Meghnad Saha — His science and life

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On March 4, 1920, Meghnad Saha communicated to the British Journal *Philosophical Magazine* a paper entitled 'Ionization in the Solar Chromosphere'. He was barely twenty seven years of age at that time having been born on 6th October 1893 at Seoratali in Dacca District as the fifth child, out of a total eight, of Shri Jagannath Saha, a small shopkeeper, and Smt. Bhubaneshwari Devi. He had joined in 1916 as a Lecturer at the Science College of the University of Calcutta which was established just one year earlier in 1915, at the invitation of the founder Sir Asutosh Mukherjee. In this paper M. N. Saha proposed his now famous 'Saha Thermal Ionization and Excitation Theory' which laid the foundations for the study of stellar atmospheres at high temperatures. This work firmly placed Saha in the forefront of astrophysicists.

The research career of Saha extended over the long period between 1917 and 1951, when he was elected to the parliament as an independent member. Over this period he did research in astrophysics, spectroscopy, nuclear physics, ionosphere, models of elementary particles and cosmic rays. He published eighty seven original papers in these areas. The intellectual activity of Professor Saha was however hardly confined to the research in physics and astrophysics. He was a staunch nationalist and deeply interested in problems of river management, energy resources, atomic energy, national planning for development and organization of scientific research among other things. He also did important work in reform of Indian Calendar. His writings on these and related subjects as well as his general and expository writings on scientific topics were prolific and important and display his originality.

M. N. Saha joined Presidency College, Calcutta, in 1911 and graduated in 1915 with an M Sc degree. Among his classmates were S. N. Bose, J. C. Ghosh and J. N. Mukherjee. All of them were to achieve distinction in science. Among his teachers were Acharya J. C. Bose and P. C. Ray. In 1916 S. N. Bose also joined the newly started University College of Science, along with M. N. Saha, as a Lecturer. He married Shrimati Radharani in June 1918.

Saha and Bose produced the *first* English translation ever published of the relativity papers of Albert Einstein and H. Minkowski. These were published by Calcutta University in 1920 with a historical introduction by P. C. Mahalanobis. It was therefore natural that the *Statesman* correspondent was directed to Saha for writing a short exposition of the relativity theory when the Reuter's Cable, about the confirmation by Eddington of light deflection prediction of general theory of relativity during the expedition to observe the total solar eclipse on May 29, 1979, was received by them. Saha immediately wrote 'Time and Space—The New Scientific Theory' and it appeared in November 13 and November 15, 1919 issues of *The Statesman*, Calcutta. This was his first general-science writing. It is interesting to read in this article Saha's 1919 perspective on the developments in the relativity theory and I quote two passages[1].

> The theory of relativity was first formulated by the great Dutch physicist, H. A. Lorentz, during the closing years of the last century, but was largely recast and elaborated by Einstein, then a rising mathematical physicist of Switzerland, and Minkowski, a Russian Jew, whom the persecutions of his country drove into Germany. The generalized theory of Relativity, which has just been brilliantly confirmed, is on the other hand, the sole work of Einstein and was first formulated in the year 1911 and elucidated in a number of papers published from 1911 to 1917.

> The physical explanation of Lorentz's mathematical formula was first elucidated by Einstein ...

Astrophysics and spectroscopy

Saha returned to the question of what one can learn from physical observations during a total solar eclipse, apart from performing a test of general relativity, about our nearest star Sun in his next general article written for *Calcutta Review* (1922, **4**, 505). The total solar eclipse of September 21, 1922 was soon to occur. Saha's own interest in this coming eclipse was in the studies of solar spectra, especially the spectra of the flash, corona, and the prominences as he demurely admits in a short aside 'A theory to explain these facts was given by the present writer about a year and a half ago, which has met with general acceptance. But an acount of this theory will be out of place here.' He was referring, of course, to his 'ionization theory'[2].

