THE GLITTERING SPECTRUM OF MEGHNAD SAHA

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Proceedings of

M. N. Saha Centenary Seminar

28—30 October 1992

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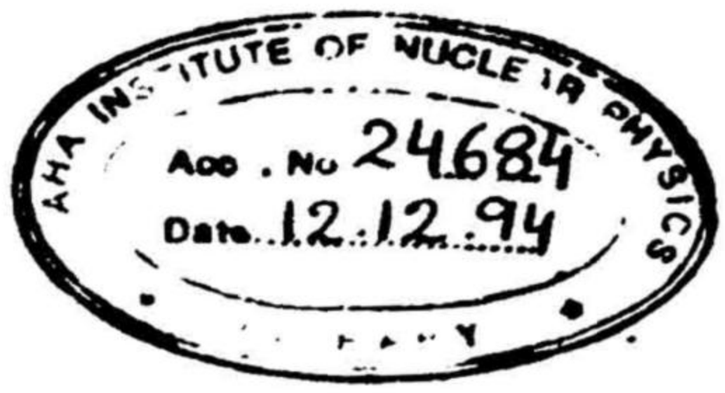
JAYANTA BASU

Local Organising Committee

Birth Centenary Celebration of Prof. M. N. Saha

SAHA INSTITUTE OF NUCLEAR PHYSICS

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MEGHNAD SAHA

Born October 6, 1893 Died February 16, 1956

PREFACE

Meghnad Saha born of a lower middle class family in colonial India rose to great heights by dint of his intrinsic merit coupled with hard work and strong determination. The theory of thermal ionization, which he developed and applied to resolve a member of puzzles in stellar spectra including the spectrum of the sun, has universally been acclaimed as a milestone in astronomy as it laid the very foundation of astrophysics. Saha also made important contributions to various other fields of science, namely, nuclear physics (the study of which he initiated in India), atmospheric and space physics, etc. He played a pioneering role in building scientific institutions and organising scientific research in the country. As a teacher he could well inspire his students, many of whom earned distinction as scientists. The book entitled 'A Text-book on Heat' (later renamed 'A Treatise on Heat'), written by him in collaboration with B. N. Srivastava, was a monumental piece of work, which endeared itself to students as well as research workers.

Saha's talent was not, however, confined to the so-called ivory tower of science ; he got himself deeply engaged in the practical application of science to the benefit of the society at large. For example, he made an extensive study of river management and framed the basic scheme of the Damodar Valley Project. As the Chairman of the Calendar Reform Committee set up by the Govt. of India, he formulated a National Calendar on scientific basis, which was accepted by the Parliament as an important step towards national integration. He was in the forefront in the matter of tackling various social and economic issues facing the country. He wrote profusely on the issues in the monthly magazine 'Science

and Culture', of which he was the Editor, and in many other reputed magazines, newspapers etc. He presented a thorough analysis of some of the issues in the speeches he made in the Parliament, of which he was a Member.

The Centenary Seminar held under the auspices of the Local Organising Committee, Birth Centenary Celebration of Prof. M. N. Saha, comprising representatives of the Saha Institute of Nuclear Physics, Indian Association for the Cultivation of Science, and Department of Physics, University of Calcutta, aimed at bringing into focus the wide spectrum of inspiring activities of the talented person. The Seminar was inaugurated by Prof. Satyasadhan Chakraborty, Minister of Higher Education, Govt. of West Bengal, at the Bidyut Bhawan, Bidhannagar, Calcutta, on 28 October 1992. The inaugural session was presided over by Dr. P. K. Iyengar, Chairman, Atomic Energy Commission, Govt. of India. Messages on the occasion were read out, as received from Dr. R. Ramanna, Chairman, National Committee, Birth Centenary Celebration of Prof. M. N. Saha, and Shri Ajit Kumar Panja, Minister for Information and Broadcasting, Govt. of India, who could not be present due to unforeseen circumstances. The session was addressed by Prof. M. K. Pal, Director, Saha Institute of Nuclear Physics, and Prof. A. K. Barua, Professor and Ex-Director, Indian Association for the Cultivation of Science.

The Seminar consisted of five academic sessions, in which invited talks were delivered by eminent scientists and experts. The first session entitled 'Meghnad Saha and Nuclear Physics' and chaired by Dr. B. D. Nagchaudhuri, former Vice-Chancellor, Jawaharlal Nehru University, New Delhi, was held on 28. 10. 92 (afternoon) at the Saha Institute of Nuclear Physics, Bidhannagar, Calcutta-64. The second session on 'Meghnad Saha and Astrophysics' and the third session on 'Meghnad Saha and Atmospheric & Space Physics', chaired, respectively, by Prof. A. K. Roychaudhuri, Ex-Professor, Department of Physics, Presidency College, Calcutta, and Prof. M. K. Dasgupta, Ex-Professor and Head, Institute of Radio Physics & Electronics, University of Calcutta, were organised on 29. 10. 92 at the Indian Association for the Cultivation of Science, Jadavpur, Calcutta-32. The fourth session entitled 'Meghnad Saha and River Research & Calendar Reform' and the fifth session entitled 'Socio-economic Role of

Meghnad Saha', presided over, respectively, by Prof. S. K. Sen, Minister of Power, Science & Technology, Govt. of West Bengal, and Prof. S. K. Mukherjee, former Vice-Chancellor, University of Calcutta, were held in the Meghnad Saha Auditorium, Science College Campus, Calcutta-9.

The present Volume contains all the invited talks presented in the Seminar, with the sole exception of the talk entitled 'Radio Astronomy and Ionospheric Effects', of which only the abstract has been received and included herein. The talk entitled 'Meghnad Saha and Cosmic Abundances of Elements', which was scheduled but could not be presented owing to unavoidable reasons, has also been included. As the talk by Prof. H. N. Mukherjee in the session on 'Socio-Economic Role of Meghnad Saha' was in Bengali, an extended abstract in English has been incorporated along with the original talk. The bio-data of Meghnad Saha, showing his multifarious activities and remarkable achievements, and a list of his scientific papers are given in the Appendices.

On behalf of the Local Organising Committee, Birth Centenary Celebration of Prof. M. N. Saha, may I express our sincere thanks to the dignitaries in the inaugural session of the Seminar, to the chairpersons and invited speakers of the different academic sessions as well as to all other participants, who made the Seminar a success by their active and hearty cooperation. We acknowledge our thanks to the Department of Atomic Energy, Govt. of India, for financial assistance towards the Seminar and publication of this Volume. Finally, I would like to thank my colleagues who have been helpful in the compilation of the materials for this publication.

Calcutta
6 October 1993

Jayanta Basu

"His (Prof. Meghnad Saha's) *famous early work on the ionisation of stellar atmosphere initiated a vast field of enquiry and alone assures to Professor Saha a worthy place in the history of the physical sciences. Since that time Professor Saha has worked successfully in many fields and has had outstanding success as a teacher and as a director of both theoretical and experimental research. Professor Saha is also distinguished by his keen interest and deep understanding of the social forces active in the contemporary world, and has concerned himself with ability and devotion to the immense practical problems facing India in its struggle for social and economic advancement."*

P. M. S. Blackett
Imperial College, London
2 October 1953

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Meghnad Saha and Nuclear Physics

MEGHNAD SAHA AND HIS CONTRIBUTIONS TO NUCLEAR PHYSICS

S. N. GHOSHAL

ABSTRACT

Following a brief sketch of the scientific activities of Prof. M. N. Saha, his own work in various areas of nuclear physics is reviewed. The initiation he made in nuclear physics research in the country is discussed.

Professor Meghnad Saha joined the University of Calcutta as Khaira Professor of Physics in November 1921 after his return from Europe. By that time he had acquired international fame because of his paper on the theory of thermal ionization and its successful application in explaining the stellar spectra.

In 1923 Saha left Calcutta to join the Department of Physics of the Allahabad University as Professor and Head of the Department. At Allahabad he reorganised the post-graduate and under-graduate teaching in physics thoroughly and initiated research in diverse branches of physics. These included, besides his own special field of astrophysics, spectroscopy, ionospheric propagation of radio waves, nuclear physics, statistical mechanics etc. As a result of his untiring efforts, the Department of Physics of the Allahabad University became one of the focal points of physics teaching and research in whole of Northern India and attracted a host of brilliant young people to work with him. Many of them attained all-India and international fame as physicists in later life. They included P. K. Kichlu, D. S. Kothari, R. C. Majumdar, Saradindu Bose (later Director General of Meterology Department in India), G. R. Toshniwal, B. N. Srivastava and others.

After about fifteen years of the most fruitful period of his academic life at Allahabad, Saha returned to Calcutta as the Palit Professor and Head of the Department of Physics in 1938.

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After his return, he proceeded to revise the post-graduate curriculum in physics at the Calcutta University and introduced nuclear physics, both as a general paper and as a special paper. With characteristic zeal, he initiated research in different branches which included nuclear physics, cosmic rays, ionospheric waves propagation, biophysics etc. Apart from these he took keen interest in various nation building activities. As a sequel to these he initiated work on vacuum technology, flood control method etc.

Saha's Own Work on Nuclear Physics

As we saw, Saha's interest in nuclear physics stems back to his Allahabad days. His main interest at that time was in the theory of beta activity. This was before the neutrino hypothesis had been advanced by Pauli. It is interesting to note how Saha had thought about the explanation of the continuous beta distribution. According to him the phenomenon was an example of the materialisation of gamma rays emitted by the nucleus to produce an electron-positron pair within the nucleus. The positron fails to come out because of the barrier penetration problem and hence only the electron is observed. The positron is ultimately absorbed by a neutron in the nucleus, which is thus changed into a proton. Saha's collaborator in these works was D. S. Kothari. In retrospect, it appears that theirs was a futile exercise. However, as in other fields of physics, out of such so-called futile efforts, the truth finally comes out. So Saha's efforts were not probably as futile as they might appear to us to-day.

Another interesting work in this period related to Saha's efforts at exploring the origin of the masses of the proton and the neutron. As a sequel to this work he calculated the mass of the magnetic monopole, the existence of which Dirac had predicted. Saha calculated the mass of the monopole on the basis of classical electrodynamics and predicted the mass to be about 2.5 times the proton mass. The important point to note is that he predicted the monopole to be quite heavy which is also the conclusion of the Grand Unification Theory. The latter theory, of course, predicts a much heavier monopole. As far as I know, the predicted mass is in the range of 1600 GeV. It is also of interest to note that Saha predicted that the monopole mass might be still heavier if its radius was taken to be smaller.

The next phase of Saha's work on nuclear physics started after his return to Calcutta. To my mind, his most important work was the proposal of a *nuclear chart* in which all nuclei, stable and unstable, are shown in

a chart plotting the isotopic number $I = N - Z$ (excess of the number of neutrons over protons) against the mass number A. This work which was published in 1940 might be regarded as a precurser to similar charts proposed by others including the well-known Segrè chart.

Personally I feel that Saha's chart is superior to the other charts in some respects. Because of the limited range of values of $I = N - Z$, its natural spread is in the horizontal direction along the A-axis. Since the Segrè chart is an N vs Z plot, it has to be broken up piece-meal to keep it within managable limits in the vertical direction and make it appear horizontal. Further, radioactive transformations are shown by changes in the vertical (for beta) and horizontal (for alpha) directions. However, there is not much point in elaborating its virtues at this late date.

Saha's interest in beta activity continued at Calcutta. With A. K. Saha he proposed some systematics for beta-active nuclei and suggested modification of the semi-emperical nuclear mass formula. Later I also collaborated in this work. Since the Second World War intervened, we were greatly handicapped in procuring the necessary data for these studies in systematics due to non-availability of journals and total stoppage of all communications.

As we all know, Saha had multi-dimentional interest in physics. One of the fields he became interested in was the application of nuclear physics in geological age determination.

Early in 1951, an International Conference on Cosmic Rays was organized at T.I.F.R., Bombay, in which Saha took part. As a sequel to this he published a paper on the origin of neon nuclei in the primary cosmic rays in *Nature*. He showed that though stripped neon nuclei formed a relatively strong group in the cosmic ray primaries, there was no evidence of neon in the spectra of the sun or of the stars. This provided a strong evidence against the local origin of the cosmic rays from the sun or the stars.

Saha's direct personal contribution to nuclear physics research ended with these works.

Initiation of Nuclear Physics Research by Saha

Saha was greatly interested in building up an active group for nuclear physics research. He realized that this effort could not succeed without

an accelerator of charged particles. Hence he planned to have a cyclotron built in the Palit Laboratory of Physics of the Calcutta University. The cyclotron he proposed to build was modelled after the 37 inch Berkeley cyclotron built by Lawrence. Unfortunately, due to the technological bottle-necks and the intervention of the war, it took a fairly long time to complete the work. The cyclotron became finally operational shortly after Saha's death in 1956.

However, lack of accelerator facility did not deter him from organizing other types of nuclear physics experiments. At his suggestion A. K. Saha proceeded to build a beta ray spectrometer indigenously and carried out a thorough theoretical study of the instrument. Some low energy beta spectra were studied using sources which Saha was able to procure from abroad when he went to Europe and America as a member of the Scientific Mission immediately after the war.

Another piece of experimental work of considerable significance was the measurement of thermal neutron fission cross-section of uranium-235 by S. Biswas and A. P. Patro. This was one of the earliest such measurements by workers outside the Anglo-American circle.

Side by side with these experimental works, an alpha decay systematics was undertaken by these same workers who proposed an improvement of Geiger-Nuttall law in 1948.

Experiments were also started on cosmic ray research. N. N. Das Gupta and P. C. Bhattacharya measured the muon mean life using the method of comparison of the cosmic ray intensities at different altitudes, first proposed by Rossi. A counter-controlled cloud chamber was set up by S. Ghosh.

Biophysical research was also started in the newly started Biophysics Division. A radon extraction plant was set up using an one gram radium source for the purpose of supplying radon needles to cancer hospitals. Autoradiographic technique was developed. Some initial work was done in the treatment of goitre using radioiodine by S. Chatterjee and others.

The Institute of Nuclear Physics which gradually took shape was the fruition of Saha's dream of an active and vigorous research centre undertaking fundamental work in nuclear physics and other related fields. It was subsequently named 'Saha Institute of Nuclear Physics' as a token of respect to his memory.

□□□

MEGHNAD SAHA : A PIONEER OF NUCLEAR PHYSICS

S. P. PANDYA

ABSTRACT

M. N. Saha plunged boldly in nuclear physics at a time when it faced a critical situation, and directly confronted one of the most fundamental problems then existing, viz., beta decay. His ideas on this problem as well as his subsequent work on stability of nuclei are discussed.

I am very grateful to the organisers of this seminar for an opportunity to join in the celebration of Prof. Meghnad Saha's birth centenary. It gives me a great pleasure to be associated with this event because I do belong — perhaps in an indirect way — to the Saha gharana in Indian physics.

Let me justify my intrusion. I did my B. Sc. degree from what was then called the M.T.B. College in Surat (Southern part of the Gujarat State.) At that time the Professor and Head of the Physics Department there was Prof. M. S. Desai, who had done his M. Sc. from the Allahabad University, when Prof. Saha was teaching there. After M. Sc. he also did some research work — in spectroscopy, I believe — under Prof. Saha's guidance. It seems he did not complete his Ph. D., but came away to Surat. He was a contemporary of Prof. D. S. Kothari and Prof. R. C. Majumdar.

Later I went to the Delhi University, and had the good fortune to learn a great deal of physics from both Prof. D. S. Kothari and Prof. R. C. Majumdar. It was a wonderful period of my life.

Only once I had the good fortune to meet Prof. Saha. He was visiting Delhi, staying with Prof. Kothari, and in the evening I happened to go

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to Prof. Kothari's house. He immediately introduced me to Prof. Saha as "Manohar's (Dr. M. S. Desai) student". Very kindly Prof. Saha made me sit near him, and after inquiring about Prof. Desai, and a few casual questions, he asked me many questions about the early history and culture of Gujarat, about various kings and monuments and so on. I was really in awe of his prodigious memory and knowledge of such matters.

Since I had no further personal contact with Prof. Saha, I can only talk about his contributions to nuclear physics on the basis of his published work in this field. From his collected scientific papers one can see that he wrote only about seven papers directly related to nuclear physics, essentially between 1933 and 1946. I will try to discuss some of this work, but first it would be useful to have some idea of the state of nuclear physics around the world at that time.

If I may briefly remind you of the development of nuclear physics, there was an initial phase of nuclear physics without the nucleus — when the attention was focussed entirely on the study of radioactivity. Apart from elucidating the properties of various radiations, the question of the actual seat of radioactivity in the atom was a major puzzle. This phase ended with the discovery of the nucleus by Rutherford in 1911.

From 1911 onwards there began a considerably active experimental program on measurements of nuclear properties — charge, mass and binding energy, spin etc. The measurements of masses being directly related to the stability questions and to radioactivity, studies were of course pursued vigorously. Various other properties such as the size of the nucleus, magnetic moments etc. were also studied. An enormous data base of nuclear properties was built up. Experimental observations also led to the conjecture of Rutherford in 1921 about the existence of a strong nuclear force.

I would consider this second phase of nuclear physics to end around 1932. Towards the end of this phase — in 1928 — the first application of quantum mechanics to the nucleus appeared. Using quantum theory, Gamow and independently Condon and Gurney were able to explain the alpha decay and all its major features. However, nuclear physics was in deep trouble by 1932. The continuous beta-spectrum, discovered in 1914, could not be understood at all with the concepts then in vogue. The puzzle was so acute that even Bohr was tempted to consider abandoning conservation laws for energy and momentum. The second puzzle

was the constituents of the nucleus. It was tempting, simple and obvious, to consider it as made up of protons and electrons — the only two fundamental particles known then. But this produced serious conflict with the data on spins, statistics, magnetic moment etc. Again at this stage, eminent scientists were tempted to postulate that the proton and the electron inside the nucleus no longer have the properties we measure in their free state. It was indeed a situation that had scientists at their wits' end. A lot of really wild ideas — as they would appear to us today — were floating around. This is where Saha appears on the scene — still young (only 40 years old), daring, always curious and questioning.

But before I come to that, permit me to make a slight detour. In 1931, Saha wrote a very brief note in *Nature* [**128** (1931) 817] on the spin of the photon. Experiments were being carried out by various groups to see if the spin of the photon can be established by studying the polarisation of light. Kastler and Frisch had concluded that photon has no spin, whereas Raman and Bhagwantam analysing the results of Bar and Hanle argued that photons possess spin. Saha briefly discusses the arguments of both the groups, and dismisses both of them out-of-hand ! He finds it unjustifiable to describe polarisation with the aid of a spin. I find this interesting—even amazing — in view of Saha's close association with S. N. Bose. Most of you must be familiar with the story related by P. Ghosh [*Physics News*, **13** (1982) 130] and quoted by A. Pais in his famous book, *Inward Bound*. The derivation of Planck's formula by Bose in his famous paper of 1924 contains an ad-hoc factor of 2, for which the paper merely says, "It seems required." The story says that in the original paper Bose has explicitly proposed that the photon carries one unit of angular momentum and this could take only two orientations, hence the factor of 2. It seems Einstein did not like this, removed this part, and wrote to Bose that at this stage it was not necessary to introduce such a concept. But Bose had indeed linked, correctly and explicitly, the polarisation of light to the spin of the photon.

This note also gives an interesting pointer to Saha's mode of doing physics. His collected papers contain several such examples. Obviously he read scientific literature voraciously, and very critically. He quickly picks up on various papers, synthesizes their results, draws his own conclusions, corrects errors, explores further implications, and writes a brief note in *Nature*.

Now I get back to Saha and nuclear physics. The very first paper he

wrote on the subject (with Prof. D. S. Kothari as co-author) was on beta decay. In this he proposed a novel solution for the continuous beta-ray spectrum, which as we know was one of the two major problems in nuclear physics. One can make several interesting comments on this paper [or rather a pair of papers — *Nature* **132 (1933) 747 ; 133 (1934) 99.]**

Obviously Prof. Saha was very well read on the subject, fully familiar with at least all the published material. Although the notes appearing in *Nature* were necessarily brief, they also wrote a detailed paper in the *Bulletin of the Allahabad Academy of Science* **[5 (1934) 257]** which shows his thorough acquaintance with the field. Saha knew about the discovery of the neutron, and immediately accepted the neutron-proton model for the nucleus. To appreciate this we should bear in mind that even in Europe the existence of electrons in the nucleus was not fully abandoned till 1934 when Fermi proposed his theory of beta decay. The reason of course was that even with the discovery of neutron as a nuclear constituent, the appearance of electrons in beta decay remained an enigma till Fermi provided the basic explanation. At the same time Saha was not familiar with the neutrino proposed by Pauli. Although Pauli discovered neutrino apparently around November 1930, he only mentioned it in personal correspondence (to Heisenberg) and orally at conferences and in seminars for several years. Perhaps as a result of isolation in India Saha did not hear of the neutrino till later.

