an All-India Academy of Sciences. In the same address he drew pointed attention to the serious problem—still largely unsolved—of recurring disastrous floods in many Indian rivers, and stressed the need for a River Research Laboratory to make a scientific study of the complex problems involved in flood control and river utilization generally. He was one of the first in India to realize the great importance of this subject. He had personal experience of some of the catastrophic floods in the Damodar Valley area (Bengal), and he often took an active part in relief measures organized to deal with them. The writings of Saha, many of which appeared in *Science and Culture*, on flood control and harnessing the water of the rivers were to no small extent responsible in creating a public awareness of these problems. In 1943 the Bengal Government appointed the Damodar Flood Enquiry Committee. Saha was a member of the Committee, and his contribution was widely recognized as a vital one. Largely as a result of the committee's report came, eventually, the multipurpose Damodar Valley Project (very much on the lines of the Tennessee Valley Authority in the U.S.A.) which has been the forerunner of the Bhakra-Nangal and other multi-purpose river projects in India. The establishment of the River Research Institute (Haringhata, Calcutta) was also, to no small extent, the result of Saha's initiative and efforts.

It was during the early thirties that the National Academy of Sciences at Allahabad (originally called the Academy of Sciences for the Provinces of Agra and Oudh), the Indian Academy of Sciences at Bangalore, and the National Institute of Sciences of India at Calcutta (headquarters transferred to Delhi in 1946) were founded. In the case of the Allahabad Academy, and so also the National Institute, the role of Saha was of the utmost importance. He was the first President (1932-34) of the Allahabad Academy and the second President (1937-39) of the National Institute of Sciences. (The first President of the National Institute of Sciences of India was Sir Lewis Fermor, the Director-General of the Geological Survey of India.) Saha was President of the Royal Asiatic Society of Bengal (now the Asiatic Society) for 1944-46.

Saha from the very beginning was closely associated with the work of the Indian Council of Scientific and Industrial Research (which corresponds to the D.S.I.R. in the U.K.) first constituted in 1942. He was a member of its Governing Body; and was for many years Chairman of the Atmospheric Research Committee, and Chairman or Member of several other research and planning committees of the C.S.I.R. He was closely connected with the planning and establishment of the Central Glass and Ceramics Research Institute at Calcutta—one of the national laboratories under the C.S.I.R.—

and was for many years Chairman of its Advisory Committee. He was the Chairman of the Indian Calendar Reform Committee, appointed by the C.S.I.R. in 1953.

Saha was a Member of the University Education Commission appointed by the Government of India in 1948 under the chairmanship of Dr S. Radhakrishnan.

The monthly journal *Science and Culture*, published by the Indian Science News Association (Calcutta), was started by Saha in 1934. The journal is now running in its 24th volume.* Saha wrote prolifically for the journal, and his many articles and editorials bear witness to his remarkable versatility, and his passionate interest in and grasp of the many scientific, industrial and economic problems facing the country. A list of his contributions is included in the bibliography at the end.

Saha was a keen student and ardent advocate of social and economic planning in India, particularly, in its relation to science, large-scale industry and technology. His general philosophy in these matters is perhaps best expressed in the following words (*Nature, Lond.*, **155,** 221 (1945)): 'The philosophy of kindliness and service to our fellow-men was preached by all founders of great religions, and no doubt some great kings and ministers of religions in every country and at all ages tried to give effect to this (altruistic) philosophy. But the efforts were not successful, for the simple reason that the methods of production of commodities were too inefficient to yield plenty for all, which is an indispensable condition for practical altruism. We can, therefore, hold that *so far as individual life is concerned*, science has achieved a target aimed at by the great founders of religions in advanced countries of the world. The effects of maldistribution of wealth, due to historical causes, are being rapidly cured by the introduction of social laws.'

He was an active member of the National Planning Committee appointed by the Indian National Congress in 1938. Saha was chairman of the power and fuels sub-committee, and member of the sub-committee on river training and irrigation.

In 1951 Saha was elected, as an independent candidate, to the Indian Parliament from the North-West Calcutta constituency. His contribution to the debates in the House, because of his special knowledge and background, was particularly valuable in relation to subjects such as education, industrial policy, river-valley projects and atomic energy.

Saha was widely travelled in Europe and the U.S.A. He had been twice to the U.S.S.R. He was the Indian delegate to the 220th Anniversary Celebrations (1945) of the Soviet Academy of Sciences.

In March 1954 the 60th birthday of Saha was celebrated in Calcutta, Allahabad and Delhi by his many friends, old students and admirers. A Commemoration Volume *Professor Meghnad Saha—His life, work and philosophy*, edited by S. N. Sen was published on the occasion. (The

* At present 35th volume

photograph of Professor Saha facing page 217 was taken in his 60th year.)*

During the last years of his life Saha was keeping an indifferent health. He was suffering from high blood pressure. But the end came rather suddenly. He passed away on 16 February 1956.

The life of Saha was in a sense an integral part of the growth of scientific research and progress in India, and the effect of his views and powerful personality would be felt for a long time to come in almost every aspect of scientific activity in the country. His dedication to science, his forthrightness and utter disregard of personal comforts in the pursuit of his chosen vocation will long remain an inspiration and an example.

Saha was married in June 1918 to Shrimati Radha Rani Saha. Her kindliness and genuine simplicity of character have won for her the affection and respect of generations of students and colleagues of Saha. Saha is survived by his wife, three sons and three daughters. The eldest son, A. K. Saha, is Professor in the Institute of Nuclear Physics.†

In the preparation of this memoir I have drawn rather freely on the Commemoration Volume presented to Saha on his 60th birthday.

D. S. KOTHARI

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* The photograph reproduced in this volume is a different one.
† The Institute of Nuclear Physics is now known as the Saha Institute of Nuclear Physics.

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