His address as President, Physics and Mathematics Section of the 13th Indian Science Congress held at Bombay in 1926 as well as his contribution to the volume *Life and Work of Sir Normal Lockyer* edited by L. M. and W. L. Lockyer in 1928, however, directly dealt with 'ionization theory', his most significant astrophysical contribution. Sir Normal Lockyer was an important precursor of Saha. In his first paper on his theory 'Ionization in Solar Chromosphere', referred to earlier, he begins with the observation that the strong line spectrum of high level chromosphere consists of those spectral lines which are stronger in spark-discharge spectrum rather than in the arc-spectrum of the elements. These lines were referred to as enhanced lines by N. Lockyer who ascribed the enhancement as due to local increase of temperature in the spark-discharge. If this explanation is taken over for the solar chromosphere it would imply an unacceptable, radially outward, increase in solar temperature. Saha proposed to investigate the hypothesis that these lines are rather due to ionized atoms i.e. 'atoms which have lost one (or more) electrons'[3]. If the observations of the intensity of the observed spectral lines are to be attributed to this hypothesis then the data demanded that calcium, strontium, barium, scandium, titanium, iron atoms

This is a revised version of the article in *Science Age*, May 1984, pp. 26–30.

M. N. Saha (standing first from left) with P. C. Ray (centre of the photograph).

are ionized over the whole of the atmosphere of the sun and are completely ionized in the chromosphere; while the hydrogen and helium would have to be unionized throughout the whole chromosphere with may be a slight ionization of helium in the lower levels of the chromosphere. In order to calculate the degree of ionization of various elements under the physical conditions prevailing in the sun, Eggert had realized that one could use Nernst formula for 'Reaction isobar' i.e., one uses the chemical reaction theory, used normally for reactions among atoms and molecules, to the process of an atom itself disintegrating into an ion and an electron. Eggert's results were published in *Physikalische Zeitschrift* of December 1919 under the title 'Uber den Dissoziationzustand der Fixsterngasse'. As Saha himself said in a letter dated 18 December 1946, to H. H. Plaskett[4] '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.... All the pieces were now in place. This was the first successful application of Bohr's atomic theory to stars and it fitted the observed features of solar atmosphere beautifully.

The way was now open to learn about the physical conditions of temperature, pressure and element distribution in stars. His next paper 'Elements in the Sun' was sent for publication on May 22, 1920 from Calcutta and appeared in the December 1920 issue of *Philosophical Magazine* 1920, 40, 809. Through a study of the observed Fraunhofer lines, definite evidence of the presence of thirty six chemical elements had been obtained. Certain other elements were indicated only by very faint spectral lines while there was no evidence for many of the others. The systematics was not such that the absence of the various elements could be explained by assuming heavier atomic weight elements to be present only deep inside in the photosphere as light elements like boron or nitrogen were missing as well as heavy elements like thallium. Of course one could take the *ad-hoc* point of view that elements not revealed by Fraunhofer lines are really absent in the sun. Saha, however, took the view[5] 'the varying records of different elements in the Fraunhofer spectrum may be regarded as arising from the varying responses of these elements with regard to the stimulus existing in the sun. The stimulus existing in the sun is the same for all elements, viz., that arising from a temperature of about 7500 K, but owing to a different internal structure, elements will respond in a varying degree to this stimulus'. To take an example, Rubidium and Caesium are not seen in the Fraunhofer spectrum. This is explained by their rather low ionization potentials and hence complete ionization and the enhanced spectrum lying in ultraviolet. However sunspots are regions of local cooling and these elements would partially return to neutral state. Hence the spectra of sunspots should show their presence. The verification of this prediction by H. N. Russel, who discovered the infrared pair λ7911, 7800 of Rb..., constitutes one of the earliest and greatest triumphs of the ionization theory[6]. The ionization potential of caesium is too low. Another prediction was that the spectra of the locally hotter regions, known as faculae, should be rather similar to that of the F-class of stars. This was also later borne out by Dr St. John's observations at Mount Wilson Solar Observatory.

This brings us to Saha's explanation of 'Spectral classification of stars'. The first major attempt in this direction was that of Father A. Secchi's in mid-nineteenth century who examined the spectra of about 4000 stars. He found that the stellar spectra fell into four types. These were essentially (i) white stars with strong hydrogen absorption, (ii) yellow stars with spectra like that of sun, (iii) red stars with band spectra, and (iv) bluish white stars with spectral lines which were later found to be due to helium. Lockyer refined the classification on the basis of a much larger number of stellar spectra. The ultimate in this direction was the spectroscopic survey of four hundred thousand stars under-taken by E. C. Pickering and A. J. Cannon at Harvard College Observatory. They found that all spectra fall essentially in a certain well-defined group which they designated by

P···O···B···A···F···G···K···M···

N···R···S

These groups gradually merge into each other. The B-stars were referred to as helium stars while A-stars were referred to as hydrogen stars.