Prof. Saha's first entry into nuclear physics began with an attack on what was obviously the most challenging problem at the time. He was also easily stimulated by the discovery of the neutron and the observations on pair production of $(e^+ - e^-)$ by photons. He was able to put together several different observations, including theory of alpha decay. He was aware of the arguments on whether a neutron is a fundamental particle in its own right or if it is a bound state of a proton and an electron. However, to suit his arguments, he actually proposed the proton as a composit of a neutron and a positron. This was probably because he was not yet aware of beta decays in which the positron is emitted rather than the electron. Otherwise he would have placed the neutron and the proton on a symmetrical footing, and might even have suggested iso-spin.

His "suggested explanation of beta-ray activity" was essentially very straightforward. If Gamow could propose the existence of a potential barrier at the nuclear surface, holding alpha particles in, Saha proposed

more than one such potential barriers in the nucleus with alpha particles tunnelling through these with specific lifetimes. Gamow's barrier arose from the well-known Coulomb force. Where could Saha's additional barriers come from ? He coolly bypasses the question. (So did editors and referees of *Nature* !). But once the existence of several barriers in the nucleus for alpha particles are granted, the rest is straightforward. The existence of alpha particles in the nucleus is not really questioned. These alpha particles tunnel through the internal barrier, in the process emitting a gamma ray. Within the nucleus the gamma ray generates a pair of an electron and a positron. To get rid of the positron, Saha postulates that it is absorbed by a neutron which converts into a proton. The electron emerges. The lifetime corresponds to that of the alpha tunnelling through the barrier, the energy is decided by the pair production site in the nucleus.

This is a remarkable model, and only serves to show us the confusion and lack of detailed knowledge of various fundamental processes that existed at the time. There were no specific calculations, and in the light of later developments, this idea soon became obsolete.

This note also reveals Saha's interest in using precise language. The pair-production was termed as "materialisation of light quanta" by the discoverers. Saha expresses his dissatisfaction, and renames the process as "electro-division of the quantum". In the second note he again revises this to "electrofission of quantum"!

The second note to *Nature* contains an interesting suggestion (attributed to D. S. Kothari) that the neutron is a dipole formed of two Dirac magnetic poles of opposite sign, separated by a distance e^2/Mc^2. (They leave us to guess whether M is the mass of the neutron or of the Dirac monopole.) Subsequently Prof. Saha developed this idea into an elaborate scheme in a note on the origin of mass in neutrons and protons.

It is noteworthy that Prof. D. S. Kothari was initiated into nuclear physics by his guru as early as 1933, when major and exciting developments were taking place in nuclear physics. Prof. Kothari subsequently went to Cambridge, which was in those prewar years a Mecca for nuclear physicists. And yet he was not attracted by the subject. I wonder why ? Was he disenchanted by the failure of the first foray into nuclear physics ? Or perhaps his interest was only in theoretical physics and

Cambridge had little activity in nuclear theory. Rutherford's aversion to theoretical physicists was well known. Anyway, the story of nuclear physics in India would have been very different if Prof. Kothari had remained in nuclear physics.

I would also like to point out that in the obituary of Prof. Saha written by Prof. Kothari for the Royal Society of London, he does not mention the early nuclear physics work of Saha. Kothari only begins with 1938—stating that "Saha early realised the growing importance of nuclear physics and the impact it was likely to have on the country's scientific and industrial progress."

After the first adventure Saha did not make any further contribution to nuclear theory. It is known that he had very clearly realised the importance of the neutron as a tool for probing nuclear structure. He wanted to study nuclear reactions induced by neutrons, but he could not gather the necessary resources. In any case, Fermi soon pre-empted this field. However, Saha continued his efforts to establish experimental programmes in nuclear physics at Calcutta, and the results are there for all of us to see in the form of a large school of nuclear physics here, and this beautiful institute named after him.

Why did he not pursue nuclear theory—which would have been so much easier ? There were so many new developments—Yukawa's theory of nuclear forces, Bohr's work on nuclear reactions, beginnings of a shell model etc. Somehow he remained aloof from all these developments.

Saha's taste for and skill in handling large amounts of experimental data brought him back to nuclear physics research again in 1940's, and resulted in two major papers. He had a keen eye for order, symmetry and systematics even when presented with apparently random sets of data. In these papers he again reverted to his familiar field of nuclear stability and beta decay. In the first paper [*Proc. Nat. Inst. Sc. Ind.* **6** (1940) 45] he, along with S. C. Sirkar and K. C. Mukherjee, proposed a specific plan to make a nuclear chart where $I = N - Z$ was plotted against $A = N + Z$. All stable and unstable isotopes then known were presented on this chart. A study of this chart enables one to see various systematics, and draw some simple rules to be able to predict where one may expect stable nuclei and where beta-active nuclei. Some of these rules would of course be rewritten now, in the light of the increased knowledge of a

very large number of unstable nuclei. It would be interesting if someone brings out a completely updated version of this chart.

We can check some of the statements made in this paper in the light of our present knowledge.

^{39}A predicted to be stable, is actually unstable, whereas ^{57}Co predicted to be unstable, and then believed to be stable is now found to be radioactive. ^{98}Ru was predicted to be stable, and is indeed found so. ^{90}Sr was predicted to be stable, but now is known to be radioactive. For Technitium (referred to as Masuriam here) stable isotopes A=97 and A=99 were predicted but now we know there exist no stable isotopes.

We need not go on, since the actual observations have now revealed much more than was known in those days. It may be noted that Saha's version of the rules for stability of nuclei is expressed in terms of the neutron excess I, whereas to-day we speak more familiarly in terms of even-even, even-odd (odd-even) or odd-odd nuclei, i.e. in terms of Z and N. In Saha's model it would be a little difficult to incorporate specific shell closure effects.

In a subsequent paper, written jointly with A. K. Saha [*Trans. Nat. Inst. Sc. Ind.* **2** (1946) 193] Saha came back to the same theme and attempted to understand the emperical rules for stability described earlier in terms of binding energies and mass formulas. Actually his prime interest was in being able to calculate the energies released in beta-decay processes. For this purpose. the authors first wrote down the energies involved in beta decay (i.e. emission of electron or of positron, or in K-capture process) in terms of the binding energies of the concerned nuclei, and then used the Bethe-Weizacker mass formula for the binding energies. As usual with him, Saha went into great details, with a very thorough discussion of all aspects, and of course, all the energy formulas were expressed in terms of A and I, rather than N, Z. Bethe-Weizacker mass formula contains in addition to the volume term, a surface term ($\sim A^{2/3}$), a symmetry term ($\sim I^2$) and a coulomb term. Saha's main contributiuon was to add to this, what he called a spin-dependent term, but today we would call it a pairing term, which distinguishes between even-even, even-odd and odd-odd nuclei. He also tried to explore spin-dependence or magnetic moment-dependence of this term, but as we now know better, such an attempt does not succeed.

This paper was really exhaustive, encyclopaedic, and a massive review of almost all known data on beta-active nuclei with $I = -1$ to $I = 6$. Each nucleus was discussed in detail, and all available data was reviewed. It reminds me of his monumental report on the proposal for a National Calendar. There is not much point today in going through all the details, since much has changed today. For example, at that time Saha was led to believe that ^{5}Li when found would be stable or would decay by extremely slow K-capture to ^{5}He—which would in turn be stable !

It is worth noting that in addition to Dr. A. K. Saha, Dr. S. N. Ghoshal, one of our speakers to-day, also participated actively and intensively in this programme.

A brief and precise summary of this massive paper appeared in *Nature* [158 (1946) 6]. This is also an indication of Saha's style—to publish in Indian journals an extensive piece of work, and then publish abroad (often in *Nature*) a summary.

I am very happy to have this opportunity to pay my humble tribute to Prof. M. N. Saha, a truly great and distinguished scientist, of whom one could justifiably say—the father of nuclear physics in India.*

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* As Prof. Pandya could not attend the Seminar due to unavoidable reasons, the paper was presented by Prof. Shyam at Prof. Pandya's request.

MEGHNAD SAHA AS A PARTICLE PHYSICIST
(AN APPRECIATION)

T. PRADHAN

ABSTRACT

A critical and appreciative exposition of M. N. Saha's contributions to magnetic monopole theory and his model of the neutron as a bound state of two equal and oppositely charged (magnetically) monopoles are presented.

Introduction

The three most important works of Meghnad Saha in physics can be listed as : (a) Theory of thermal ionization, (b) Text book on heat, and (c) Theory of magnetic monopoles. His interest in particle physics of his time led him to the investigation of magnetic monopoles which is also an exciting topic in contemporary particle physics. In this talk for which I have the previlege to be invited to his Birth Centenary Seminar I propose to give a critical and appreciative exposition of his theory of magnetic monopoles and his model of the neutron as a bound state of two monopoles of equal and opposite strength.

During his fifteen year long tenure at the Allahabad University one of Saha's interests was the origin of masses of elementary particles. It was thought at that time that masses are of electromagnetic origin, and there were models for the same. Saha realized that such models would not apply to the neutron since it has no charge. However, since it has a magnetic dipole moment, on the suggestion of D. S. Kothari, he worked out a theory in which a neutron is taken as a bound state of two magnetic monopoles of equal and opposite strength. The mass of the neutron would then arise from the magnetostatic energy of the two monopoles. Calculation of this required magnitude of the mass and magnetic charge of the monopole. This led Saha to one of the most important results of the

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century in theoretical physics—the quantization of electric charge, a result which had been obtained by P. A. M. Dirac by a different method.

Dirac-Saha Quantization

Saha [1] derived Dirac's result [2] for the electric charge quantization by an elegant method. He considered a two-body system of a monopole of strength g and electric charge e, which is shown in Fig.1 along with the electric and magnetic fields generated at two external points C and A.

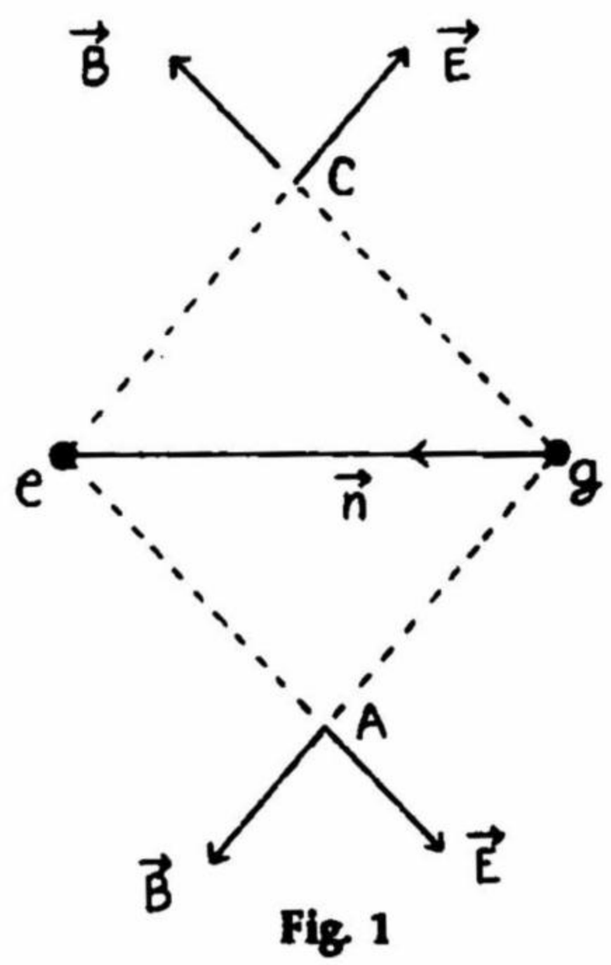


Fig. 1

It will be seen that while the elctromagnetic momentum $\vec{E} \times \vec{B}$ at C points up (relation to the plane of the paper), it points down at A, which means that an angular momentum is generated. Summing the contributions of all the points in space one gets

$$\vec{J} = \int d^3r \times (\vec{E} \times \vec{B}) \tag{1}$$

The integration has been carried out in the book *Classical Electrodynamics* by J. D. Jackson [3], and the result is

$$\vec{J} = \frac{eg}{c}\vec{n} \tag{2}$$

where $\vec{n}$ is a unit vector from g to e. This result was obtained by J. J.

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Thomson and H. Poincare around 1895 and is to be found in the book *Mathematical Theory of Electricity and Magnetism* by J. J. Thomson [4]. It will be noticed that the angular momentum is independent of the distance between the magnetic monopole and the electric charge. It is thus an intrinsic angular momentum. Saha applied quantization rule and equated it to the fundamental unit of angular momentum $\hbar/2$. This gives

$$\frac{eg}{c} = \frac{\hbar}{2} \tag{3}$$

which is Dirac's result for charge quantization. This formula was derived much later by H. A. Wilson [5] following exactly the same method as that of Saha without any knowledge of Saha's work. Having come to know of this, Saha [6] reiterated his result in a letter to the Editor of the *Physical Review*, in which Wilson's letter had been published.

Jackson in his book remarks that it is rather surprising that a spinless two-body charge-monopole system can carry half a quantum of angular momentum. But it transpires that this has been advanced recently for motivating supersymmetry dynamically [7]. Should we say that Saha had some inner vision which prompted him to invoke such an idea ?

Monopole Mass

As already mentioned, Saha obtained the monopole mass by equating its magnetostatic energy to Mc^2 :

$$\frac{g^2}{2R} = Mc^2 \tag{4}$$

The radius R was obtained from the equation

$$\frac{e^2}{2R} = mc^2 \tag{5}$$

for electron mass with Eddington's assumption [8] that radii of all elementary particles are equal. Using eqns. (3), (4) and (5) Saha [1] obtained

$$M = \frac{m}{4\alpha^2} = 4712m \tag{6}$$

where α = fine structure constant.

Dirac Equation for $g^{(+)}\,g^{(-)}$ Bound State

As mentioned earlier, Saha [1] at the suggestion of Kothari considered neutron to be a bound state of two equal and oppositely charged monopoles. Since the monopole strength according to eqn. (3) is about 70 times that of the electronic charge, the potential between $g^{(+)}$ and $g^{(-)}$ would be about 5000 times larger than that between proton and electron in the H-atom. The binding energy calculated on the basis of the non-relativistic Schrödinger equation would be very large compared to the rest mass of the monopole. It is on account of this that Saha used Dirac equation to the $g^{(+)}\,g^{(-)}$ bound state problem. It is relevant to ask why he did not use Klein-Gordon equation which would be the correct thing to do for a spinless system. One thing is immediately clear that the KG equation bound state will not have half odd integer angular momentum. Saha needed $j = 1/2$ for the $g^{(+)}\,g^{(-)}$ ground state in order that it represents the neutron which has spin 1/2. It is presumably for this reason that Saha used Dirac equation. It may be recalled in this connection that Sommerfeld's old quantum theory treatment of a relativistic spinless electron in a Coulomb field [9] yields the result of the Dirac equation.

Saha was aware of the problem of a suitable co-ordinate system for the relativistic two-body system where each particle has its own individual space and time. His artifact is to reduce the two-body system to a one-body one by assuming that the two bodies are always at the opposite ends of a diameter passing through the centre of gravity and their motions are equal and opposite. This is equivalent to taking $\vec{p}_1 + \vec{p}_2 = 0$.

With the above assumption, the Dirac equation for the $g^{(+)}\, g^{(-)}$ system reduces to

$$[\,\vec{\alpha}.\vec{p} + \beta M + V(r)]\,\psi = E\,\psi \tag{7}$$

with $V(r) = -\frac{g^2}{2v} = \frac{e^2}{8\alpha^2}\frac{1}{r}$ and $M = \frac{m}{4\alpha^2}$. Writing

$$\psi_{jlm} = \begin{pmatrix} ig(r)\Omega_{jl'm}(\theta, \varphi) \\ -f(r)\Omega_{jlm}(\theta, \varphi) \end{pmatrix} \tag{8}$$

where $l' = 2j - l$ and $\Omega_{jlm}(\theta, \varphi)$ are spinor spherical harmonics, equation (7) reduces to

$$\frac{dg}{dr} + (1+k)\frac{g}{r} - \left(E + M + \frac{1}{8\alpha r}\right) f = 0 \tag{9a}$$

$$\frac{df}{dr} + (1-k)\frac{f}{r} - \left(E + M + \frac{1}{8\alpha r}\right) g = 0 \tag{9b}$$

where

$$k = \begin{cases} -(l+1) \;\; for \;\; j = l + \frac{1}{2} \\ -l \;\; for \;\; j = l - \frac{1}{2} \end{cases} \tag{10}$$

Solution of eqns. (9) gives for energy

$$E = \frac{Mc^2}{\sqrt{1 + \left(\frac{\beta}{n_r + \sqrt{k^2 - \beta^2}}\right)^2}} \tag{11}$$

where $\beta = \frac{1}{8\alpha} = 17.16$. Saha put $n_r = 0$ and $|k| = 18$ for the ground state and obtained

$$\frac{E}{Mc^2} = \sqrt{1 - \frac{\beta^2}{k^2}} = 0.302 \tag{12}$$

from which he got

$$M_n = 2E = 2 \times 0.302 \times \frac{m}{4\alpha^2} = 2846m \tag{13}$$

for the neutron mass which is 1.52 times the experimentally observed neutron mass.

It might be noted that for $n_r = 0$, $|k| = 18$

$$n = n_r + |k| = 18$$

$$j = \left(|k| - \frac{1}{2}\right) = 17\frac{1}{2} \tag{14}$$

which cannot be the ground state and does not give the observed $j = 1/2$ for the neutron. For $|k| < 18$, $s = \sqrt{k^2 - \beta^2}$ becomes imaginary and the series expansion

$$f = r^s (a_0 + a_1 r + \dots)$$

$$g = r^s (b_0 + b_1 r + \dots) \tag{15}$$

used to obtain eqn. (11) does not hold. The situation is similar to the Coulomb bound state when $(Z\alpha)^2 > k^2$. A different method [10] is needed to deal with $n < 18$. It will be most appropriate to complete Saha's work

for the $g^{(+)}\, g^{(-)}$ bound state by including states $n < 18$ particularly in view of current interest in such matters. Salam [7] has put this topic in its proper perspective in his opening address at the 1981 Trieste *Monopole Meeting* : ". . . Saha also suggested that the neutron might consist of bound pole pairs. This anticipated in some ways another idea which has been used by Schwinger, Barut and others to suggest that the basic entities of which all matter may be composed of, may be monopoles carrying electric charge (dyons)".

For the $g^{(+)}\, g^{(-)}$ bound state Sommerfeld's relativistic theory [9] would also require modification for n < 18. The orbit for such quantum numbers would not be precessing elliptic orbits. It would be interesting to look into this problem and find out how the orbits look like and how the change-over takes place from n > 18 to n < 18. The point of change-over has E = 0. Saha notes that E = 0 corresponds to complete annihilation of $g^{(+)}\, g^{(-)}$ pair into radiation.

Another topic in particle physics in which Saha was interested is nuclear beta decay. He, along with Kothari [11], constructed a model to explain the continuous beta spectrum without being aware of Pauli's neutrino hypothesis and Fermi theory. Since the Saha-Kothari model has turned out to be obsolete and discussed by Professor Pandya in his lecture, I do not want to discuss this topic.

I conclude my talk with great admiration and appreciation of Meghnad Saha, the great physicist with a broad interest who was ready to learn new techniques and apply them to the numerous creative ideas which were continuously being generated in his fertile brain. In this birth centenary year I pay my homage to this great son of India.

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Meghnad Saha and Astrophysics

MEGHNAD SAHA : HIS JOURNEY TO THE PHYSICS OF THE STARS

BINAYAK DUTTA-ROY

ABSTRACT

The evolution of Professor Meghnad Saha's approach to the problems of selective radiation pressure and thermal ionisation is discussed. This paper is an attempt at an exposition of his earlier work which laid the foundations of Saha's trail-brazing researches in astrophysics.

Having faced heavy odds every step of his way, in a country under alien rule, and immersed in a caste-ridden, proverty-stricken, intensely superstitious and backward society, Meghnad Saha, son of an indigent shop-keeper, born in an obscure village in 'British India' a century ago, struggled through the disputed passage into the world of science and left an indelible mark in astrophysics through basic contributions which proved to be of cardinal importance. He was appointed a Lecturer in the Department of Physics at the University of Calcutta in 1917 when he was twenty-four years of age. It was a time when the conceptual basis of physics was in deep turmoil. Already at the beginning of the century the classical world-view, resting on the foundations laid down by Galileo and Newton, had been shaken at its very base by Einstein through the Special Theory of Relativity which necessitated a radically different understanding of the nature of space and time ; and the classical notion that energy residing in various modes of electromagnetic waves in a cavity, following the description afforded through the Maxwell's equations, could take any value (and thus constituting a continuum) simply failed to account for the observed characteristics of black-body radiation (particularly in the regime of high frequencies or short wavelengths), a contradiction which required for its resolution the introduction by Max

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Planck of the idea of energy quantisation. That the description of micro-systems (phenomena involving small distance and time scales) seemed to make no sense without invoking this apparently arbitrary procedure of quantisation became increasingly evident as the classical world-view was shown to be totally inadequate for the understanding of atomic phenomena to the extent that even the stability of atoms and their line spectra could only become explicable at the cost of imposing the rather *ad hoc* quantisation hypothesis introduced by Niels Bohr in 1913. The need for quantisation was quite evident but its incorporation into a systematic mechanics had yet to come (by the second half of the following decade) and physicists all over the world were still groping in the realm of these new ideas. With great zeal and enthusiam the young Meghnad plunged into a serious all-absorbing study of this New Physics, spurred on by his quest to seek answers to many questions that intrigued him, as also by his assigned duty to organise the teaching programme at the Masters' level (with his class friend Satyendra Nath Bose and later with C. V. Raman). In this arduous endeavour he received little or no help from the older teachers who had not kept pace with the remarkable and perplexing developments in the field. Indeed, as unravelled by his activities during these first few years and his early publications one can discern out a relentless and determined step by step approach, a demanding meticulousness, a deep desire to see everything for himself. Later (in 1925 at the Indian Science Congress meeting) he was to express, what seems to the present author to have been, the guiding spirit of the young Saha, when quoting from Dhunduka-nath in 'Rasendra Chintamani' of the IXth Century, he upheld a practical and materialistic viewpoint (carefully sieved out, as a beacon of light, from the plethora of otherwise highly spiritualistic and obscurantic elements of the Hindu tradition) :

"I have heard much from the lips of savants,
I have seen many formulae 'well established' in the scriptures ;
But I am recording none that I have not done myself.
I am recording those fearlessly which I have carried out
.... *by my own hand.*
They alone are to be regarded as real teachers,
Who can show by experiment what they teach.
They are the deserving pupils,

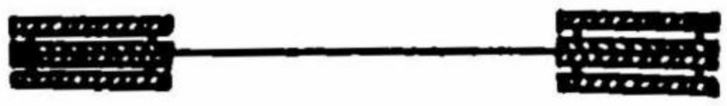
Who having learnt from their teachers,
Can actually perform them, and improve upon them.
The rest are mere stage actors."

The problem that first attracted the attention of Saha seems to have been the question of radiation pressure on matter. It appears that a book by Agnes M. Clarke entitled 'Problems of Astrophysics' stimulated this interest in him. To explain the bending of the tails of comets away from the sun Johannes Kepler had invoked the role of radiation pressure on matter. On the other hand phenomena (such as the occurrence of solar prominences) were 'explained' through strange and sometimes bizarre ideas such as a mysterious 'force of levitation' acting on atoms and molecules in the gaseous state, thereby reducing the gravitational attraction acting on them. Some authors even went to the extreme by speculating that the gravitational force suffers a diminution with temperature. Saha was evidently attracted by the notion that radiation pressure must be an important agent in such phenomena. Such a view was largely discounted at that time as arguments based on Maxwell's theory seemed to indicate that the pressure of radiation would not be operative on objects of size smaller than of the order of the wavelength of light impinging on them. Saha began to examine this with characteristic depth and thoroughness by starting from the very beginning. His first paper 'On Maxwell's Stresses' published in the *Philosophical Magazine* [Sr. VI, **33** (1917) 256] is a critique of Maxwell's approach to the problem of radiation pressure in terms of elastic displacement of 'aether particles' or with dielectric stresses in matter. He contrasts this viewpoint with that of Bartoli who had deduced the presence of radiation pressure through thermodynamical reasoning, as also with Planck's derivation based on the consideration of electromagnetic waves falling upon a perfect reflector (a superconducting surface). It is interesting to note that the only two references in this paper are to Maxwell's '*Electricity and Magnetism*' and to Planck's '*Wärmestrahlung*'. His next paper on the subject 'On the Pressure of Light', which he published with S. Chakravarti in the *Journal of the Asiatic Society (Bengal)* [New Series **14** (1918) 425], not only reflects his resolve to record 'none that he has not done himself' but also his staunch insistence on the relationship between theory and experiment, which he was to express later through a quotation from William Rowan Hamilton :

"Theory and Experimental Investigation are the two eyes of Physics,
And research works flourish best where workers see with both eyes."

Incidentally, for those not familiar with the Asiatic Society (the recipient of Saha's second work on this subject) it may be pointed out that it was this once august body that was called upon to resolve the mystery of what had appeared to be a strange marine animal (later revealed to be Captain Nemo's submarine, the Nautilus) in Jules Verne's classic *'Twenty Thousand Leagues Under the Sea'*. In this paper Saha repeats 'with his own hand' an experimental demonstration of the pressure of light. It was for this purpose that Crookes in 1874 had invented his famous 'radiometer', which consisted of a delicated cross of four mica vanes suspended on a pivot and enclosed in a glass vessel from which the air could be pumped out at will. The alternate faces of the vanes were covered with lampblack. It was observed that when light was made to impinge on the absorbing black surfaces the cross began to rotate rapidly about the pivotal axis. Though Crookes was inclined to ascribe this motion as being due to the pressure of radiant energy, Zöllner in 1877 (following a suggestion by James Clark Maxwell) showed that the effect observed was rather spurious and in fact exceeded the expected value of the pressure by a factor of the order of a thousand, and that it was actually due mainly to the unequal heating of the two faces of the vanes leading to (a) pressure difference of the surrounding gas due to the disparity in temperature of the two faces (radiometer action), (b) 'rocket action' caused by the expulsion of absorbed gas molecules from the heated surface, and (c) the torque due to convection currents in the surrounding gas. However, Zöllner was not able to provide an experimental demonstration of the effect of radiation pressure. Lebedew (the Russian scientist) and almost simultaneously Nichols and Hull in 1901 at last observed the long expected radiation pressure, by appropriate modification of Zöllner's unsuccessful experiment. Lebedew utilised very thin platinum foils whereby any difference in temperature in the two sides of the vane was quickly equalised, and the pressure in the vessel was reduced to 10^{-4} mm of mercury in order to marginalise the disturbing factors. Nichols and Hull, on the other hand, reduced the effect of the convection currents by making the vanes exactly vertical so that the airflow, tangential to the surfaces of the vanes, did not exert any turning couple ; furthermore they found that in their set-up the rocket action and the radiometer effect balanced out at a pressure of 16.5 mm of mercury. In Saha and Chakravarti's arrangement they made the vanes out of reflecting films (thereby doubling the radiation pressure as compared to absorbing surfaces) covered by equal thickness of glass on either side. When light previously filtered of all wavelengths capable of heating glass (having been passed through

sufficiently thick glass lenses) is allowed to fall on the vanes, the glass surfaces are hardly heated by the passage of light and the two sides of the reflecting film quickly achieve the same temperature (being so thin and conducting). This contraption thus minimises both the radiometer and the rocket actions, and with the vanes set vertically the torque caused by convection is reduced. The turning couple on the vane A (refer to Fig. 1) given by $L = p.l$ (p = total thrust due to radiation pressure, and



Vanes made out of reflecting films covered by glass plates.

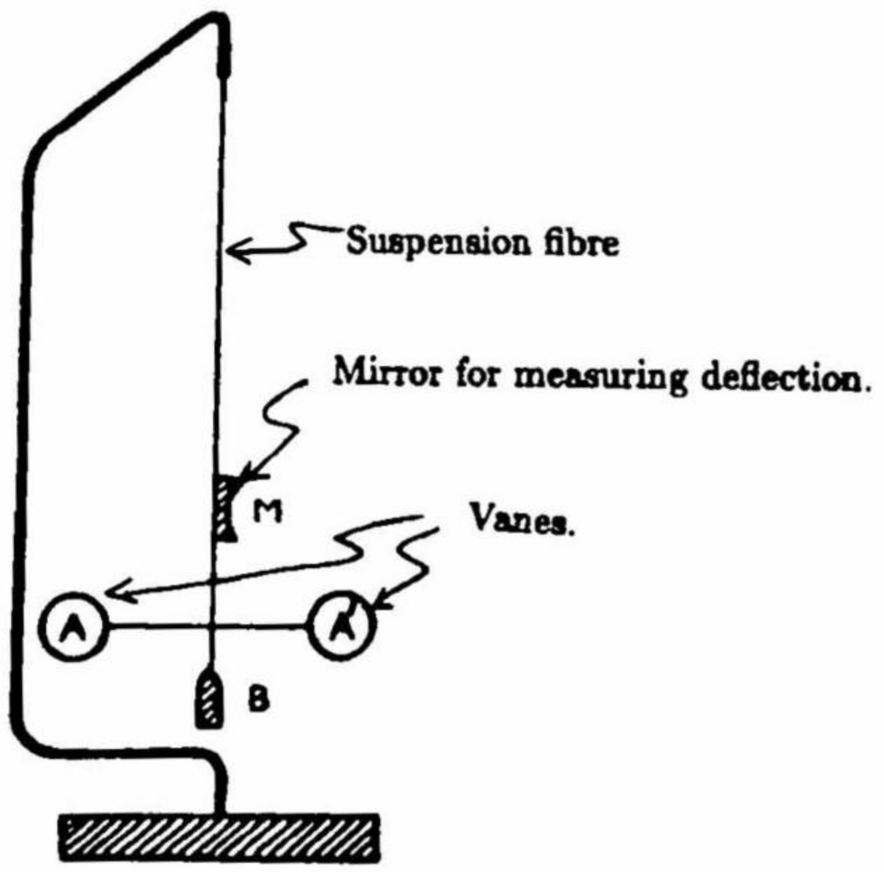


Fig. 1. *The arrangement used by Meghnad Saha to measure radiation pressure.*

l = distance of the centre of the disc from the axis of rotation) was balanced by the restoring torque of the suspension fibre ($\mu\theta_0$ where μ = torsional coefficient of the fibre and θ_0 = the angle of deflection at equilibrium). The deflection was measured by a beam reflected off a mirror M fixed to the suspension fibre and reflected onto a scale kept at a distance. The

torsional coefficient (μ) was determined by observing the free oscillations of the system governed by the equation :

$$I\frac{d^2\theta}{dt^2} + k\frac{d\theta}{dt} + \mu\theta = 0$$

with I = moment of inertia about the fibre axis (easily calculable from the masses and distances involved), and k = viscosity factor (determinable from the measurement of the rate of damping of oscillations). From a measurement of the frequency of free torsional oscillations and its damping, μ could be determined. Thus the thrust $p = \mu\theta_0/l$ due to radiation pressure could be measured. However, 'owing to the lack of means' Saha was unable to properly measure the amount of radiant energy falling on the disc but this did not deter him. Using a tungsten filament lamp supplied by Messrs. Westinghouse and Co. (because the arc lamp they had originally used proved to be too unstable) they theoretically estimated the intensity of light falling on the disc. The result, therefore, could at best be qualitative but it did confirm the essentials of radiation presure. More importantly, it gave the young Saha the confidence to surge onwards in his quest.

In his next paper on the subject, 'On Radiation Pressure and the Quantum Theory—A Preliminary Note' published in the *Astrophysical Journal* [50 (1919) 220], Saha moves on to directly confront the question 'Does radiation exert pressure on atoms and molecules?'. Reviewing the previous discussion on radiation pressure by Maxwell, Bartoli, Poynting and Larmor he comments that all these deductions are in essence statistical in nature and the results hold only when the surfaces encountered by the radiation are large compared to the wavelength and are thickly set with matter. Indeed, Schwarzschild, Nicholson and Klotz had shown on the basis of classical consideration that for particles of molecular size the effect of light pressure would be evanescent. Saha, however, asserts that one must use quantum theory and that a photon of frequency ν carrying a momentum $h\nu/c$ absorbed by a molecule (of mass m) would impart its momentum to it, and that the molecule would accordingly move forward with a velocity $h\nu/mc$. Confronting the observation that hydrogen does not normally absorb its characteristic radiation (represented by the Balmer line) he points out that this is merely because hydrogen atoms being normally in the ground state ($n = 1$) do not do so since the Balmer line corresponds to the transition from the $n = 3$ to the $n = 2$ state, so that

an H-atom would absorb the Balmer line if it were in the 'active' $n = 2$ state to begin with. He conjectures that in the conditions prevailing in the sun there could be a sufficient number of such active H-atoms (in the $n = 2$ level) and the pressure of radiation may be sufficiently great to endow such atoms (selectively) with a large velocity as associated with the tops of solar prominences. However, later work has evidently revealed that the phenomenon of prominences requires for its understanding the consideration of magnetohydrodynamics, a mechanism not appreciated at that time. He also asserts in this paper that selective radiation pressure should present the entire problem of the equilibrium of solar atmospheres in a new light. It is, therefore, with a deep sense of fulfilment that Professor Saha records in the *Journal of the Department of Science, Calcutta University* [2 (Physics) (1920) 51], that Eddington had developed an elegant theory on radiative equilibrium (based on the existence of radiation pressure on atoms) in the interior of stars and had thereby successfully explained many of the observational results on the evolution of stars discovered by Hertzsprung and Russell. He, however, goes on to emphasise an important aspect of his earlier paper, namely, that the action of light pressure may be selective particularly when it strikes a resonance. He states that it would be important to develop the theory of selective radiation pressure rather than merely the aggregate effect of light pressure as discussed by Eddington. Professor Milne of Oxford, who is generally credited with the development of this theory, recognises Saha's contribution through a remark made by him in his publication in *Nature* (1921) which reads : 'These paragraphs develop ideas originally put forward by Saha'. Here it is also important to record that a longer paper by Saha on the subject had been sent to the *Astrophysical Journal* for publication but it was never printed as it had been misplaced in a drawer at the Yerkes Observatory and much later in 1936 when Saha visited that observatory it was handed over to him.

As early as 1917 Saha, recognising that an important clue to the physical state of a star lay in the spectra of the light emitted from it (extensive data was available through the painstaking work of Fraunhofer, Norman Lockyer, Father Sechi, Pickering, Canon and others), again, in his characteristic style, began at the very basics. Indeed, his second publication was 'On the Limit of Interference in the Fabry-Perot Interferometer' which appeared in the *Physical Review* [10 (1917) 782]. A monochromatic source of radiation examined through the two parallel plates (separated by a distance d) of a Fabry-Perot Interferometer yields bright and narrow frin-

ges of maximum intensity with wide dark bands in between. If the distance d between the plates of the etalon is gradually increased, the maxima gradually decrease in brightness until a critical distance d_{cr} is reached when it is no longer possible to distinguish between the maxima and the minima. This is due to the fact that the emitting atoms (of mass M, say) in a low pressure source (where collisional broadening is negligible), at a temperature T possess random thermal motions with root-mean-square velocity $\sqrt{3kT/M}$ (as the average kinetic energy is $3kT/2$), and consequently the emitted light (of wavelength λ) does not remain monochromatic but suffers a broadening as a result of the Doppler-Fizeau effect, yielding an overlapping of fringes which leads to the observed limit of interference. The underlying theory, in its general context, was worked out by Lord Rayleigh, who had deduced that $d_{cr} = \lambda A\sqrt{M/T}$, where the constant A depends on the details of the arrangement. This constant had previously been calculated by taking into account the interference between the direct beam and the twice reflected one. Saha in his paper shows that the series which emerges when one takes into account the multiple reflections is nothing but a geometric series which is easily summed and thereby one obtains a corrected value for the constant A. He underscores the importance of this study through a remark that the masses of emitting atoms of many lines of unknown origin in the solar corona and from many nebulae (which at that time had been attributed to the hypothetical elements coronium and nebulium) could perhaps be determined through the use of interferometry. In a follow-up of this work, 'A Note on the Secondary Spectrum of Hydrogen', published in the *Philosophical Magazine* [Series VI, 40 (1920) 159], he addresses the problem of the so-called secondary spectrum of hydrogen which relates to the observation of lines other than those due to atomic hydrogen. Though theoretical physicists tended to ascribe these additional features to emission from hydrogen molecules or hydrogen molecular ions, experimentalists (particularly those belonging to the French School of Opticians, Fabry and Buisson, for example) disagreed because the mass of the emitters deduced from the method described earlier led to the value $M = 1$ according to their analysis of the data. Saha ascribed this discrepancy to errors in the theoretically estimated value of the constant A due to reasons such as the one he had already pointed out in his earlier paper. Accordingly he insisted that it would be wiser to take the ratio of the critical distances for the different sets of lines which procedure would eliminate the constant A, and proceeding to do so concluded that the ratio of the masses of the emitting centres, thus determined, was in fact 2 in agreement

with the expectation that the sources were atomic hydrogen on the one hand and molecular hydrogen (or its singly ionised state) on the other. He goes on to recount his attempts at applying Sommerfeld's generalisation of the Bohr theory (Wilson-Sommerfeld quantisation) to H_2^+ (two fixed positive centres and one electron) and refers to an imcomplete work which he had communicated to the Indian Science Congress held at Bombay in January 1919, wherein he had obtained expressions containing the energy from the quantisation conditions appearing as elliptic integrals of the first, second and third kinds. He also notes that the identical result (with no reduction of the energy expressions) had subsequently appeared in a paper by Silberstein in the *Philosophical Magazine*. In this context it is amusing to note that the quantisation of such systems (H_2^+ and He-atom) as extensions of Bohr's approach was the thesis problem of Wolfgang Pauli who was working with Arnold Sommerfeld.