It was while thinking about these above spectral classifications that Lockyer gave his theory of 'inorganic evolution' which was a precursor of Saha's theory. If we regard B-stars to consist of essentially helium and if it evolves by cooling to G type star i.e. like our sun then either sun should consist of mainly helium or there should be an evolution of elements, called by Lockyer 'inorganic evolution', as well. He supported his argument by the observed difference between spark-discharge and spectrum. If atoms are fixed and unbreakable then why is the spectra different in these two cases? He believed that these imply breakup of atoms into proto-atoms at higher temperatures. In case of silicon he identified four successive stages of break up. As Saha wrote[7] 'But the scientific world, trained to the fetish of an invariable and further indivisible atom, refused to listen to the arguments of Lockyer..., he was like the mythical Greek aeronaut Icarus who, in trying to reach the heavens with wings of wax, had to end by falling into sea. But such unsuccessful attempts are more important for the progress of science than spectacular successes in narrow, well chalked out lines'. Not available to Lockyer, in 1874, were developments in thermodynamics (Nernst) and modern atomic theory given by Bohr which were crucial ingredients which went into Saha's theory. In a paper 'On a Physical Theory of Stellar Spectra' published in *Proceedings of the Royal Society of London* (1921, *A99*, 135), and received by them on January 18, 1921, Saha finally showed that the Harvard classification was basically a temperature classification.

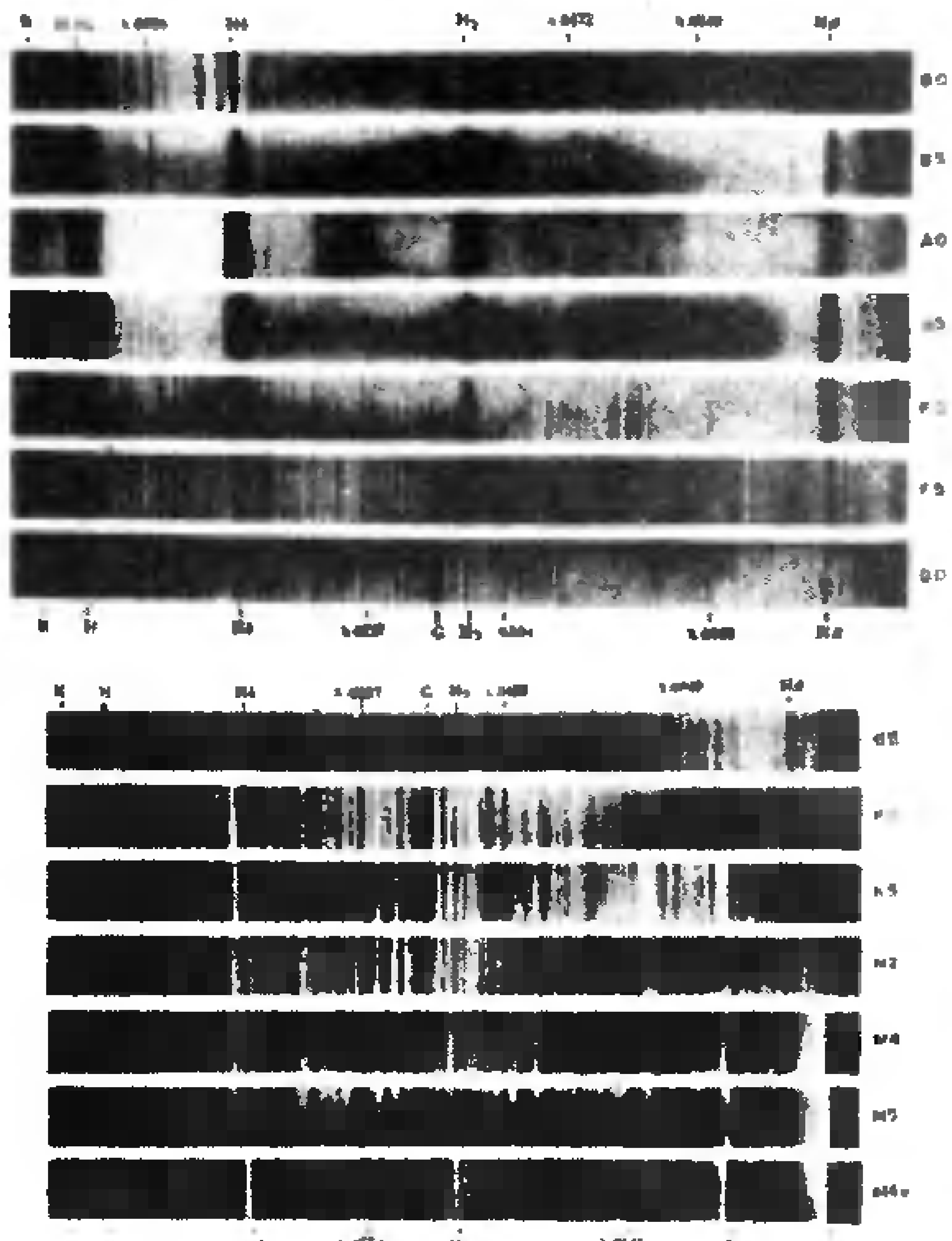
Early workers to pursue further theoretical implications of Saha's ionization theory were R. H. Fowler and A. Milne in England, A. Unsöld in Germany and H. N. Russel in United States of America. H. N. Russel wrote in 1922 (ref. 8) 'The principles of the *ionization theory will* evidently be of great importance throughout the whole field of astrophysics and Dr Saha has made an application of the highest interest to the question of the physical meaning of the sequence of stellar spectra .... The possibilities of the new method appear to be very great. To utilize it fully, years of work will be required to study the behaviour of the elements in the stars, in laboratory spectra and by direct measurement of ionization, but the prospects of increase of our knowledge, both of atoms and of stars, as a result of such researches, make it urgently desirable that they should be carried out.'