Having prepared for himself the ground Meghnad Saha was to venture next into a problem which was to occupy his unidivided attention for a number of years and which was to constitute a contribution of cardinal importance in astrophysics. This was the question of the state of ionisation of atoms in stars (and in particular those in the solar chromosphere) as a function of temperature and pressure. The theoretical basis of this study had to some extent been already developed in the theory of chemical reactions. Indeed this led Saha's friend Satyendra Nath Bose to make a statement much later that 'the pearls were in a sense already there but it required a Meghnad to recognise them and to string them together into a necklace of unsurpassable beauty'. The story goes back to Napoleon's Egyptian Campaign when Berthollet found that while in the laboratory sodium carbonate and calcium chloride when brought together reacted to form calcium carbonate and sodium chloride, on the shores of some saline lakes in the delta of the Nile the opposite kind of reaction appeared to be taking place. He ascribed this to the presence of a large excess of sodium chloride in the lake water which seemed to drive the reaction backwards. It was left to Guldberg and Waage, two Norwegan scientists, to state the Law of Mass Action (the underlying mechanism) in exact terms in 1867. For a chemical reaction described by $\Sigma_i \nu_i X_i \Leftrightarrow \Sigma_p \nu_p X_p$ where i and p stand for ingradients and products respectively, X_r are the reactants and ν_r are the corresponding stoichiometric numbers ; the first thing to recognise is that though the reaction may spontaneously occur in the forward direction the reaction as such is re-

versible. At given conditions of temperature T and pressure P the forward (f) (and the backward (b)) reaction proceeds at a rate equal to the products of the concentrations of the ingradients (products) raised to the power of their respective stoichiometric number with a constant of proportionality known as the rate constant k_f (k_b); and equilibrium is established when the two rates are the same. Thus representing by x_r the concentration of X_r we have

$$k_f \prod_i (x_i)^{\nu_i} = k_b \prod_p (x_p)^{\nu_p}$$

and, therefore,

$$\frac{\prod_p (x_p)^{\nu_p}}{\prod_i (x_i)^{\nu_i}} = \frac{k_f}{k_b} = K(P, T)$$

where $K(P, T)$ is called the equilibrium constant at pressure P and temperature T. Thus for the Berthollet's reaction :

$$2NaCl + CaCO_3 \Leftrightarrow Na_2CO_3 + CaCl_2$$

one has

$$\frac{x_{Na_2CO_3} \cdot x_{CaCl_2}}{x^2_{NaCl} \cdot x_{CaCO_3}} = K(P, T)$$

and if the concentration of NaCl is large, then the amount of Na_2CO_3 present at equilibrium shall be large. The next nodal point in this development was the determination of the temperature and pressure dependence of the equilibrium constant in the hands of Nernst. The basic idea here is that for a given temperature and pressure the condition for equilibrium is the minimisation of the Gibbs Free Energy $G = U + PV - TS$. Now the change in the Gibbs Free Energy G with respect to the number of moles (N_r) of a reactant (r) at fixed P and T is defined to be the chemical potential μ_r and accordingly $(\delta G)_{P,T} = \Sigma_r \mu_r \delta N_r$. Here it is useful to introduce the notion of the reaction coordinate τ which is simply the number of chemical transitions $\Sigma \nu_i X_i \rightarrow \Sigma \nu_p X_p$ which have taken place. Clearly then $\delta N_i = -\nu_i \delta\tau$ while $\delta N_p = +\nu_p \delta\tau$ for the ingradients and the products respectively. Thus the condition for equilibrium at a given pres-

sure and temperature becomes

$$(\delta G)_{P,T} = (\Sigma_p \mu_p \nu_p - \Sigma_i \mu_i \nu_i)\delta\tau = 0$$

and hence

$$\Sigma_p \nu_p \mu_p = \Sigma_i \nu_i \mu_i$$

The chemical potential μ_r for a given reactant in the system will be the chemical potential of the pure reactant $\mu_r^0(P, T)$ added to the contribution to the chemical potential arising from the entropy of mixing. The latter is readily found to be $kTln(x_r)$, where k is the Boltzmann constant. This is easily seen by considering, say, the mixing of two gases with molecules N_1 and N_2 in number. Using the Boltzmann formula we have $S_{before} = kln[(N_1)!] + kln[(N_2)!]$. Suppose now that the two gases are in a thoroughly mixed state so that the entropy would now be $S_{after} = kln[(N_1 + N_2)!]$. The change in entropy (the entropy of mixing) then becomes

$$\Delta S = S_{after} - S_{before} = kln[(N_1 + N_2)!] - kln[(N_1)!] - kln[(N_2)!]$$

Using the Stirling's approximation $\ln(n!) \sim nln(n) - n$, we get

$$\Delta S = -kN_1\ln(x_1) - kN_2\ln(x_2)$$

where $x_1 = N_1/(N_1 + N_2)$ and $x_2 = N_2/(N_1 + N_2)$ are the relative concentrations of the molecules of types 1 and 2, respectively. This result is easily generalised to the case at hand and we obtain $(\Delta S)_{mixing} = -k\Sigma N_r \ln(x_r)$. And going back to the definition of the chemical potential in terms of the Gibbs Free Energy we deduce that $(\mu_r)_{mixing} = +kT\ln(x_r)$. This leads to the result that $\mu_r = \mu_r^0(P, T) + kTln(x_r)$. Now imposing the condition for equilibrium $(\Sigma \nu_i \mu_i = \Sigma \nu_p \mu_p)$ we arrive at the relation

$$\frac{\Pi_{products}(x_p)^{\nu_p}}{\Pi_{ingradients}(x_i)^{\nu_i}} = \exp[\Sigma(\nu_i\mu_i^0 - \nu_p\mu_p^0)/kT] = K(P, T).$$

where $K(P, T)$ is the equilibrium constant and what we have here is nothing but the Law of Mass Action with the additional feature that the

such that $\Sigma\varepsilon_i - \Sigma\varepsilon_p$ gives that heat of dissociation and C_r , the Nernst Chemical Constant, is simply related to S_0 and is readily evaluated by putting in the values of the constant to give $C_r = -1.6 + \frac{3}{2}\ln(m_r)$. Thus at a given temperature and pressure the equilibrium concentrations of the different reactants stand determined.

The process of thermal ionisation can also be considered as a reversible chemical reaction and this, not surprisingly, was first pointed out from W. Nernst's school (by John Eggert in December 1919). Meghnad Saha with his characteristic zeal and vigor pushed through the idea. As he wrote later : "Eggert, who was Nernst's pupil...had given a formula for thermal ionisation, but it is rather strange that he missed the significance of ionisation potential of atoms, the importance of which was apparent from the theoretical work of Bohr, and the practical work of Franck and Hertz...While reading Eggert's paper I saw at once the importance of introducing the value of 'ionisation potential' in the formula of Eggert, for calculating accurately the ionisation, single or multiple, of any particular element under any combination of temperature and pressure. I thus arrived at the formula that goes by my name. Owing to my previous acquaintance with chromospheric and stellar problems, I could at once see its application...." Putting in values of the ionisation potentials of various atoms directly determined from experiments on gaseous discharges, or from the study of the convergence limits of the principal series of terms obtained from their spectra, Saha was able to arrive at the extent of ionisation of various elements at different conditions of temperature and pressure obtained in the sun. In a series of papers starting with his publication 'Ionisation in the Solar Chromosphere' in the *Philosophical Magazine* [Sr. VI, **40** (1920) 472], he was to spend a number of years deeply studying the implication of his theory of thermal ionisation in the physics of the sun. Applying these ideas Saha solved many problems such as the enhanced spectral lines of ionised calcium from the upper solar chromosphere despite the apparently lower temperature available in that region (evidently the answer to the riddle lay in the lower pressures existing there) ; the absence of lines corresponding to neutral rubidium (Rb) in the solar spectrum [this he ascribed to the low ionisation potential of Rb so that it hardly can remain in its non-ionised state and he went on to predict that these should appear in the spectrum of light from sunspots (which are at a relatively lower temperature) and this was indeed found when the observations were made]. Indubitably it was Meghnad

Saha who laid the strong physical foundations for the interpretation of stellar spectra, which led Rosseland in his book *'Theoretical Astrophysics'* to comment, "The impetus given to astrophysics by Saha's work can scarcely be over-estimated, as nearly all later progress in the field has been influenced by it, and much of the subsequent work has the character of refinement of Saha's ideas".

In keeping with the spirit of Meghnad Saha it may not be too inappropriate to append here (for those who are young in age or perpetual students like the present author) two homework problems :

Q1. Calculate the chemical constant of the electron gas in the non-degenerate (rarefied) state and use the result to compute the thermal equilibrium between atoms, ions and electrons in a hot gas in terms of the ionisation energy of the atom.

[From *'Theoretical Physics'* by Georg Joos.]

Q2. The photosphere of the sun consists essentially of H, H^- and electrons. The electron affinity of H is 0.72 eV. Find an expression for the relative concentration of the three species as a function of temperature and pressure.

[From Oxford University Examination Papers, 1962 ; in *'Elements of Thermodynamics'* by D. ter Haar and H. Wergeland.]

And to end by stating that with verity it could be said of Meghnad Saha,

Ad astra per aspera et per ludum
To the stars through hard work and fun !

□□□

CONTRIBUTIONS OF M. N. SAHA IN ASTROPHYSICS

J. C. BHATTACHARYYA

ABSTRACT

The talk covers the outstanding problems in astrophysics in the early part of the twentieth century, when M. N. Saha entered the scene. His early papers on selective radiation pressure and on thermal ionization are described. His efforts in Allahabad in building up of a laboratory astrophysics group, and other researches in astrophysics are covered. His visualization of space astrophysics and the possibilities of emission of 21 cm radiation is touched upon. Finally, his efforts in building a central astronomical observatory in the country are described.

I feel, indend, honoured to have a chance of describing some of the immortal contributions of Prof. M. N. Saha to this august audience, and to express my thanks to the organizers for giving me this opportunity. Prof. Saha's writings covered a wide field of knowledge, but astrophysics happens to be the one topic, which received the fondest attention from him ; in today's talk I shall attempt to cover some of his major contributions, which altered the course of astrophysics.

I shall try to give a glimpse of the developments in the fields of physics and astrophysics during the first two decades of the present century. Classical physics had come to the cross roads ; the enormous confidence of the nineteenth century in its infallibility had received severe jolts from the results of radioactivity and Michelson-Morley experiment; new quantum ideas have been introduced and many unexpected experimental results have revealed new features in the structure of the atom. The technique of spectroscopy, which had been in physical laboratories

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for more than half-a-century, had started throwing broad hints of its capability of probing inside atoms. The mechanism of emission and absorption processes have thrown open some more enigmas ; it has come to notice that the characteristic patterns of emission lines from any substance change drastically, when produced in a flame, arc or spark. The first consistent model of a hydrogen atom had just been published ; this information, having reached India a few years later, was yet to imprint its enormous significance on the scientific community.

Big changes were happening in the field of astronomy also. Interest was shifting from elaborate numerical calculations of Simon Newcomb in positional and dynamic astronomy to the strange indications through spectroscopy. Using the new technique, Hale at Mount Wilson had detected strong sunspot magnetic fields, while Evershed at Kodaikanal had drawn up clear pictures of material flow around sunspots. Hertzsprung and Russell diagram had been drawn, and the astronomers at Harvard had collected thousands of spectra of celestial objects, and faced bewildering varieties in them. Two major questions still eluding answers were : i) what are the temperatures of stars and ii) what are their compositions ?

In the observational front, great progresses had already been achieved. After years of initial difficulties, photography had finally proved to be a more sensitive detector of light, than the human eye. This at the focal plane of big telescopes had started bringing in startling bits of information. Several telescopes with apertures around sixty inches had already been in use, the hundred inches telescope had just started operations. One could now reach much fainter objects than what human eyes could ever perceive earlier. And with several new instruments added to observations, newer types of observations could be planned and carried out.

In India, the position was not that rosy. Some specialised instruments were put up at Kodaikanal, mainly for solar observations. The largest telescope was one of twenty inches aperture at Poona Observatory, used by Naegamvala, which had been closed down for financial reasons. Newly started Nizamiah Observatory had acquired a 15 inches refractor, while the eight inches Madras Equatorial was operational at Kodaikanal.

So, the information about all these new developments came through foreign journals, there being no established scientific journal in the country. The Kodaikanal Observatory sometimes used to publish memoirs whenever the situation demanded ; some universities and learned societies also brought out occasional issues. For conducting many types of investigations in astrophysics, it was essential to consult these foreign journals, which were available only in some selected libraries.

Meghnad Saha arrived at the scene of astrophysics in India against this background ; his achievements particularly when viewed from this perspective appear nothing sort of miracles. Later in his life, while building up the scientific infra-structure in the country, he paid maximum attention to remove these shortcomings, which I shall touch upon shortly.

The first paper on a topic in astrophysics which Saha published dealt with an idea of selective radiation presssure in stellar atmospheres. The pressure generated by light was not a new idea, both in classical as well as in quantum theories ; the absorption and scattering of radiation should result in this. Saha sought to explain some observed features on the sun and stars.

Let me explain the point ; it the laws of thermodynamics are applied, the envelope surrounding the sun should have been very thin, the density should have dropped a millionfold within a few hundred kilometers. But actually we find the chromosphere and the corona much more extensive; it appears that there are forces of levitation working against gravity. Saha speculated that the radiation pressure provides that force.

There are other points also ; on the limb of the sun, seen in the light of certain selected chromospheric lines one often finds huge protuberances, known as prominences. If we use time-lapse photography, we can see that some of them move away from the limb with enormous velocities; they are called eruptive prominences. Also, from eclipse experiments it was seen that emission of some lines comes from very high reaches of the solar atmosphere, thereby suggesting that there are abnormally high concentrations of selected atoms. A pair of such lines, called Fraunhofer H and K lines, which are clearly identified as being due to once-ionized calcium atoms, reach the highest levels. Saha sought to prove in this paper that calcium atoms are selectively pushed up to higher levels.

A preliminary note outlining the idea was published in *Astrophysical Journal* of 1919, and a more detailed paper in the *Journal of the Department of Science, Calcutta University*. But Saha did not pursue the topic further; the idea was picked up by Milne six years later, who developed it into a very important factor shaping the structure of stellar atmospheres. Today the important questions of stellar wind and mass loss from hot stars are intimately tied to the idea of selective radiation pressure due to resonance lines mostly in the ultraviolet. Of course, Milne in his first paper had gratefully acknowledged Prof. Saha's pioneering work in this field.

To put matters stright, none of the two features mentioned by Saha, viz eruptive prominences, or the anomalous strength of C_a^+ line in the solar atmosphere, are now-a-days accepted as due to selective radiation pressure. The first is recognized as an MHD phenomena, the theory of which was developed by Alfven years later, while the second was answered by a completely new idea, which brought about a big change in astrophysics.

The second riddle was answered by Saha himself, a few months later, bringing in the concept of thermal ionization under astrophysical conditions. This is an idea which later pervaded the entire literature of astrophysics and introduced a new era in our understanding of stellar atmosphere.

Let me try to explain the riddle. In the visible part of the solar spectrum, the strongest lines are the Fraunhofer H and K ; I have mentioned that these lines are traced upto very high levels in the solar chromosphere (Fig. 1). Now, according to ideas prevailing at that time the intensity of the lines should depend mainly on abundances ; but from other evidences it had been noticed that calcium is not a major constituent of solar gases. Then, how is it that the strength of lines due to calcium, and that, too, once ionized, is so high ?

Saha wrote a paper on 'Ionization in the Solar Chromosphere', which was published in an issue of the *Philosophical Magazine* in 1920. He derived a quantitative relation for ionization of various atoms with their atomic properties as influenced by surrounding parameters, which later became

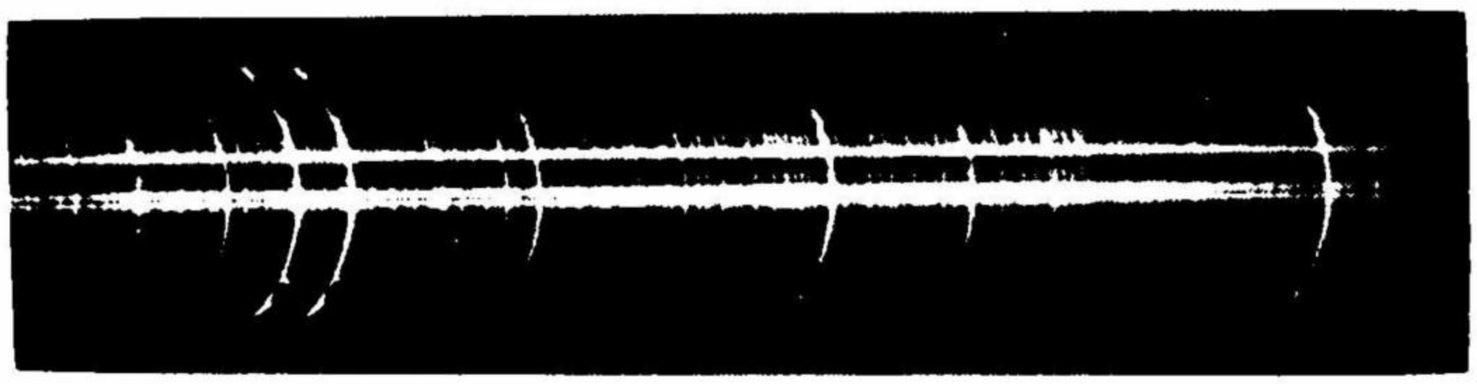


Fig. 1. *Flash spectra with* Ca^+ *lines.*

famous as 'Saha Ionization Equation'. It came out of a beautiful combination of new quantum ideas and classical thermodynamics. In this paper Saha considered the process of ionization as similar to reversible chemical reactions, so well studied in physical chemistry. This approach had been employed by others, notably by Johann Eggert, a young researcher from Nernst's laboratory in Germany, but all of them had somehow missed to take into account the ionization potential of the atom, which had assumed great significance from new atomic models. Saha incorporated this quantity in his calculations and derived the now famous equation, which shows the balance between ionization and recombination, under superincumbent physical conditions.

It resolved the anomaly in the H and K line strengths completely. Computations proved that under the conditions prevailing in the solar chromosphere the Ca atoms present there will remain totally in the ionized state providing a heavily absorbing layer for these characteristic radiations. It is not necessary to have a layer enriched in calcium to produce this ; a combination of low electron pressure and low ionization potential and appropriate temperature will bring this about.

The idea of ionization equilibria under different physical conditions is the beginning of solutions of many outstanding problems in astrophysics. Immediately following this paper Saha calculated ionization equilibria of many more elements, and published another paper entitled

'Elements in the Sun' in the same journal, in which he speculated that rubidium lines should be seen in the spectra of sunspots. This prediction was verified by Russell at Mount Wilson, and the information conveyed to Saha, personally by him.

One more paper was sent by Saha to the same magazine almost at the same time ; it was titled, 'On the Problems of Temperature Radiation of Gases'. Here he discussed theoretical possibilities of emission of different lines under varying conditions. In this paper he made a strong plea for setting up of Laboratory Astrophysics Groups for determining these vital bits of information about the atomic structure and the universe at large. Today there are big institutes for laboratory astrophysics, all over the world, but in those early days, he had the vision to suggest these experiments ; part of his dream could be realised at Allahabad a few years later.

Still one more paper Saha prepared at that time, and it was titled 'On the Harvard Classification of Stellar Spectra', and like the other three papers it was communicated to the *Philosophical Magazine*. But shortly thereafter Saha went to England and was attached to Prof. Fowler's laboratory. From there he recalled that paper, and rewrote a part of it, as suggested by Prof. Fowler, who then communicated it, with a new title 'On a Physical Theory of Stellar Spectra', to the *Proceedings of the Royal Society of London*. In this paper Saha cleared another long standing enigma of stellar spectra ; this paper indeed opened up a new chapter in astrophysics.

The riddle was like this ; Harvard astronomers had collected thousands of stellar spectra, and had tried to arrange them in a rational order. A somewhat crude indicator was the apparent colour of the star, which was used to draw up the preliminary sequence, which had to be slightly altered to keep continuity of varying strengths of Fraunhofer lines. The sequence then known ran like this, B, the blue stars, followed by A, the white ones, then FGKM yellow and red stars in that order. There were strong hints that this is a temperature sequence, but the apparently erratic variation of strengths of absorption lines defied any easy explanation (Fig. 2).

The ionization theory explained the appearance and disappearance

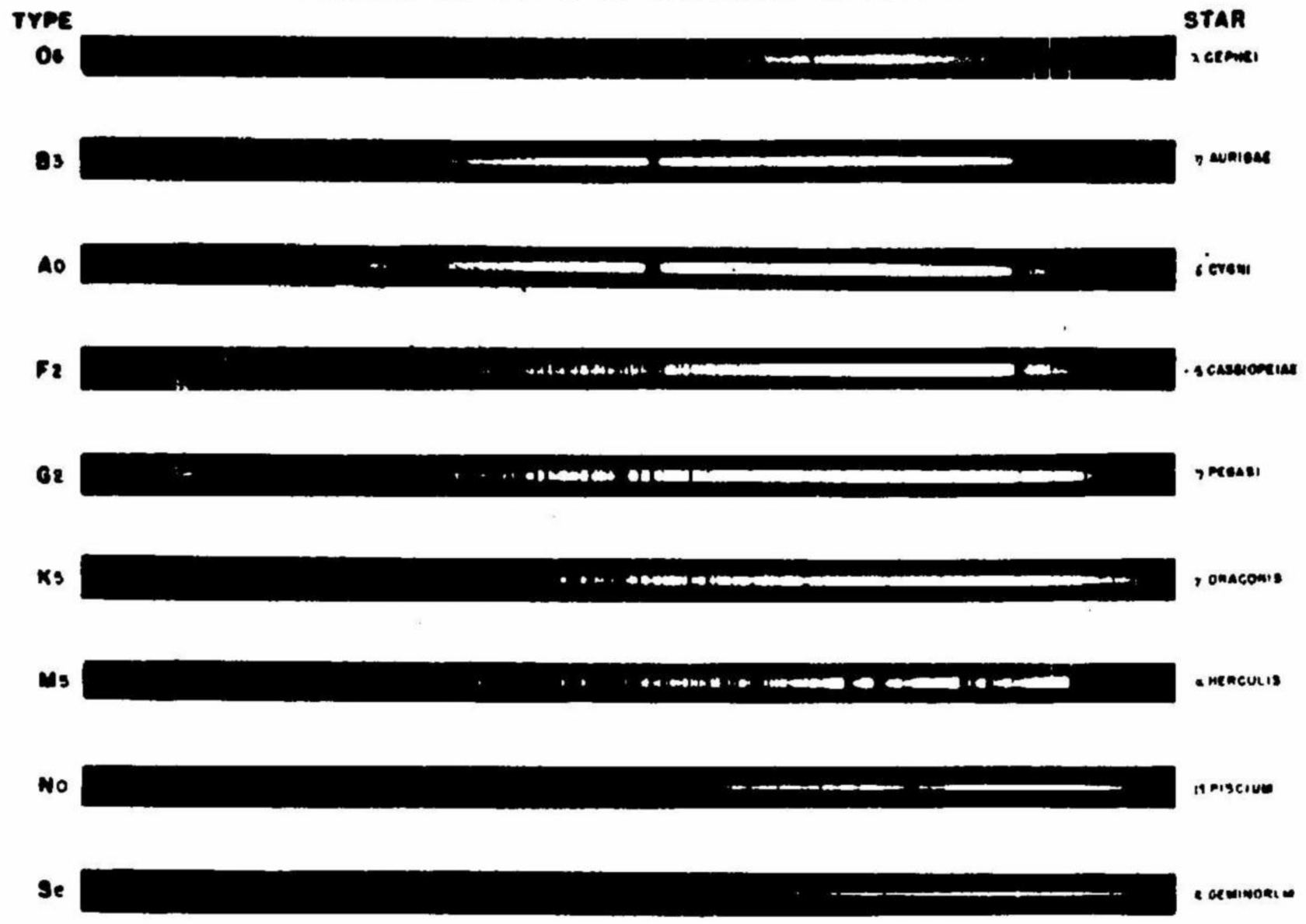


Fig. 2. *Stellar spectral sequence end.*

of Fraunhofer lines neatly, and confirmed the sequence as due to temperature. To forward a simple explanation in very hot stars, hydrogen is fully ionized and that is why there are no hydrogen lines, and at the other end, at low temperatures excitation is insufficient to produce characteristic hydrogen lines. Metal lines appear only when the temperatures come down to values where neutral and singly ionized metal atoms with low values of ionization potential can exist. Previously it was speculated that there may be difference in composition in various types of stars, now it was established that it is mainly the temperature and not the composition which produces different spectra.

The series of four papers by Saha provided a quantitative relation between stellar spectra and the physical conditions in stellar atmospheres. It provided a calibrated temperature scale for the stars. For the first time, spectroscopy could be used for quantitative measurements of the stellar

atmospheres. Eddington has described the ionization equation as one of ten great discoveries since Gaileo introduced telescopes for astronomy studies.

Saha's ionization paper created world wide impact. Many laboratories where efforts to develop a physical theory of stellar spectra were being made immediately switched over to Saha's approach. Among them, H. N. Russell from Princeton, USA and A. E. Milne and R. H. Fowler in Cambridge, England, carried out several refinements in the derivations of the equation. On several other aspects of stellar spectroscopy and a stellar temperature scale, Cecilia Payne wrote an excellent thesis based on Saha Ionization Equation, where she proved that hydrogen is the most abundant gas. Otto Struve had described her thesis as 'Undoubtably the most brilliant Ph. D thesis ever written in astronomy'.

Saha left Calcutta for about a year towards the latter part of 1920 and worked in the laboratories of Prof. Fowler in UK and Prof. Nernst in Germany. All throughout, he had the problems in astrophysics uppermost in his mind and he contributed about eight papers during this period, almost all of them concerning problems in astrophysics. In Nernst's laboratory he even did some experimental work, the results of which were published a few years later.

After his return, Saha remained in Calcutta till 1924 ; most of his papers during this period were on the problems of thermal ionization and spectroscopy. In 1925, he moved over to Allahabad, and turned the Physics Department into an active centre of research working on statistical mechanics, spectroscopy, with experiments on thermal ionization and electron affinity of electronegative elements, active modification of nitrogen and high temperature dissociation of molecules. Gradually other emerging fields in physics began to occupy his mind more and more, and his papers in astrophysics became fewer in number. But his love for astrophysics remained supreme throughout his life ; I shall quote a few instances in support of that.

In all his deductions, Saha felt and often expressed that lack of information of Lyman radiation from the sun and stars appears as a stumbling block in our understanding of the celestial bodies. If only we could detect the ultraviolet radiations, the doubts could be easily cleared. Saha dreamed of a stable platform above the absorbing layers of the atmos-

phere, from where the full ultraviolet spectra could be obtained ; he publicly expressed that view in a special convocation of the Harvard University in March 1937. To us, with examples of astounding feats of space experiments, the idea may appear quite common place, but we have to remember that this happened almost a full decade before our modern space age. It was only in October 1946, when a V-2 rocket with an ultraviolet spectrograph sped skywards from the White Sands Missile Range in New Mexico, that space age was ushered in. That was followed by the first artificial satellite another decade later, and then came the realization of the great dream. Years later, I have heard from a space scientist, Dr. Herbert Friedman, famous for his X-ray astronomy experiments, who was a student at Harvard at that time, that he was thrilled at that novel idea, and he took the realization of the dream as his life's aim.

In the early forties, when the first experiments on celestial radio sources brought out positive results, many scientists were wondering about the emission mechanism. In a paper in *Nature* in 1946 titled 'Origin of Radio Waves from the Sun and the Stars', he speculated about the possibility of transitions between the hyperfine split levels of hydrogen atom, emitting characteristic 21 cm radiation, but did not proceed any further. Thereby he possibly missed another epoch-making discovery. Although this radiation from stellar bodies is very small, because of very low probability of this transition, vast clouds of cold hydrogen in the universe can give detectable signals. In fact, a young scientist in Holland, H. C. Van de Hulst had already published this possibility ; owing to wartime conditions in Europe, his idea did not spread much, the paper having come out in print just a few months before Saha's paper in *Nature*. Saha was totally unaware of this at the time of its publication Only in 1951, two groups of experimental scientists from USA and Australia detected this radiation from cold hydrogen clouds along the spiral arms of our galaxy. This is considered as one of the major discoveries in astrophysics of this century.

Prof. Saha had proposed a theory of the solar corona ; his ideas were spread over three papers written in a span of seventeen years. The underlying question is this : in the spectrum of solar corona one comes across several unfamiliar lines, which at one time was thought to be due to a new element, coronium. In 1938, Edlen convincingly proved that these are due to highly stripped atoms of Fe, Si, Ca etc. Now to maintain these in this state required very high temperatures, the mechanism for

whose generation and maintenance is not well understood, even today.

Prof. Saha did not believe in high coronal temperatures ; instead he believed that such a situation may arise due to nuclear fissions. The present understanding of solar corona, however, prefers the high temperature option, and several processes for generation and maintenance of high temperatures have been proposed. But the idea of surface runaway nuclear reactions in celestial bodies is not altogether rejected in the present day astrophysics, for in novae such a scenario is current.

Among Prof. Saha's papers one often comes across glimpses of such original ideas as are indicative of having risen from a great scientific mind with incisive logic. All relevant information from experiments was at his fingertips and his ideas were always supported by deductions from these. Although basically a theoretical physicist, he knew that scientific progress cannot be achieved without experimental investigations. His efforts at Allahabad for building up of a Laboratory Astrophysics Group is well known ; but what is not so well-known is his efforts to create observational facilities in the country. And this is the last topic, I would like to bring before you.

In 1945, the Government of India set up a committee for drawing up of a post-war development plan for astronomy ; Prof. Saha took up this responsibility. The committee's recommendations covered four specific points, two of them concerning creation of new astronomical facilities. One of these was creation of a central astronomical observatory with at least one large telescope. The Vainu Bappu Observatory at Kavalur, in fact, was established as a result of this recommendation, which Dr Bappu fully utilised in setting it up. The observatory today has an optical telescope, which is the biggest not only in India, but also in the entire continent of Asia. I know, Dr Bappu expressed his intention of naming the telescope after Saha more than once. But this did not happen ; Bappu had died prematurely before the telescope could be completed. Through a tortuous course of events later, the name of Saha could not be immortalised here. It remains now a sacred duty for the present generation of scientists to correct this omission, and put Meghnad Saha's name on a proper pedestal, which will remind the posterity of the great astrophysicist, who raised the prestige of our country in scientific achievements, single-handed, and made a grand start of the process of revival of astronomical studies in India.

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MEGHNAD SAHA AND COSMIC ABUNDANCES OF ELEMENTS

K. D. ABHYANKAR

ABSTRACT

After reviewing the state of astrophysics before the advent of Meghnad Saha in the field, his monumental contribution in the form of the ionisation equation, which bears his name, is highlighted. It is pointed out that Saha's equation not only explained the spectral sequence of the stars on the basis of the differences in the conditions prevailing in their atmospheres, but also laid the foundation for determining the abundances of the elements in stars.

The similarities in the chemical composition of the stars, the planets, the interstellar medium and the cosmic rays indicate that the elements have a common origin. The main features of the abundance curve indicate that the equilibrium processes at high temperatures and high densities as well as the neutron capture process are responsible for producing the cosmic abundances of elements. The comprehensive theory put forward by Burbidge, Burbidge, Fowler and Hoyle is described in detail, and its consequences are discussed.

Meghnad Saha published his monumental paper on the theory of thermal ionisation in 1920 and unravelled many mysteries in the solar spectrum by employing the theory [1]. In 1921 he applied the theory to provide a physical basis of stellar spectra [2,3].

I. State of Astrophysics in 1921

Let us first review the state of astrophysics at the time of Saha's outstanding work on stellar spectra.

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(a) Physical properties of stars :— Firstly, a study of the visual, spectroscopic and eclipsing binary stars had provided the masses (M), radii (R) and luminosities (L) of several stars. The mass and radius give the mean density $\bar{\rho} = 3M/4\pi R^3$, while the radius and the luminosity give the surface temperature by the relation $L = 4\pi R^2 \sigma T^4$, where σ is the Stephen's constant.

(b) Spectral classification of stars :— Secondly, a study of the stellar spectra by Father Sechi, Pickering, Miss Cannon and Miss Maury had established a temperature sequence from the hottest O type stars to the coolest M,N,R type stars as shown in Table 1.

Table 1—The sequence of stellar spectra

Spectral type	Main characteristics	Colour		$Log(L/L_\odot)$	
		Description	(B–V)*	Dwarfs	Giants
O	He II lines	Deep blue	–0.4	5.0	
B	He I lines	Blue	–0.3	3.0	
A	H I Balmer lines	White	0.0	1.7	
F	Metals (II & I)	Greenish	+0.2	0.7	
G	Metals (I & II)	Yellow	+0.6	0.0	1.6
K	Metals I and mol.	Orange	+1.0	–0.3	2.0
M	TiO bands	Red	+1.4	–1.3	2.7
R & N	Carbon bands	Deep red			

*B and V are the blue (λ 4350 Å) and visual (λ 5340 Å) magnitudes of stars.

(c) Hertzsprung–Russell diagram :— Thirdly, a plot of luminosity against the colour (B–V) or spectral type by Hertzsprung and Russell, independently, indicated groupings of stars as shown in Fig. 1, which is called the HR-diagram.

(i) The main sequence—75 per cent of all the stars are found to lie on a diagonal running from the top-left, i.e., the most luminous O type stars, to the bottom-right, i.e., the least luminous M type red stars. This is known as the main sequence.

(ii) The giants—About 1 to 2 per cent stars occupy the middle right

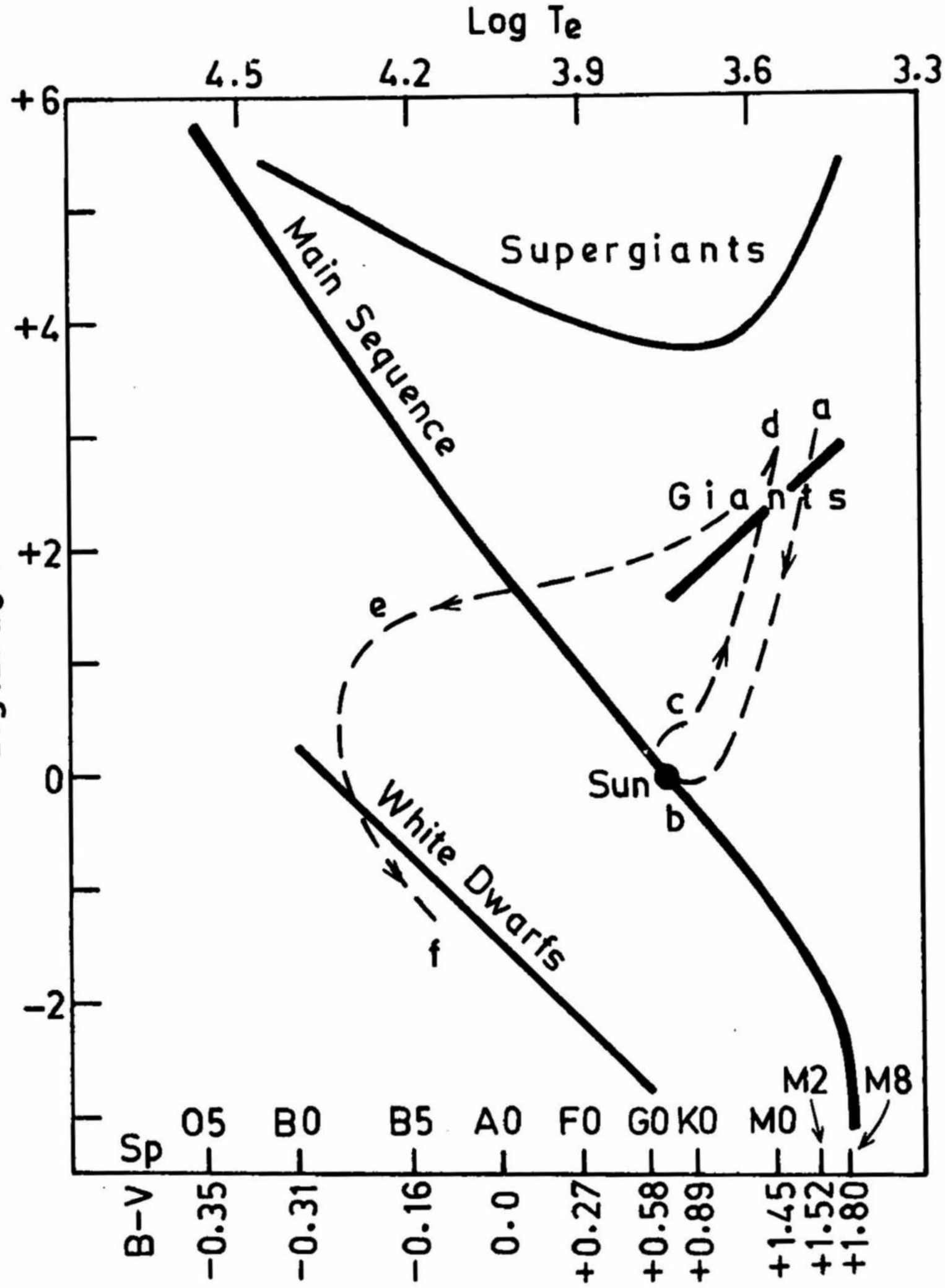


Fig. 1. *The Hertzsprung-Russell diagram*

space, i.e., the luminous GKM stars of orange and red colour. They have much larger size than the main sequence stars. Hence they are called giants, while the main sequence stars are designated as dwarfs.

(iii) The supergiants—There is a sprinkling of stars of all spectral types at the top of the figure, which are even more luminous and bigger in size than giants ; they are called supergiants.

(iv) The white dwarfs— About a quarter of all the stars lie in the lower left corner of the HR-diagram. The low luminosity stars of A and F types are extremely dense objects of the size of the earth and mass equal to that of the sun ; they are the white dwarfs.

(d) **Chemical composition** :— In 1921 the elemental make-up of the stars was completely unknown. Astronomers wondered whether the OB stars are made of helium, A stars of hydrogen and FG stars of metals. The presence of the molecular bands in the coolest stars and their absence in the hotter stars was easy to understand as it was known that the molecules dissociate at higher temperatures. But it was Saha's theory of thermal ionisation which completely solved the mystery of the elemental abundance in stars.

II. Saha's Equation of Ionisation

(a) **The law of mass action** :— Saha considered the process of ionisation to be similar to that of dissociation of a molecule. When two atomic species A and B combine to form a molecule AB, there developes an equilibrium between the process of dissociation and recombination : $A + B \Leftrightarrow AB$. It was known that the amount of AB is proportional to the product of the masses of A and B. This is known as the law of mass action. In terms of numbers N, we can write $N_{AB} = C(T)\, N_A N_B$, where C(T) is a constant which depends on temperature. it is called the equilibrium constant.

Now, considering the neutral atom denoted by I to be a combination of the ion denoted by II and the free electron e, we can write : $II + e \Leftrightarrow I$. The law of mass action for this process can be written as $N_I = C(T)\, N_{II}\, N_e$. Saha derived the constant C(T) from thermodynamic and statistical considerations to obtain his equation of ionisation, which, in an extended form, is as follows :

$$\frac{N_{II}\, N_e}{N_I} = 2\,\frac{(2\pi m k T)^{3/2}\, B_{II}}{h^3\, B_I} \exp\,(-\chi_I/kT) \qquad (1)$$

where χ_I is the ionisation potential.

(b) Simple derivation :— We can consider the ionisation equation to be a generalisation of the Boltzmann's equation of ionisation.

$$\frac{N_r}{N_1} = \frac{g_r}{g_1} \exp\left(-\chi_r/kT\right) \tag{2}$$

where g_r and g_1 are the statistical weights of the r-th and 1st levels, respectively, and χ_r is the excitation potential of the r-th level. Introducing the partition function

$$B = \sum_r g_r \exp\left(-\chi_r/kT\right) \tag{3}$$

we get

$$\frac{N_r}{N} = \frac{g_r}{B} \exp\left(-\chi_r/kT\right) \tag{4}$$

where N is the total number of atoms. Thus B represents the total statistical weight for all the atoms taken together. Then we can write

$$\frac{N_{II}}{N_I} = \frac{g_{II}}{g_I} \exp\left(-\chi_I/kT\right) \tag{5}$$

Here $g_I = B_I$, while $g_{II} = B_{II}\, g_e$, where g_e is the average weight of a free electron. Now from statistical mechanics we have

$$g_e = 2\left(2\pi mkT\right)^{3/2}/h^3 N_e \tag{6}$$

Substituting g_{II} and g_I in equation (5) we get

$$\frac{N_{II}}{N_I} = 2\frac{\left(2\pi mkT\right)^{3/2}}{h^3 N_e}\frac{B_{II}}{B_I} \exp\left(-\chi_I/kT\right) \tag{7}$$

On putting $N_e kT = P_e$, the electron pressure, we have

$$\frac{N_{II}}{N_I} = 2\frac{\left(2\pi m\right)^{3/2}\left(kT\right)^{5/2} B_{II}}{h^3 P_e B_I} \exp\left(-\chi_I/kT\right) \tag{8}$$

This is Saha's equation of ionisation.

(c) Explanation of the spectral sequence :— The main consequences of the ionisation equation are :

(i) The degree of ionisation increases with increasing T.

(ii) The degree of ionisation decreases with increasing p_e.

(iii) The degree of ionisation decreases with increasing χ_I.

We can now explain the spectral sequence, as shown in Table 2.

Table 2—Explanation of the spectral sequence of stars

Spectral types	Temperature °K	Process	Spectrum
M → K	3000 → 5000	Dissociation of molecules	Molecules → Neutral atoms
K → G	5000 → 6000	Ionisation of species with low χ_I	K I → K II Na I → Na II Ca I → Ca II
G → F	6000 → 7600	Ionisation of species with higher χ_I	Fe I → Fe II etc.
F → A	7600 →10000	Excitation of the 2nd level of H I	Balmer lines of H I become stronger
		Double ionisation	Ca II → Ca III
A → B	10000 →25000	Ionisation of H I	Balmer lines weaker
		Excitation of He I	He I lines strong
B → O	25000 →40000	Ionisation of He I	He II lines strong
Dwarfs to Giants	p_e decreases	More ionisation	Ion lines stronger

Thus it became clear that the differences in the stellar spectra are caused by the differences in the physical conditions of temperature and pressure prevailing in the atmospheres of stars. Consequently these conditions must be taken into account for deriving the elemental abundances in stars. This was the clear massage of Saha's equation.

III. Survey of the Elemental Abundances in the Universe

(a) Uniformity of the elemental abundance :— Let us consider the chemical composition of the various components of the universe.

(i) Stars and galaxies— One has to use the elaborate techniques of the model atmospheres and the curve of growth for determining the physical conditions in the stellar atmospheres and their chemical composition [4]. Such studies have brought to light the remarkable similarity in the chemical composition of all the stars not only in our galaxy but also in other external galaxies. All of them show the preponderance of the lightest element hydrogen which forms nearly 70 to 75 per cent of their mass ; it is denoted by X = 0.70 to 0.75. Hydrogen is followed by the next lightest element helium which accounts for about 23 to 28 per cent of the total mass ; it is denoted by Y = 0.23 to 0.28. The remaining heavy elements occur in very small proportion which varies from a negligible amount in the oldest stars to about 4 per cent in the youngest stars ; their abundance is denoted by Z = 0.001 to 0.04. Although this is the composition of the surface layers of the stars, there are several reasons to believe that it represents the abundance of the elements in the interior also.

(ii) Planets— In the case of giant planets Jupiter and Saturn we find that their mass, mean density and oblateness all together indicate that they contain 78 and 63 per cent of hydrogen by mass, respectively. The remainder is mostly helium as in the sun and stars. Uranus and Neptune have somewhat less hydrogen and more helium.