Cecilia H. Payne (late Payne-Gaposchkin) undertook the detailed task of checking Saha's ionization theory and its developments against observation, when she joined Harvard Observatory as a Fellow in 1923. In her own words, 'In my last year at Cambridge, I had come to know E. A. Milne who (with Ralph Fowler) had just published the historic paper on stellar atmospheres. They in turn had been inspired by the brilliant idea with which Meghnad Saha had applied the principles of physical chemistry to the ionization of stellar material, the idea that gave birth to modern astrophysics. Before I left Cambridge, Milne told me that if he had my opportunity, he would go after the observations that would test and verify Saha's theory. When I told Dr Shapley that this was what I should like to do, he promptly opened up to me the riches of the Harvard plate collection'[9]. She published these results in her book *Stellar Atmospheres*, which was submitted as her Ph D thesis to Radcliffe College and published for the Harvard College Observatory in 1925. It has been called 'undoubtedly the most brilliant Ph D thesis ever written in astronomy'[10].

Saha returned after a two-year stay in England with A. Fowler at Imperial College London and in Germany at the Laboratory of W. Nernst at Berlin as Khaira Professor of Physics to Calcutta University in November 1921. Since he found that it was not possible for him to set up a laboratory at Calcutta he started looking around and finally accepted the offer as Professor of Physics at Allahabad University. Here he remained for the period from 1922 to 1938. Even here the laboratories and library facilities were very poor. The University financial authorities, though well-meaning, wanted him to read all the books in the sectional library first before ordering a new book. Only after he was elected Fellow of Royal Society in 1927 did Sir William Morris, the then Governor of Uttar Pradesh and a class fellow of Lord Rutherford, sanction him a personal research grant of Rs 5000 per year. He initially tried with a student, N. K. Sur, to experimentally verify his theory but this 'was not very successful due to *absence of means*'[11]. His main interest during this period was on spectroscopic studies especially complex spectra. These are reflected in his choice of the subject matter of his six Readership lectures on Atomic Physics which were delivered at Patna University in 1927. His contribution to Sir P. C. Ray 70th Birthday Commemoration Volume on *Spectroscopy in the Service of Chemistry* gives an account of his studies on photochemical reactions.