Among the smaller terrestrial planets we can study only the earth in great detail. Chemical studies of its crust and seismological studies of its interior indicate that the the most abundant element in the earth is iron, which forms 39 per cent of its mass. Next in order come oxygen 27 per cent, silicon 14 per cent and magnesium 11 per cent. The five elements S, Ni, Al, Ca and Na make up 8 per cent of the earth's mass, while the remaining elements contribute less than one per cent of the total mass. We note that hydrogen and helium, which are found to be the most abundant elements in the universe, are present in negligible proportion in the earth. These light gases as well as the inert gases Ne, A, Kr, Xe and some O and C must have been lost by evaporation due to the heat of the sun in the past.

Composition of the moon is similar to the earth's crust as it has no nickel-iron core like the earth. Venus, which is almost a twin of the earth, is likely to have the same composition as the earth. And that of Mercury and Mars would be intermediate between the earth and the moon. All of them have lost the lightest elements by evaporation.

(iii) Other sources— The chemical composition of the interstellar medium reflects the chemical composition of the stars. The same is the case with the meteorites, comets and cosmic rays.

Thus we come to the conclusion that all the material in the universe has more or less the same proportion of elements. Hence it is termed as cosmic mixture, which must have a common origin.

(b) **The main features of the cosmic abundances** :— Fig. 2 shows the cosmic abundances of the elements by numbers. We find the following regularities in the relative amount of the elements as discussed by Aller[5].

(i) Abundances decrease with increasing atomic weight roughly exponentially upto A = 100, or, Z = 42–43.

(ii) The decrease of abundances is much slower beyond A = 100 and it terminates abruptly at U^{238}.

(iii) Superposed on the general trend there is a pronounced peak in the neighbourhood of Fe^{56}, which is called the iron-peak.

(iv) Less pronounced peaks occur near Sr^{88}, Ba^{138} and Pb^{206} which have closed shells of nuclei containing the magic numbers of neutrons, viz. 50, 82 and 126.

(v) Nuclei of even atomic weights are usually more abundant than those with odd atomic weights.

(vi) Among the nuclei with even atomic weights, those with atomic weights divisible by 4 are more abundant, e.g. C^{12} and O^{16} are more abundant than N^{14}.

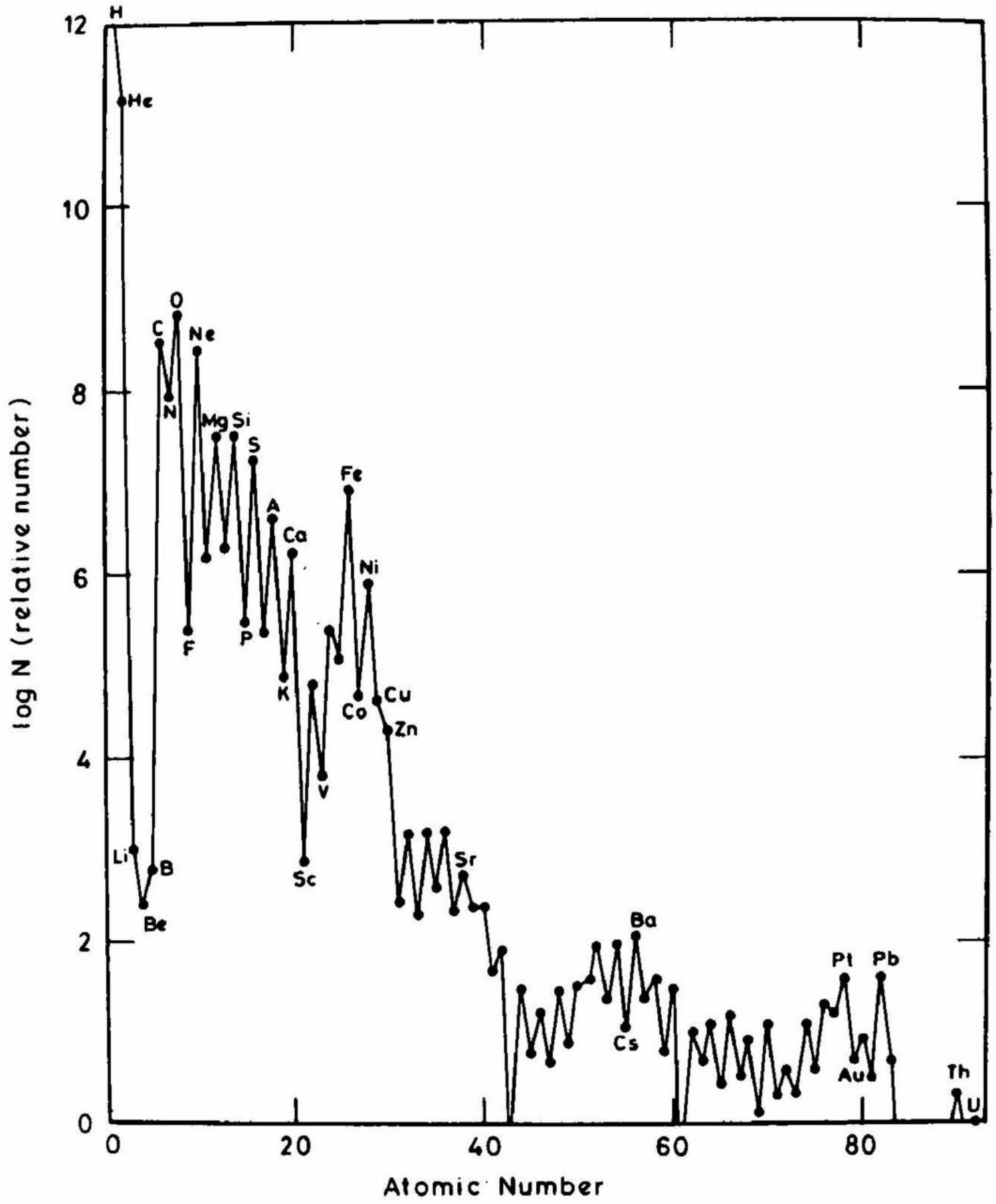


Fig. 2. *The relative abundances of elements plotted against atomic number.*

(vii) Deuterium, lithium, berylium and boron are much less abundant compared with the neighbouring elements H, He, C, N and O.

IV. Theories of Nucleosynthesis

(a) **Earlier theories** :— The uniformity in the abundances suggests that all the elements were perhaps formed simultaneously at one place and time by a single process. Two theories came into prominence

in the earlier days, viz. the equilibrium theory and the neutron capture theory.

(i) The equilibrium theory :— Here it was argued that the various nuclei and their components such as protons, neutrons and alpha particles will be in equilibrium among themselves and with the lighter particles like the beta particles and photons at some very high temperature and density. Such conditions could have existed at the centres of some enormously massive stars that might have been formed in the earliest epoch of the universe. Violent explosions of these objects would spread the elements so formed throughout the universe. The abundances will thus be determined once for all by the conditions in those stars and they might have been frozen in for all times. This equilibrium theory, considered by Chandrasekhar and others [6], explains most features of the abundance curve except (ii) and (iv), because the other features only emphasize the preponderance of the stable nuclei. However, stars of mass greater then 100 solar masses are so unstable that they might never have been formed.

(ii) The neutron capture theory :—In order to explain the abundances of the elements heavier than silver, Gamow [7] put forward a non-equilibrium theory which he tied with the theory of the expanding universe. If the presently observed expansion of the universe is reversed, all the matter in the universe would have been concentrated within a very small volume some 15-16 billion years ago. In that highly compressed state with a very high temperature, the material would have consisted of a gas of neutrons, to which Gamow gave the name of Yelum. As the universe started expanding with the big bang, the neutron gas would also expand and the neutrons in it would begin to decay into protons. The two fundamental particles would then combine in various proportions to form all the elements in a short period of about two hours. The abundances of all the elements will thus be fixed for ever. In this process the amount of an element produced would be inversely proportional to its neutron capture cross-section. Since the neutron capture cross-section increases uniformly with atomic weight A = 100, and remains more or less constant thereafter, one can explain the relative abundances of the light, medium and heavy nuclei quite easily. Further the abundance peaks at the magic number nuclei can also be understood. But it cannot explain the iron-peak elements because they have fairly high capability of capturing neutrons. But the main stumbling block in this theory is the difficulty of building the elements heavier than helium, because helium is the most stable

nucleus and it is difficult to add neutrons to it to form lithium and beryllium. Once Be is formed, one can build the heavier elements by the neutron capture process. But the gap between helium and berylium is hard to bridge.

(b) **The modern theory of nucleosynthesis** :— It is clear from the above discussion that the equilibrium and neutron capture theories both explain a part of the observed abundances of some elements but fail for some other elements. Hence we have to conclude that both of them might have occurred at some epochs. It is better to abondon the idea of forming all the elements at one stroke. It is now believed that the element building i.e. nucleosynthesis is a continuous process that goes on in the interiors of stars in the advanced phases of evolution. There is evidence for this in the progressive increase in the proportion of the heavy elements from the oldest to the youngest stars, as noted earlier.

The theory of the elemental synthesis inside stars has been developed during the last 30 years ; we shall now discuss the picture that has emerged from this work. For this, we have to first consider the evolution of a star like the sun as shown in Fig. 1. A star is formed by the gravitational contraction of a cloud of dust and gas in the interstellar space, like the Orion nebula. As the cloud contracts, the gravitational energy is converted into heat energy. Half of it is radiated away and the other half raises the temperature of the cloud, the rise being maximum at the centre of the cloud. Finally, when the surface temperature becomes as high as 3000°K, the condensed mass begins to shine as a star. The newly born star continues to contract until the central temperature reaches a value of 10^7K, when the thermonuclear reactions begin to operate. Thereafter the star stops contracting and continues to live on its nuclear fuel for millions of years as a main sequence star. This path of the star is shown in Fig. 1 by the section marked 'ab'. On the exhaustion of the nuclear fuel the star first expands slowly and then rapidly to become a giant as shown by the path 'bcd' in Fig. 1. Finally, the star explodes as a supernova and its core becomes a white dwarf or neutron star by following the path 'def' in Fig. 1. New stars are formed from the debris thrown out during the supernova explosion. With this understanding about the formation and evolution of stars, we can now trace the following steps in the progressive building of the heavier elements in the stellar interiors.

V. The Comprehensive Theory

We shall now consider the comprehensive theory of nucleosynthesis put forward by Burbidge, Burbidge, Fowler and Hoyle [8].

(a) **The first generation stars** :— The earliest or the first generation stars would have consisted of hydrogen and helium only. Their central tempertures range from 10 to 30 million degrees K, depending upon the mass. At these temperatures the following pp-chain reactions can provide energy by the conversion of hydrogen into helium.

$$H^1 + H^1 = H^2 + e^+ + \gamma$$
$$H^1 + H^2 = He^3 + \gamma$$
$$He^3 + He^3 = He^4 + H^1 + H^1 + \gamma$$

Result : $4H^1 = He^4 +$ energy

When the hydrogen in the core gets exhausted, the helium core contracts and the envelope expands, taking the star to the giant stage of its life. When the central temperature reaches 100 million degrees, the star can derive energy by the conversion of helium into carbon through the triple reaction $3\,He^4 = C^{12}$ + energy. Such triple reactions are necessary, because two helium atoms cannot combine to form beryllium without the supply of energy ; in other words it is an endothermic reaction. This means we have to explain the formation of the elements between helium and carbon in a different way.

Conversion of helium into carbon does not provide enough energy to the star, so the star continues to contract. When the central temperatures between 10^8 and 10^9 K are reached, carbon can combine with helium to produce still heavier elements oxygen, neon and magnesium by the following reactions :

$$O^{12} + He^4 = O^{16} + \gamma$$
$$O^{16} + He^4 = Ne^{20} + \gamma$$
$$Ne^{20} + He^4 = Mg^{24} + \gamma$$

Most of the helium is consumed at this stage, after which the core has to contract further until one reaches a temperature of 1.3 billion degrees K. At this high temperature the density of radiation will be so high that

the photon-disintegration of neon will take place with the release of oxygen and helium. The alpha particles so released can combine with the remaining neon to produce Mg, Si and S by the following reactions :

$$Ne^{20} + He^4 = Mg^{24} + \gamma$$
$$Mg^{24} + He^4 = Si^{28} + \gamma$$
$$Si^{28} + He^4 = S^{32} + \gamma$$

At these temperatures oxygen and neon can also interact with carbon, producing heavier elements along with neutrons, protons and alpha particles. In this way elements with atomic weights which are not multiplets of four can also be created as follows :

$$O^{16} + C^{12} = Li^6 + Na^{22}, \text{ or, } B^{10} + F^{18}, \text{ or, } 2N^{14}$$
$$Ne^{20} + C^{12} = Li^6 + Al^{26}, \text{ or, } B^{10} + Na^{22}, \text{ or, } N^{14} + F^{18}$$

But it is not possible to produce heavy elements beyond sulphur.

When the nuclear fuel is exhausted, the star has to depend on its gravitational energy released by contraction. The core contracts so fast that the star explodes due to gravitational collapse in the form of a supernova and scatters its content of heavy elements into the interstellar space where new stars are formed.

(b) **The second generation stars** :— The second generation stars will contain carbon. The more massive stars among them with mass greater than the mass of the sun will have central temperaturs of 15 to 30 million degrees. So they can derive energy from the following carbon-nitrogen cycle in which N^{13}, N^{14}, N^{15} and O^{15} will also be produced.

$$C^{12} + H^1 = N^{13} + \gamma$$
$$N^{13} = C^{13} + e^+ + \nu$$
$$C^{13} + H^1 = N^{14} + \gamma$$
$$N^{14} + H^1 = O^{15} + \gamma$$
$$O^{15} = N^{15} + e^+ + \nu$$
$$N^{15} + H^1 = C^{12} + He^4 + \gamma, \text{ or, } O^{16} + \gamma$$

Result : $4H^1 = He^4 +$ energy

Here again, after the exhaustion of hydrogen in the core, there will follow the contraction of the core, burning of helium and production of the heavy elements upto sulphur as in the first generation stars. They will now include elements of odd atomic weights also.

If the star can contract futher after this stage without undergoing the catastrophic supernova explosion, then temperatures of the order of 3 to 4 billion degrees K and densities of the order of 10^5 gm/cm^3 can be reached at the centre of the star. Under these conditions equilibrium processes described earlier will take place and elements between A = 46 and A = 66 will be produced. In this way the iron peak elements will come into existence.

At the same time, in the shell surrounding the core, where hydrogen is abundantly available and temperatures are sufficiently high, a neon-sodium cycle will operate exactly like the carbon-notrogen cycleas follows.

$$Ne^{20} + H^1 = Na^{21} + \gamma$$

$$Na^{21} = Ne^{21} + e^+ + \nu$$

$$Ne^{21} + H^1 = Na^{22} + \gamma$$

$$Na^{22} = Ne^{22} + e^+ + \nu$$

$$Ne^{22} + H^1 = Na^{23} + \gamma$$

$$Na^{23} + H^1 = Mg^{24} + \gamma, \text{ or, } Ne^{20} + He^4 + \gamma$$

Result : $4\,H^1 = He^4 +$ energy

This will convert hydrogen into helium with the production of Na^{21}, Na^{22}, Na^{23}, Ne^{21} and Ne^{22}. The production of Ne^{21} is important, because when it comes into contact with the helium in the core, it can get converted into Mg with the emission of a neutron by the reaction : $Ne^{21} + He^4 = Mg^{24} + n$. The neutrons so produced can start the neutron capture process envisaged by Gamow and the iron group elements can be converted into still heavier elements. The exact nature of the element building will, however, depend upon the rate at which neutrons become available.

(c) **The s and r processes** :— If the stellar evolution is progressing at a moderate speed, the time interval between the successive neutron captures will be of the order of 1 to 1000 years. In this slow, or, so-called s-process, the nuclei formed by neuton capture will have sufficient time to emit beta particles before the capture of the next neutron. Therefore, the chain which builds the heavier elements will pass through beta-stable elements. In this way the iron-peak elements at A = 56 will converted into elements with A about 70, which in turn will be converted into still heavier elements. In this process the magic number nuclei with 50, 82 and 126 neutrons will be more abundant, producing peaks at Sr^{88}, Ba^{138} and Pb^{206}. But this slow process cannot produce elements beyond Bi^{209}, because Po^{210} produced from it by the capture of a neutron and subsequent beta emission disintegrates rapidly into Pb^{206} by the emission of an alpha particle. Thus Th and U cannot be produced.

On the other hand, if the star contracts very rapidly after the formation of the iron-peak elements, then the neutrons will be produced at a very fast rate so that the interval between the successive neutron captures will be of the order of one second. In this rapid, or, so-called r-process, the nuclei built by the neutron capture have no time to emit beta particles. So the heavier elements that are built will pass through the beta-unstable chain. In this way one can build the heaviest elements upto Cf^{254}. Californium is the heaviest possible element because it undergoes spontaneous fission.

VI. Conclusion

In the final stages of the life of the star, there are no sources of nuclear energy. So the gravitational collapse is extremely fast, deserving the name of an implosion. Consequently the star explodes as a supernova and its core contracts into a neutron star. It is estimated that a supernova of Type I becomes 100 million times brighter than the sun and the accompanying implosion is responsible for the production of the heaviest elements. The half life of 55 ± 1 days for the decrease in the brightness of a supernova of Type I is significantly close to the half-life of 56 days for the fission of Cf^{254}. We can say tht these explosions of the whole stars are huge californium bombs triggered by the gravitational collapse of the star. The supernova observed in the Magellanic Cloud during 1987 indicated that it might have been a cobalt bomb instead of a californium bomb.

Now, both the slow and rapid neutron capture mechanisms will gradually increase the abundance of the heavy elements in the interstellar space. Therefore, each new generation of stars will contain progressively more and more amounts of the heavy elements. Thus, although our sun is four-and-half billion years old, the material in it must have been produced in the interiors of other older stars which had run through their life span before the sun was formed. By comparing the present ratio of U^{238}/U^{235}, which is 140, to the ratio of 0.6 expected in the supernova, one obtains an age of six-and half billion years for the solar material, which thus appears to be two billion years older than the sun.

We have still to account for the formation of the light nuclei D^2, Li^6 and B^{10}. These elements are unstable at temperatures of a few million degrees that prevail in the stellar interiors. Hence they can neither be created nor will they survive in the interiors of stars. It is suggested that they are produced in the outer layers of stars by the bombardmant of the heavier nuclei with the high energy particles accelerated in the stellar magnetic fields by the cyclotron action. We find that the rare earth lines in the recently formed T-Tauri stars support this hypothesis. The light elements produced in this way are supplied to the interstellar medium through the mechanism of the stellar winds, and then to the protostars. However, during the evolution of the star they are destroyed, particularly if a large convection zone occurs in the stellar envelope, as happens in the case of the sun. This explains why D and Li are less abundant in the sun as compared to their proportion in the earth.

We have now seen how most of the elements were formed in the interiors of the stars during the various phases of their evolution. Therefore, the cosmic abundances of elements do not appear to be a matter of chance but only as a product of the evolution of our galaxy according to physical laws. This is a fine example of the indivisibility of knowledge in which astrophysics and nuclear physics have worked together to explain the mystery of the all-pervading common abundances of the elements in the universe. It also shows that the material in our bodies was once processed in the interiors of massive stars, so that we are truly the descendents of the stars. All this progress would not have been possible without Saha's theory of ionisation in the first place.

You may now appreciate the following Hindi poem by the author.

तारों का संदेश

आसमान मे तारें अनेक है
लाल नीले सफेद वे हरि है
इन मे जो पुलराज्य है
शरीर के सब अंगो मे है
इन से जो प्रकाशक आते है
भविष्य मे विकास जगाते है
अमरत्व के वे प्रतीक है
जड चेतन के संपुल है
इन कीडाओ से हम मरजावे
आसमंत को जगलावे

एक दूसरे से चमकीले है
हमारे लक्ष से परे है ॥ १ ॥
वहीं धरती के ही कलेवर मे है
किंतु हमारे संबंध टुटे है ॥ २ ॥
अतीत की याद दिलाते है
मन मे क्यो फिर अंधेरा है ॥ ३ ॥
अनादि अनंत स्वरूप है
मृत्यु पर क्यो हमे डेरे है ॥ ४ ॥
अविरत कार्यरत हो जावे
मर कर भी अमर हो जावे ॥ ५ ॥

(देवरुखाद — १३ अगस्त १९५९)

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Meghnad Saha and Atmospheric & Space Physics

PROF. M. N. SAHA'S WORK ON ATMOSPHERIC SCIENCE

S. N. GHOSH

ABSTRACT

In this paper the work of Saha on atmospheric science is presented. His work on propagation of radio waves through ionized layer, which was admired by even Appleton, is first considered. Afterwards Saha's works on solar UV and EUV radiations, which were inaccessible to observations from ground, are dealt with. The characteristic features of these radiations and their control of upper atmospheric phenomena, which were predicted by him, are then considered. It is shown that subsequent work carried out by rockets and satellites confirmed his predictions. Finally, his meeting with Einstein is referred to.

1. Introduction

Saha became well-known by formulating 'Ionization Theory'. It is a great theory as it has the simplicity and beauty, and at the same time wide applications which characterize a great theory. In addition to this theory, Saha carried out important research work in other fields, for example, atmospheric science. In course of nine papers, which he published in this field, he investigated two aspects of atmospheric science, namely

(i) Propagation of radio waves through the ionized regions of the Earth's upper atmosphere.

(ii) Characteristic features of solar spectrum in the UV and EUV regions and their control of upper atmospheric phenomena.

In this paper Saha's work on atmospheric science is considered. In his lifetime solar spectrum was known mainly upto 2900 Å. Saha postu-

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lated that if spectrographs were taken to high altitudes, solar UV and EUV radiations would be known. He predicted certain characteristic features of solar radiations in these regions and their control of upper atmospheric phenomena. Subsequent work after saha's demise with rockets and satellites showed the correstness of his predictions.

2. Propagation of Radio Waves through the Atmosphere

The propagation of radio waves through upper atmospheric ionized regions was first considered theoretically by Eccles [1], who derived expressions for their velocity and absorption. He supposed that the effective charge was due to ions of atomic mass, and that the medium acted like a conductor. It is difficult to reconcile these two conditions, since the conducting medium requires the collisional frequency to be large compared with the angular wave-frequency and it is not feasible for massive ionic charge. Larmor [2] then examined the problem. The essential difference between the two approaches is that Larmor considered electrons and Eccles ions of atomic mass. Larmor supposed the collisional frequency to be small for the medium to behave like a *dielectric* while Eccles considered the frequency to be large and the medium to behave as a *conductor*. A conductor absorbs energy strongly and Eccles realising this postulated a sharply bounded ionosphere from which waves would be partially reflected without being absorbed. In Larmor's dielectric medium, however, the absorption could be much smaller and the waves would return to the Earth by a process of gradual refraction. Larmor's picture of the ionosphere is thought to be correct except for long waves for which a mechanism similar to that of Eccles is effective.

Later on, Appleton and Barnett [3] referred to Larmor's paper and pointed out the need to take account of the Earth's magnetic field. They extended the analysis of Lorentz [4] and gave an expression for the complex refractive index of the ionosphere. It is now widely used.

3. Saha's Work on Radio Wave Propagation

Appleton postulated three conditions for the reflection of radio waves from the ionosphere, Saha postulated that there is an additional one, assuming that the radio waves are not absorbed in the ionosphere. This investigation he did during his stay at Allahabad in collaboration with his students Rai and Mathur [5-8].

Coming to Calcutta, he continued the work or radio wave propagation. Together with his student, B.K. Banerjea, Saha [9] showed that the single condition $\psi = \frac{\pi}{2}$, where ψ is the angle between the electric and the displacement vector, is equivalent to the various conditions of reflection of radio waves by the ionosphere. Again, along with Banerjea and Guha [10], he deduced expressions for refractive indices of the ordinary and extraordinary waves—the split-up components of radio waves by the magnetic field of the Earth. He also studied polarization and absorption. These investigations had drawn appreciation from none less than Sir E. V. Appleton, N.L., who formulated the famous magnetoionic theory for the ionosphere. His letter and its reply by Saha are given below :

Extract of letter from Sir E. V. Appleton, N.L., Department of Scientific and Industrial Research, Park House, 24, Rutland Gate, London, S.W. 7, dated 13. 1. 1948 :—

My dear Saha,

This is to thank you for the most interesting reprints you have sent me.

I am glad to see that you and your pupils are tackling magnetoionic problems in a rigorous manner, and I greatly admire your mathematical skill. My original formulation of the theory was very crude and needs the hand of a ***real methematician*** *to put things right.*

On the question of solar radio noise I expect you will be applying your theory to the thermal radiation from the corona at 10^6 ^oK. *Martyn has written a short article in Nature on the subject and I am reading his fuller Proc. Roy. Soc. paper for him (he is in Australia) on Thursday next at Burlington House.*

With kind regards and all good wishes for 1948 to you all,

Yours ever,

Sd/- E. V. Appleton

Extract of letter from Prof. M.N.Saha, D.Sc., F.R.S., 92, Upper Circular Road, Calcutta (India), dated 25. 2. 1948 :—

My dear Appleton,

Thanks for your letter dt. 13.1.48.

I am glad to receive your opinion about our work on the 'propagation of electro-magnetic waves through the ionosphere'. Coming from a scientist of your eminence, your remark has been highly stimulating to my research scholars and they are now tackling other problems arising out of it, e.g. (i) Propagation of e.m. waves over any general station, (ii) Virtual and true paths for Chapman layer.

We shall be very grateful if you kindly send us reprints by yourself and your scholars from time to time. They will materially help us in our work.

*Re : **Origin of microwaves from the sun** :— My paper deals only with the propagation of the microwaves through the solar atmosphere, but I have not yet tackled seriously the problem of origin of the microwaves. I am unable to take seriously the suggestion that the corona has a temperature of the order of a million degrees. The advocates of the view have to explain how such temperature can be produced in the corona. I have suggested alternative theories of the solar corona a few years ago in a lecture delivered to the Physical Society of London. Though criticisms have been offered against my view, I do not think they are serious enough, but I had not yet time to tackle them seriously.*

With kind regards,

Yours sincerely,

Sd/- M. N. Saha

4. Saha's Work on Solar UV and EUV Radiations and their Control of Atmospheric Phenomena

The other aspect of atmospheric science which Saha investigated is the characteristic features of solar spectrum in the UV and EUV regions

and their control of upper atmospheric phenomena. As there is a strong solar-terrestrial atmospheric relationship, the solar radiations during quiet and disturbed conditions are mentioned in brief.

The Sun is a spherical object (of 1.4 million km diameter) of hydrogen and helium gas with traces of all remaining elements, many of which show up prominently in the solar spectrum. The thermonuclear conversion of hydrogen to helium at the solar centre provides energy flux which escapes from the surface mainly as radiations in the visible and infrared regions but small amounts of energy have also been detected over the rest of the whole spectrum from X-rays to the longest radio waves. In addition, a minor fraction of low energy particles constitutes the solar wind with sporadic bursts of faster particles, which are varying in energy from a few KeV to a few GeV.

The Sun is observed through the transparent solar atmosphere down to the white surface (photosphere) which is the sharp upper boundary of an opaque fog of negative hydrogen ions having 6000°K temperature. The temperature decreases from the photosphere to a minimum of 4300°K in the lower chromosphere, and again rises through the chromosphere to about 10^5 °K at the abrupt interface, the density in the corona gradually decreasing and ultimately merging with the interstellar background.

The solar atmosphere is the scene of constant and vigorous action. The white surface has bright granules. At the photosphere and the lower chromosphere exist vertically oscillating waves that probably carry energy which sustains high temperature of the chromosphere and corona. Through the chromosphere hair-like spicules rise several thousand km into the corona. These actions occur in the presence of a magnetic field.

The steady state of the Sun is sometimes disturbed by the onset of an active centre, a region of strong magnetic field which excites a number of spectacular features known collectively as solar activity, of which sunspots are the most important. They can be seen in telescopes and were first discovered by Galileo. In addition to sunspots, the slowly varying features and the plages and the stable dark filaments generally endure through the lifetime of the active centre, from a few hours to several months.

The most exciting features of the Sun are the explosive flares and many fast phenomena associated with them. These solar features affect the Earth's upper atmosphere.

As mentioned before, the solar spectrum observed at the ground extends only upto 2900 Å and not below. Saha visualised that if the spectrum is photographed from altitudes of about 40 km it would extend deep into the ultraviolet. In 1937, while presenting a talk at Harvard University, he described the enormous scientific information that could be obtained about the Sun if observed above the ground [11]. Further these aspects of solar spectrum were elaborated in the Presidential Address at the National Institute of Science (now Indian Academy of Science) at Labore in 1938 [12-15].

In this address Saha proposed :

(i) A satisfactory theory of upper atmosphere and the phenomena occurring there must be based on precise knowledge of the action of solar ultraviolet rays below 2900 Å on O_2 and N_2. In addition to observations from space, well-planned laboratory experiments on the spectrum of these molecules are essential.

(ii) The ultraviolet radiation from the Sun differs widely from that of a blackbody and in selected wavelength regions must be emitting many times more photons than are given by a blackbody at 6000°K,

(iii) The ultraviolet spectrum of the Sun consists of a continuous spectrum with superimposed lines of H, He, He^+, Fe ions etc.

These are indeed very bold assertions arising out of deep intuition. To prove Saha's predictions there was a need to carry recording instruments above the Earth's absorbing layer. Unfortunately, during Saha's lifetime (Saha died in 1956) balloons carrying recording instruments could reach only low heights and rocket-borne experiments had just started. It was then extremely difficult to know the solar characteristic features in the deep ultraviolet region and hence their control of upper atmospheric phenomena which Saha predicted remained unexplored.

Before World War II the atmosphere was studied by a direct method

using balloons which could carry recording instruments to low altitudes. After World War II the study of the upper atmosphere by direct methods was greatly enhanced. Fig. 1 shows that, in addition to radio wave propa-

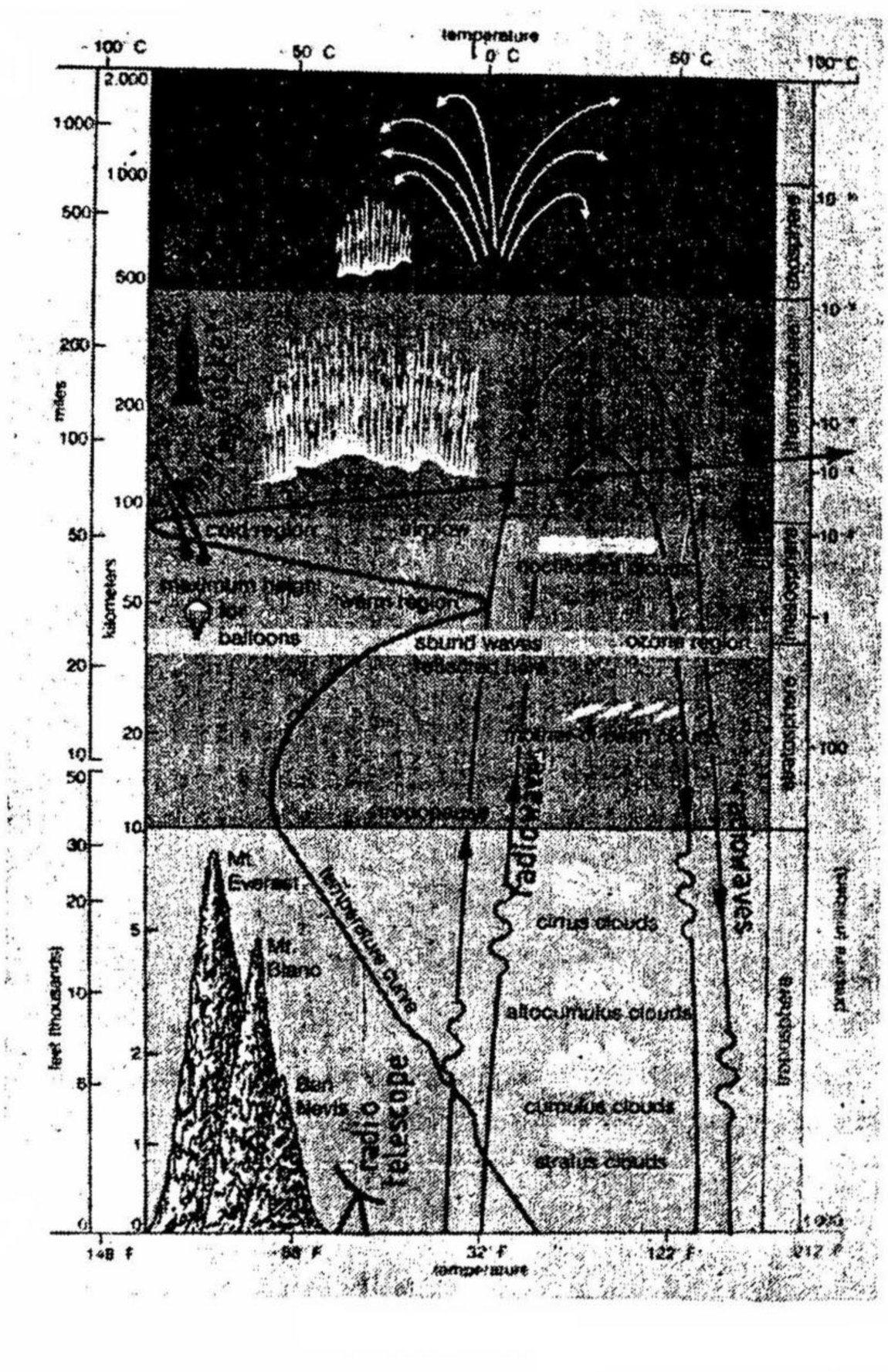


Fig. 1. *Different atmospheric regions and the phenomena occurring therein.*

Before World War II the atmosphere was investigated mainly by ground-based apparatus e.g. radio wave sounding of ionosphere. After World War II the investigation by direct methods was enhanced by using rockets and satellites.

gation through the ionosphere, the investigation of the upper atmosphere is carried out by other methods also. Balloons were replaced by rockets. There is, however, a difficulty in using rockets. It is due to the short time of about 5 minutes ebtween the time of launch of a rocket and its return to ground, necessitating a compromise between the sensitivity and speed of response of observing instruments. This difficulty was removed by using satellites (Fig. 2).

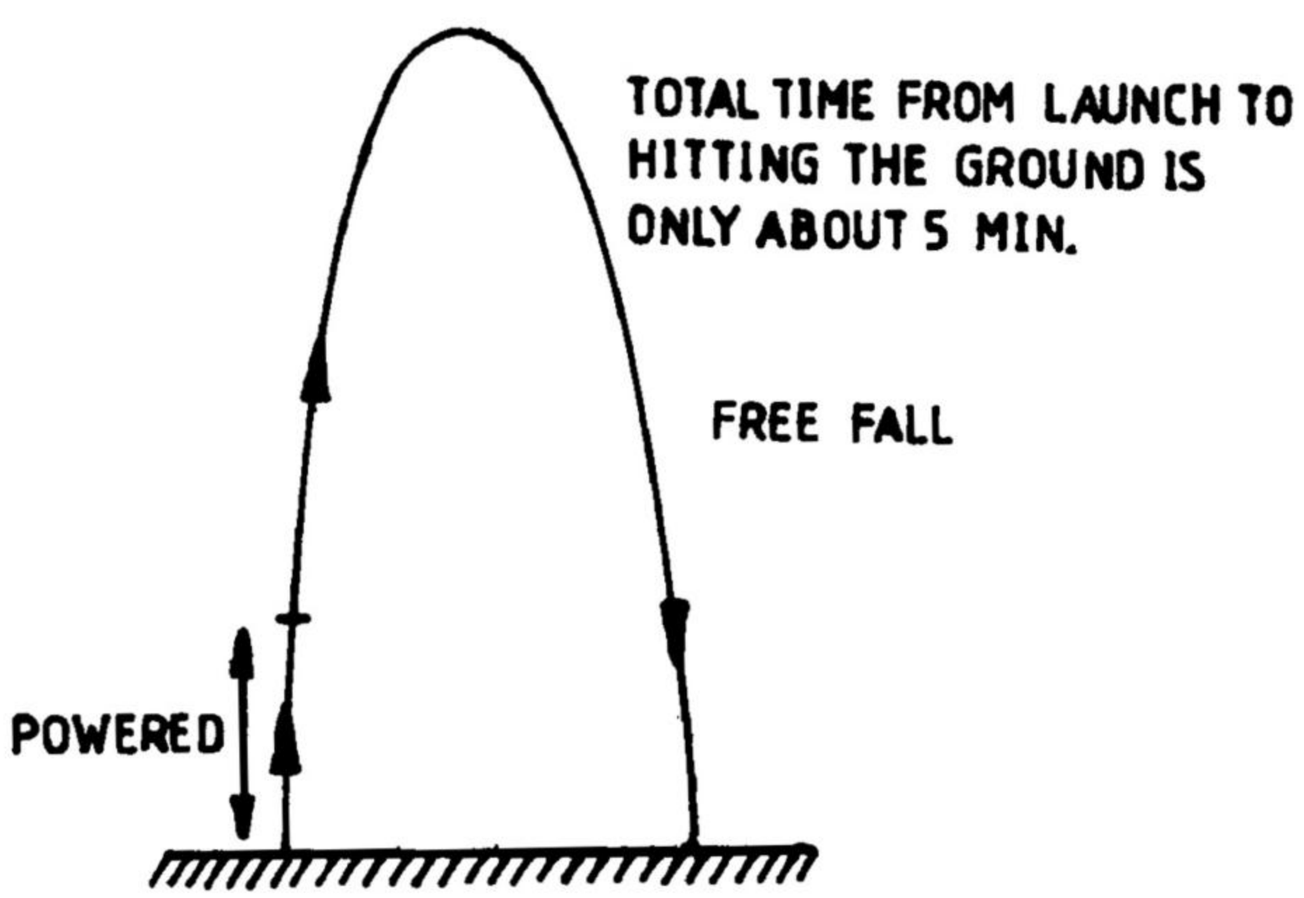


Fig. 2. *The projectile being followed by a rocket.*

After being powered, the rocket falls as a free-fall body in a parabolic path. The travelling time being small, a compromise should be made between sensitivity and speed of response of observing instruments.

5. Saha's Predictions Came True

As more rockets and satellites observed solar radiations in the UV and EUV regions (Figs. 3-5), Saha's assertions were confirmed. In the region between 2000 Å to 60 Å over 200 solar emission lines have been detected [15]. They are produced in the chromosphere and corona. Saha's prediction of strong emission lines in the UV and EUV regions of solar spectrum also came true. Resonance lines of neutral HI (1215.7Å Lyα), HeI (584Å) and lines of ions HeII (304Å), MgX (625Å), NeVII (430Å), OIV (790Å), OV (630Å) and NIV (765Å), SiXII, FeXV, FeXVI and others as well as continuum of H, He etc in the far ultraviolet regions of solar spectrum are observed.