Under the stimulus provided by his student G. R. Toshniwal, Saha also got interested in ionospheric research. His address 'Solar control of the atmosphere' as the President of National Institute of Sciences of India at Lahore Session (1939) touches upto this interest. It discusses Pännekoek's theory of ionization layers of atmosphere which was an extension of Saha's theory as modified by E. A. Milne to take into account the solar radiation not being in equilibrium with the atmosphere.

One of the most significant theoretical results obtained by Saha, during his Allahabad period, was his masterly rederivation of Dirac quantization condition for a magnetic monopole in 1936. It is one of his most quoted papers at present. In 1937 in *Harvard College Observatory Bulletin* he made the first and rather visionary suggestion for a Stratosphere Solar Observatory to photograph the solar spectrum, above the ozone layer, at a height of some 50 kilometers. In his paper 'The Mystery of the Solar Corona Solved' (1941) he reported on the identification of the two prominent coronal lines with wavelengths equal to 5303 and 6704 Å as lines of highly ionized iron atoms, with respectively 13 and 9 electrons removed, by Bengt Edlen. In the absence of these identifications these lines had been attributed to a new chemical element



The Spectral Sequence from B0 to M6

Flash Spectrum

which was named 'coronium'. In a talk 'On the origin of cosmic rays' given at the International Conference on Primary Cosmic Radiation held in Bombay (1951), he expressed the view 'The only hypothesis worthy of consideration ... for the injection of protons is the supernova hypothesis'[12]. More than 30 years later this is still holding up well.

Saha founded the U. P. Academy of Sciences at Allahabad in 1931 in order to encourage scientific research activity there. It was renamed The National Academy of Sciences in 1934. Saha was elected the General President of the Indian Science Congress held at Bombay in 1934. His presidential address was in two parts; the first part dealt with 'Fundamental cosmological problems' while the second part consisted of a note on a proposed Indian Academy of Sciences and another note on a proposal for establishment of the National Institute of Science of India in 1935 at Calcutta. Shri L. L. Fermor was elected as its first President with Saha as one of the Vice-Presidents. Saha became its President during 1937–1939. The Government of India recognized the National Institute of Science as the premier scientific society in October 1945. In May 1946 the National Institute of Science moved from Calcutta to Delhi. It was renamed 'Indian National Science Academy' in February 1970.

Saha had a strong sense of the past. He visited 'the ruins of the Ur of the Chaldees, lately excavated by Sir Leonard Woolley, in order to satisfy his thirst of knowledge of ancient times'[13] in 1936. He quotes with approval a passage from Rasendra Chintamani of Dhunduknath (C. ninth century) '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 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'[14]. He also notes among achievements of ancient Indian chemistry that Indians knew flame-test for elements in ores. 'Copper yields a blue flame ... that of tin is pigeon coloured ... that of lead is pale-tinted ... that of iron is tawny ... that of 'peacock ore is red' (*Rasarata Samuccaya*, C. 8th century)[15]. This was a precursor of spectrum analysis discovered by Kirchoff in the last century. He made a 'Plea for an astronomical observatory at Benaras' in an article written for Pandit Madan Mohan Malaviyaji's 70th Birthday Commemoration Volume (1932). He is, however, not shy also to point out 'But, in India, the votaries of the astronomical science apparently found it difficult to go against the scriptures. The Greek savants, with characteristic boldness and freedom of thought, had pooh-poohed the Homeric and Hesiodic cosmogony, they made light of the Olympic Gods. But the Indian Savant never showed equal boldness. On the other hand, being accustomed to easy-going pantheistic tendencies, he was always ready to compromise and be accommodating in his views'[16]. He quotes from Bhaskaracharya (12th Cent. A. D.) 'It is said that the earth rests on the hood of a huge snake, which when it feels uneasy gives a shake and causes earthquakes. Well, the snake must have something to rest upon. So we have to assume the hypothesis of an endless string of supported and supports. A better explanation would be that the earth has no support, i.e. it is suspended in space ... but since these things are mentioned in the *Sastras*, there may be some truth in them'[16].

Nuclear physics and atomic energy

Saha was recalled to Calcutta University in July 1938 as Palit Professor of Physics. He did not wish to continue work on Raman Effect for which Palit Laboratory was well equipped [as C. V. Raman had been the Palit Professor earlier (1917-1932)]. S. K. Mitra had already set up a good ionosphere laboratory and for Saha there was no point in starting another similar laboratory to continue his interest in ionosphere research which he had developed in Allahabad. Hereafter his interest in this field was to be purely theoretical.

Saha had been gradually getting interested in nuclear physics. Indeed already in 1933 he had attempted to give a theory of beta decay with his student D. S. Kothari. Their idea was a high energy gamma ray, internally produced 'due to the passage of an alpha-particle or proton from one barrier to another[17], materializes as an electron–positron pair and the positron is not able to come out of and is absorbed by the nucleus'. This was before the Fermi theory of beta decay. His lecture 'Ultimate constituents of matter' delivered at the Calcutta University under A. C. Mookherjee Trust in September 1934 dealt with nuclear physics. His interest in nuclear physics was further fanned by his visit to the Laboratory of E. O. Lawrence in Berkeley and attending of a conference on nuclear physics organized by Niels Bohr at Copenhagen (June 17–20, 1936), in which both M. N. Saha and H. J. Bhabha were participants. He gave a report of this conference (with P. Kapur) in the magazine *Science and Culture* which had been founded essentially by him in 1935. This magazine was to serve as an important forum for his writings on atomic energy and other national problems. He then decided to start a laboratory for nuclear physics at Calcutta.

Saha received a grant of sixty thousand rupees from Dorabji Tata Trust towards a cyclotron in 1941 which was later augmented by Calcutta University. Pandit Nehru was supportive of Saha in this venture. Later in 1947 he received support from the Government of India and Calcutta University to start an institute of nuclear physics with the cyclotron laboratory as its nucleus. Formally the new institute was inaugurated on 11th January 1950 by Irene Curie Joliot. The Senate of Calcutta University approved its constitution on 12th May 1951 with the status of an autonomous institute. Following the death of Saha the institute was renamed 'Saha Institute of Nuclear Physics'.

Saha was also responsible for nuclear physics teaching being taken more seriously at the universities. For instance at Agra University in mid-fifties the teaching of the 'nuclear physics' part of the paper on 'modern physics' at the Master's level was generally not given much attention as the teachers felt more comfortable teaching the 'atomic physics' part of that paper. Around that time Saha, in the setting of modern physics paper of that university for examination, decided to emphasize nuclear physics problems. It was no longer possible to ignore nuclear physics after that.

The Uranium Fission was discovered by O. Hahn and F. Strassman on December 15, 1938. Saha followed these developments and realized their importance immediately. In his talk 'Uranium fission' before Indian Physical Society on March 26, 1941 he already noted '...the discovery opens up a new vision of energy-production, which is extremely exciting'[18]. He compared the new energy source to conventional power resources such as coal. Even more remarkably he goes on to notice 'But in each process of fission 2 to 3 fresh neutrons are produced, and these may cause further fission. We have, therefore, the possibility of having a chain reaction, but the practicability of the idea can be only gauged when experiments have been carried out. Experiments of this kind are being carried out in Germany but no knowledge of progress on these lines is available'[18]. It is interesting to note that the controlled chain reaction was first achieved by E. Fermi at Chicago on December 2, 1942. Saha also shows himself alert to the possibility of atomic explosives and I quote 'It is quite possible that a process may be discovered which would render the reactions to proceed with explosive violence.... Still the idea that a tablet, a U^{235}... may blow off a mighty Super Dread nought .... cannot but be an exciting one'[18]. This was fully four years before the first atomic fission bomb explosion at Alamogordo test on July 15, 1945. This paper was probably the first published discussion of the possible use of the nuclear fission as a source of energy.

The world, at large, became aware of atomic energy as a result of the atomic bombs dropped over Hiroshima (August 6, 1945) and three days later on Nagasaki. Saha, with his student B. D. Nagchaudhuri, wrote an account 'The Story of the Atomic Bomb' for *Science and Culture*, 1945, **11**, 111 within a few months. He also reproduced a British Government publication cotaining a statement by W. Churchill on August 6, 1945 and a report on 'Directorate of Tube Alloys as Britain's part in the Evolution of the Atomic Bomb' in *Science and Culture.*

The moral issues arising out of the atomic bombs were faced by Saha in an editorial 'The Logic of the Atomic Bomb' in *Science and Culture* (1945, **11**, 212). He began by recounting that Louis the Fourteenth had his guns inscribed by the words 'Logice Regum'. This 'Logic of the kings' worked for a while but eventually it failed and Louis had to suffer defeat as the other nations started using the same logic on him. Similarly the idea of dominating the world through use of atomic weapons may work for a while but in a few years the secret will be out and the effect on mankind of the atomic weapons race will be disastrous. In fact as he noted the race is already on. He did not think much of the argument that was made by allied statesmen that the use of atomic weapons was justified by its shortening the war and thus saving many lives. Saha compared it with a similar 'humanitarian' plea by Chenghiz Khan when he massacred the inhabitants of Balkh. He brought in the example of Pax-Romana and eventual ruin of Roman empire to point out, 'If in the near future, we have a one Power World, as appears to be the tendency from the intended use of the logic of the Atomic Bomb, its effect on the rulers would be no less ruinous than on the ruled'[19]. He however concluded on the optimistic note that 'The story of the production of the atomic bomb illustrates as nothing else does, the tremendous powers which science has placed in the hands of man, for good and for evil. It also shows that if a team of well-chosen scientists be selected for studying a problem in an objective way, and be directed to find out the remedy, and if sufficient funds and power be placed in their hands to execute their plans, they can be trusted to solve problems of reconstruction which baffle the professional politician and centuries of neglect can be compressed into decades'[19].

Saha had been appointed a member of the Atomic Energy Committee, along with H. J. Bhabha (Chairman), S. S. Bhatnagar and D. N. Wadia as members of CSIR towards the end of 1945. His thinking about 'Industrial Utilization of Atomic Energy in India' at that time is the subject of his *Science and Culture* article (1947, **13**, 86 and 134).

He was approached in 1948 by the Government of India about the proposed Atomic Energy Commission. It seems that 'He unequivocally expressed himself against the suggestion, because he thought

(1) that atomic energy could not be developed without the prior development of industrial power;

(2) that India should have first trained the personnel necessary for the development of atomic energy, in case they decided to start an A.E.C.'[20]. This was not found acceptable by the Government of India and an Atomic Energy Commission was started with H. J. Bhabha (Chairman), and K. S. Krishnan and S. S. Bhatnagar as members. Hereafter the role of Saha in the country's atomic energy program was only as an outsider to the establishment. One wonders how all this came to pass[21]. R. S. Anderson, in his essay 'Building Scientific Institutions: Saha and Bhabha' attributes the different life trajectories of Saha and Bhabha to the very different family and environment backgrounds from which Saha and Bhabha came. Could it be that Saha was not just not mentally ready for handling large industrial type projects which setting up of an Atomic Energy Commission entailed?

In 1954 the Government of India set up the Department of Atomic Energy. H. J. Bhabha was, naturally, chosen as the Secretary of the Department. Saha took an active part in the Debate on Atomic Energy in Loksabha, of which he was now an elected member since 1951. He gave a talk of 'Future of atomic energy' in India to a group of parliamentarians and others on September 28, 1954. The talk was presided over by Jawaharlal Nehru. His main themes were

(i) India should favourably respond to President Eisenhower's proposals for 'Peaceful utilization of atomic energy' given at the U. N. General Assembly on December 8, 1953. Saha had discussed these in a *Science and Culture* article (1954, **19**, 363).

(ii) India should adopt the French model for Atomic Energy Commission. He had discussed Organization of Atomic Energy work in various countries in *Science and Culture* (1954, **19**, 368).

(iii) There should be no secrecy in atomic energy work.

Saha attended the World Assembly for peace at Helsinki (June 1955) and his address 'Atomic weapons, disarmament and use of atomic energy' appeared in *Science and Culture*, 1955, **21**, 70. His last article 'End of an Unscientific Era' relating to atomic energy begins with the hopeful note 'We hope... the Geneva Conference... will mark the end of a period which has been disliked by all genuine lovers of Science viz., the era of suspicion and secrecy'[22].

National problems

Saha had strong nationalist feelings. Even as a student he took part in a boycott demonstration, on the occasion of the Governor Sir Bampfylde Fuller, in protest against the enforced division of Bengal in 1905. He was, as a result, expelled from the Collegiate School at Dacca and had to lose his stipend and free studentship. When Acharya P. C. Ray organized the North Bengal Relief Committee in 1923, after a catastrophic flood, Saha took an active part and was given charge of publicity. He came in contact with Subhash Chandra Bose who was entrusted with the field work. His interest in river management dates from this period. He later formulated plans for Damodar River Valley Project along the lines of Tennessee River Valley Project in USA[23].

Saha was quite perturbed when after hearing a speech from K. N. Katju, who was the Industries Minister in the first congress government in United Provinces (later Uttar Pradesh) in 1938, in which Katju projected the view 'that a great step was taken by the opening of the match factory towards large scale industrialization'[24]. Saha found such an attitude harmful. So when Netaji Subhash Bose was elected Congress President, Saha approached him, and discussed with him the need for an appropriate national planning. As he put to Bose 'The Congress is now getting into power. But how would you solve the problems of poverty, unemployment and disease after you get power?' As Saha recalled later 'The Netaji said that the Congress leaders had been engrossed in the struggle for independence, and the leaders had no time to consider other problems, but he would like to have my advice on this point. I... told him that if Congress leaders were of the same mentality as Katju as he had revealed himself in his speech and thought, that the 'Spinning wheel' and match factories meant that we have taken a great step towards industrialization, the Congress would bring disaster to the country, when they get into power. The Netaji admitted the strength of my remarks and asked me what was to be done. I advised him to form a National Planning Committee to thrash out problems of industrialization and national reconstruction. He readily agreed...'[24]. Saha later worked behind the scenes to get Pandit Jawaharlal Nehru to accept the chairmanship of the proposed committee. K. T. Shah, an eminent economist, was appointed as honorary General Secretary. Saha was an active member of this committee. He was also a member of the subcommittee on River Training and Irrigation, as well as Chairman of the Power and Fuels Subcommittee.

Saha passionately believed that Science and Technology offer a rational way to solve the national problems. After his move to Calcutta in 1938, he began to come out more and more from the 'ivory tower' of scientific research. He brought to bear his sharp intellect to analyse problems relating to the country's water and energy resources, industrialization and planning[25]. Not being satisfied with the slow progress that the country was making under the early years of independence he stood for parliamentary elections of 1951 as an independent candidate from Calcutta North-East Constituency and was elected with a large majority. His later thinking on national problems is contained in a lengthy pumphlet *Rethinking Our Future* which he published in 1953 as 'an objective review of the report of the Planning Commission and its industrial programme'[24].

Saha passed away on 16th February 1956 in New Delhi on his way to the Planning Commission Office.

Epilogue

Saha also wrote a text book *A Treatise on Heat*, with his student B. N

Srivastava and first published it in 1931. That the book was written at Allahabad, with its hot climate, comes through vividly in the following passage in it. 'The slow velocity of penetration of the daily heat wave must have been familiar to all observant minds in a tropical country. Here the house-roofs are exposed to the scorching heat of the sun and at 2 p.m. the temperature may be as great as 60°C. But this temperature travels inward at the extremely slow rate of 9.1×10^{-4} cm/sec or 6.4 cm per hour in a mass of concrete (For concrete h may be taken to be 0.0058). Hence to penetrate a wall depth of 30 to 40 cm is the usual thickness of walls, a period of 5 to 6 hours is needed. The inside of the room, provided the windows are shut, therefore reaches its maximum temperature at about 7 or 8 p.m. when the walls become intolerably hot and begin to radiate. Most people must have experienced that it is found impossible to sleep indoors at this time. The minimum at the top of the room is reached at about sunrise. So the rooms are found to be cool from 11 a.m. to about 2 p.m. when the outside is blazing with heat'[26].

Saha's 'treatise' was quite influential and went through many editions. I myself learnt about the work of M. N. Saha on thermal ionization and that of S. N. Bose on quantum statistics through this text book. It was a source of inspiration to us to see the work of our countrymen alongside those from the West, where modern science started.

C. N. Yang once mentioned to me that when, as a young student, he was in Calcutta, on his way to USA for graduate studies, he went on to make a call on Saha. He had been asked to do that by his teacher. Given the developing nature of Science in Asia we all needed our heroes and he was one of them.

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Edited and published by Prof. S. Ramaseshan, Current Science Association, Bangalore 560 080.
Typeset by Book Makers (I) Pvt. Ltd., Bangalore 560 009, Printed at Printek Printers, Bangalore 560 079.