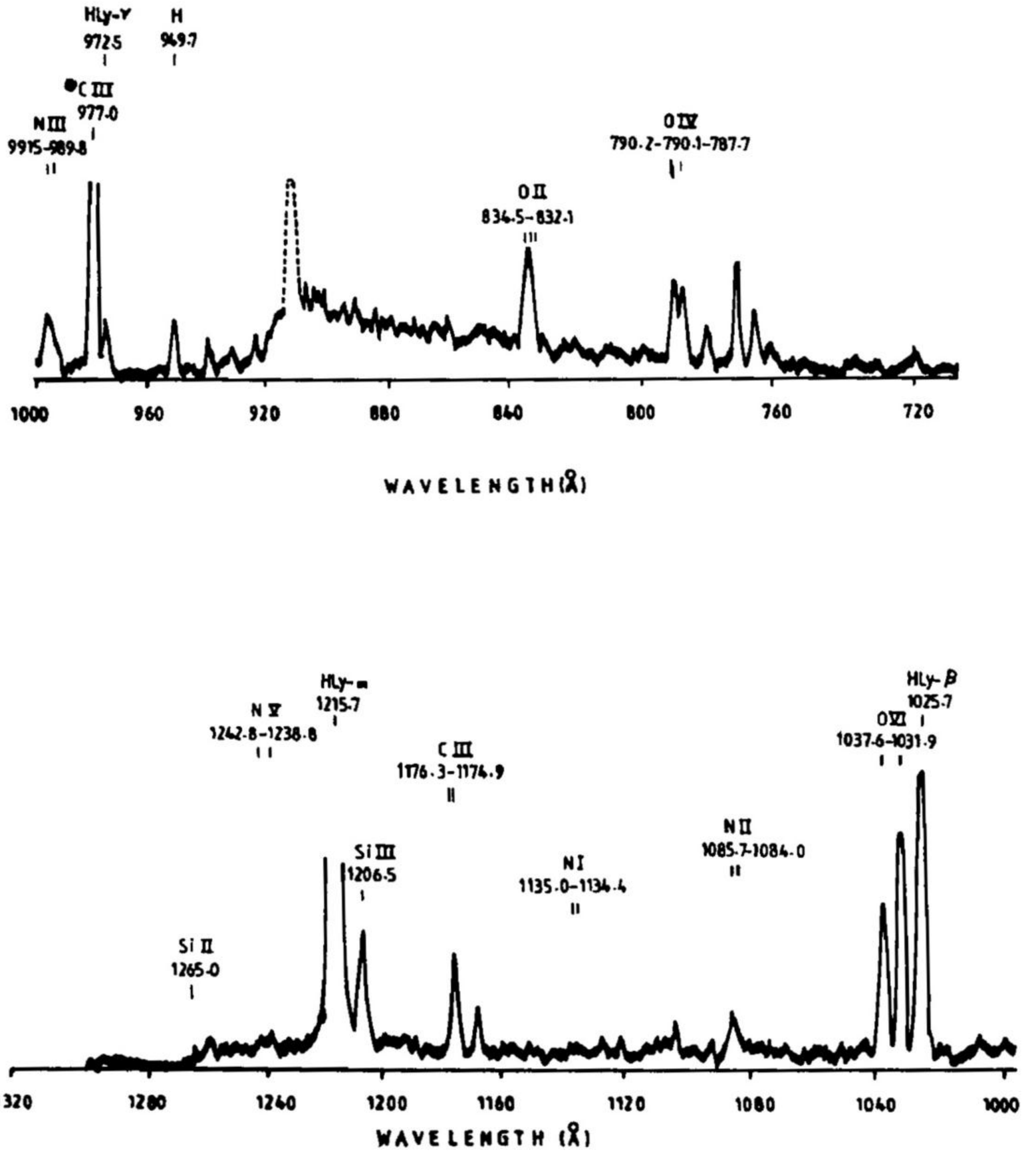


Fig. 3. *Solar spectrum observed by rocket-borne monochrometers between 1320 and 720 Å. Note strong lines at different regions of the spectrum [16].*

As regards control of upper atmospheric phenomena by solar UV and EUV radiations it may be mentioned that by absorbing solar radiations, atmospheric molecules are dissociated. Again, the dissociated atoms combining with molecules produces other molecules. The absorption of shorter wavelengths causes ionization and produces ionized layers

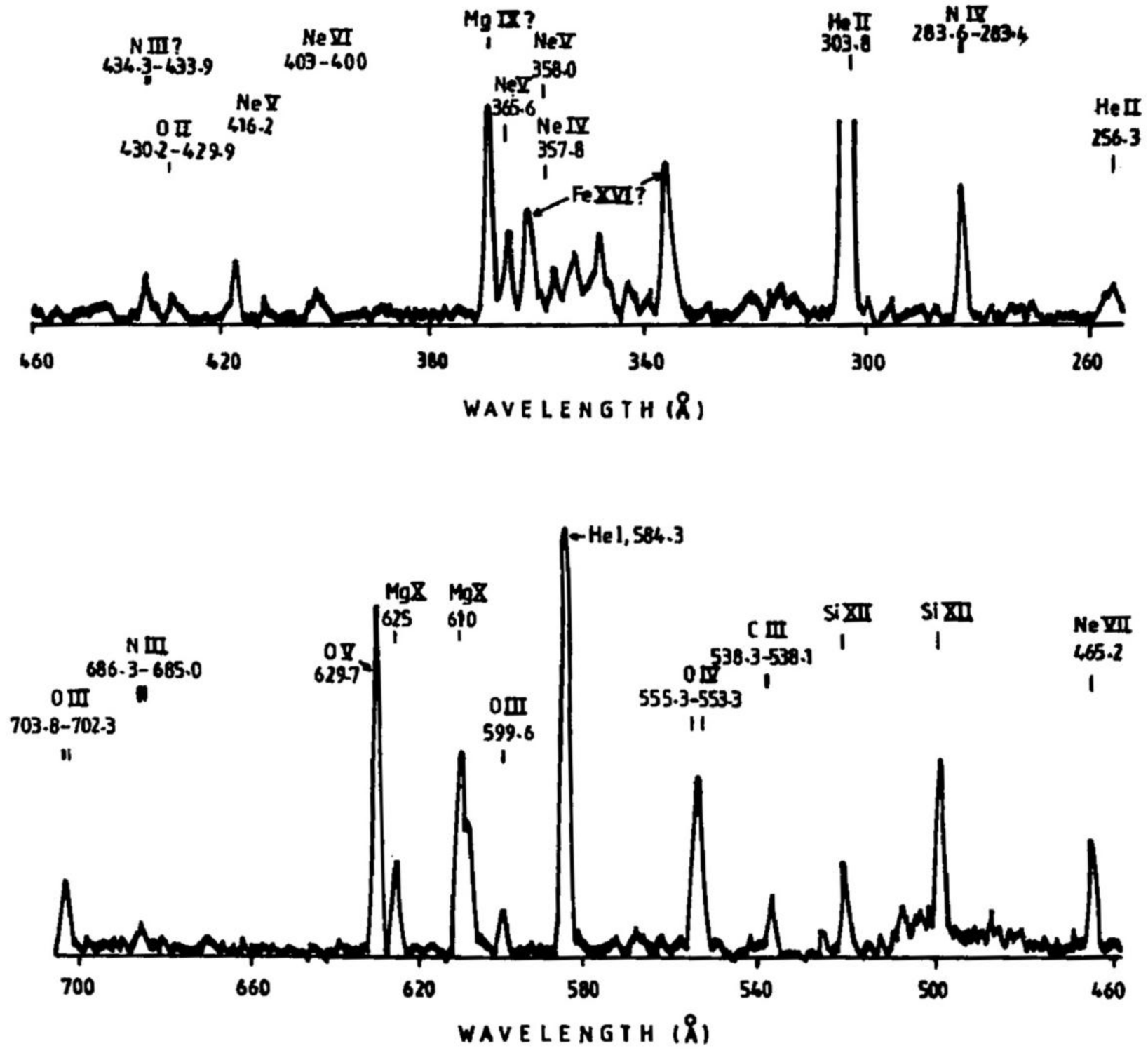


Fig. 4. *Solar spectrum observed by rocket-borne monochrometers between 700 and 260 Å. Note strong lines at different regions of the spectrum [16].*

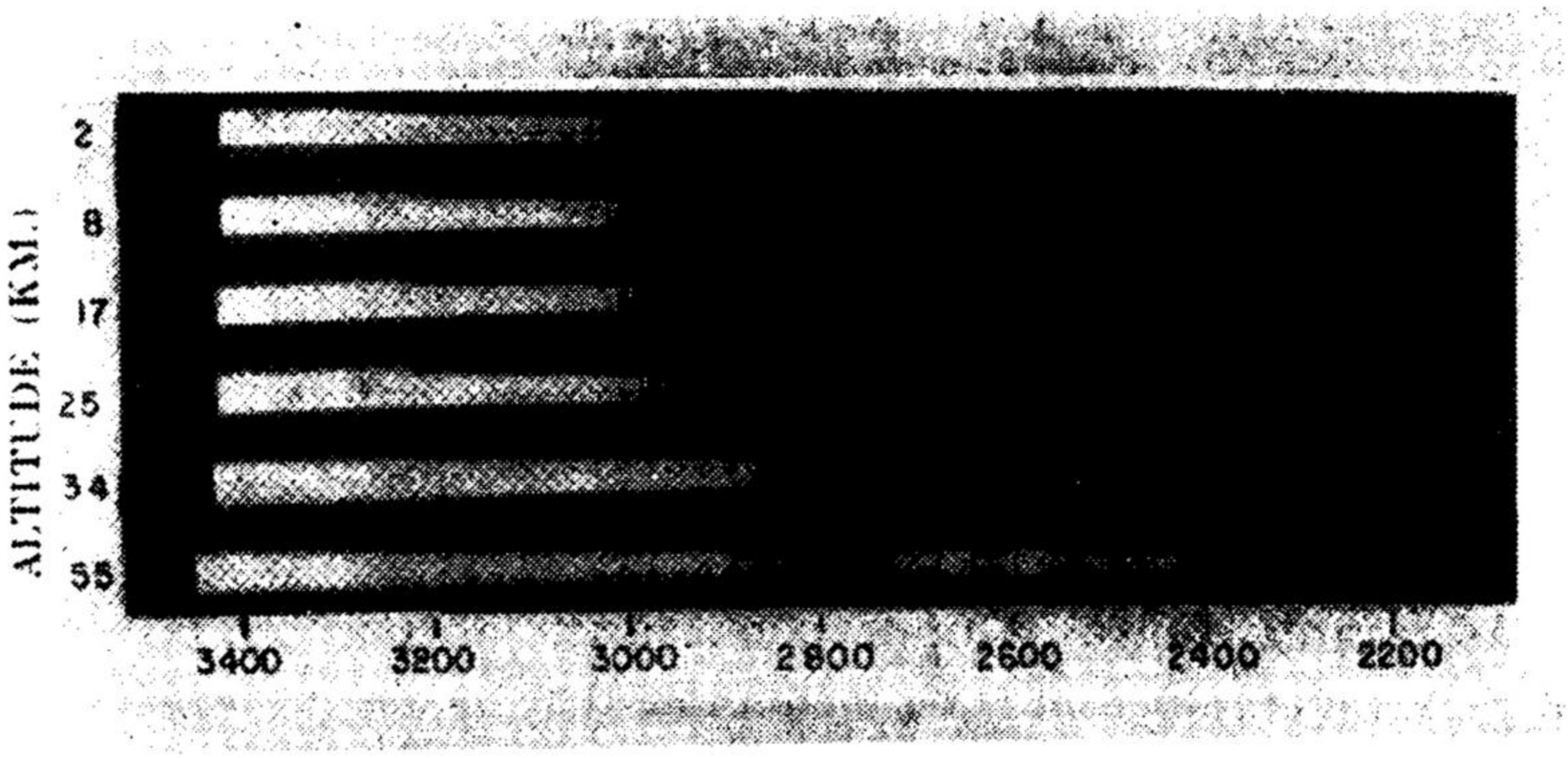


Fig. 5. *Solar spectrum extends to shorter wavelengths as higher altitudes are attained [17].*

(Fig. 6). The absorption above 2000 Å principally causes O_3 production, that between about 2000 Å and 850 Å due to O_2 produces dissociated O atoms. Absorption below 850 Å caused by atmospheric constituents produces various ionized layers. (Table 1) (Figs. 7-10).

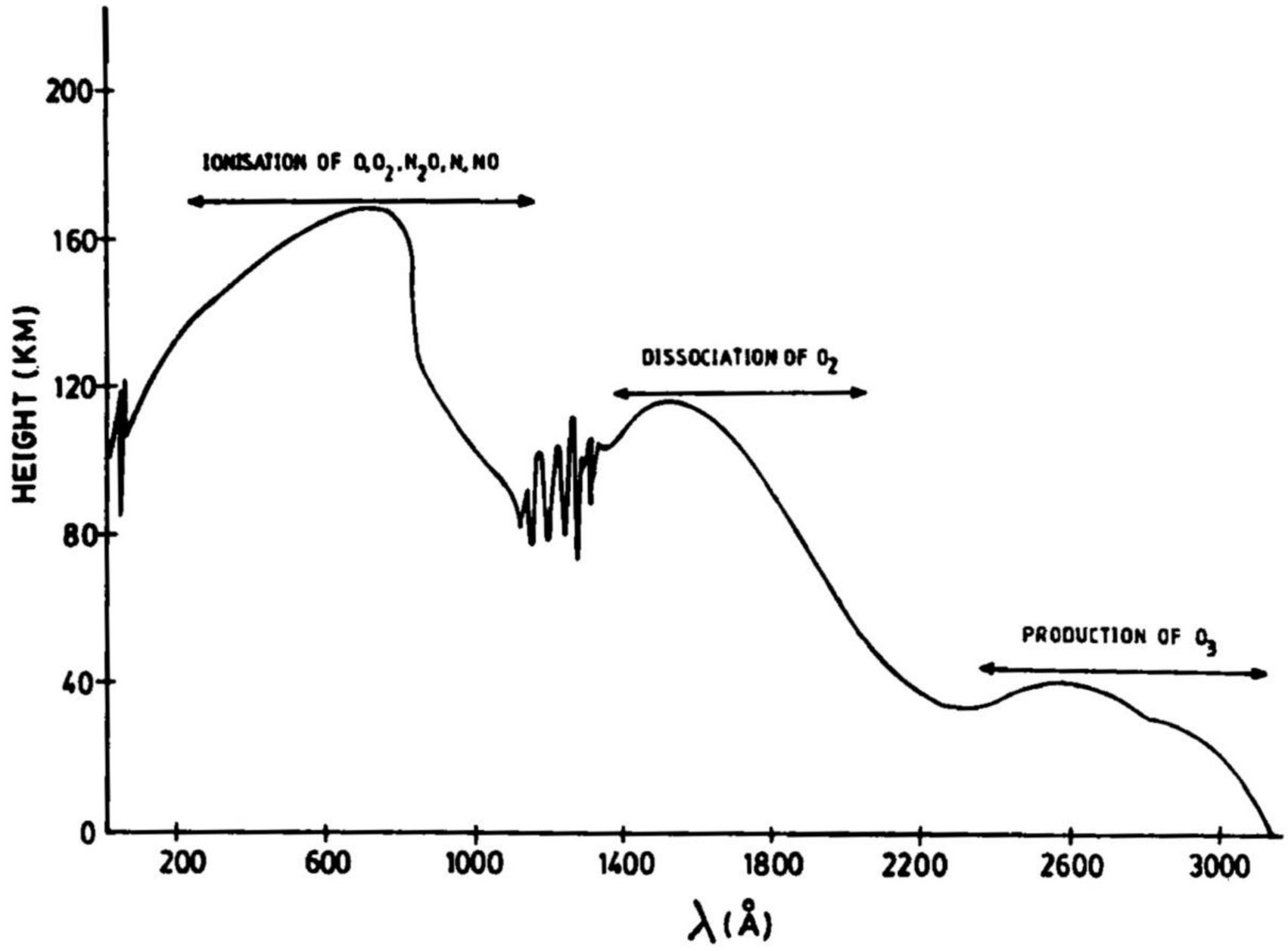


Fig. 6. *Absorption of solar UV and EUV radiations at different regions of the atmosphere producing O_3 and causing dissociation of O_2 and ionization of atmospheric constituents producing ionized regions.*

The information obtained from rocket and satellite experiments in ultraviolet and X-ray solar spectrum clearly indicates the importance of such studies for understanding upper atmospheric phenomena. Saha had asserted the characteristic featrues of these radiations and showed the importance of observations from space for such studies many years ago—long before modern facilities of space probes were available. He also predicted control of upper atmospheric phenomena by these radiations. We regret that he did not have a longer life to realise the grand success of his predictions.

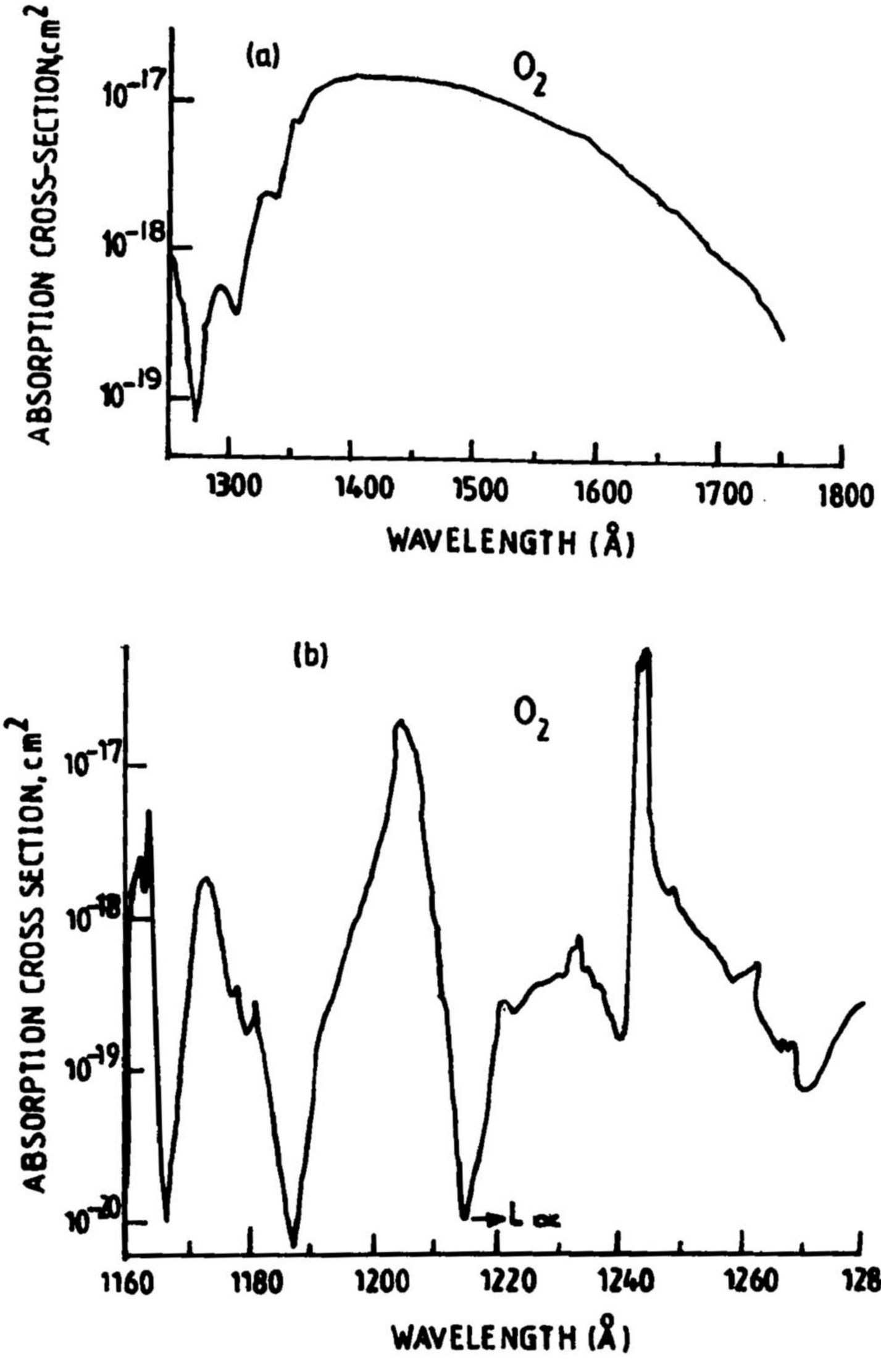


Fig. 7 Laboratory experiments showing absorption of O_2 by UV and EUV radiations. (a) 1800-1300 Å, (b) 1280-1160Å, [19-20].

6. Conclusion

In conclusion, Saha as a man and his love for the country are briefly referred to. Also his meeting with Albert Einstein is mentioned.

Table 1—Solar–Terrestrial Atmospheric Relationship [18]

		D Region, 50-90 Km	E Region, 90-150 Km	F Region, 150-600 Km
(a)	Production of Ionized Regions			
	(i) Photoionization by solar UV, EUV and X-ray	Around Ly 1216Å, NO ionized	911—1027Å, O_2 ionized	170—911Å, O ionized by <911Å, N_2 ionized by <796Å.
	Principal radiations	Lyα 1216Å	Lyβ 1026Å	HeII 304Å, HeI 584Å
	Photoionization by solar X-ray radiations	1—10Å	10—170Å	———
	(ii) Corpuscular ionization (more important at high latitudes, especially auroral zone)	Electrons, Protons, Cosmic rays	Electrons cause some nighttime and sporadic E ionization	Electrons (probably small ; might be significant at night)
(b)	Photodetachment of Electrons from Negative Ions by Solar Visible and Near UV Radiations	Main cause of Day/night change of negative ion to electron density ratio	Effective by day	Largely responsible for the absence of negative ions
(c)	Solar Flares cause the following :			
	(i) Ionospheric disturbances known collectively as Sudden Ionospheric Disturbances (SID).	During solar flares X-ray fluxes, particularly <10Å, increase significantly and cause SID which interfere with certain types of radio communication.		
	(ii) Polar Cap Absorption (PCA)	Protons and heavier particles following occasional large solar flares, bombard polar region and produce ionization.		
(d)	Production of Dissociated O-atoms from O_2 Molecules by Solar Radiations between 2000Å and 850Å	The discret S-R bands begin at 2026Å with small absorption. At 1759Å, the limit of bands, the absorption is continuous and very strong producing dissociation according to $O_2 + h\nu \rightarrow O\ (^3p) + O\ (^1D)$		
(e)	Production of O_3 Layer by Solar Radiations above 2000Å	Production of O_3 $O_2 + h\nu \rightarrow O + O$ $O + O_2 \rightarrow O_3$ $O + O_2 + M \rightarrow O_3 + M.$ Loss of O_3 $O_3 + h\nu \rightarrow O + O_2$ $O + O_3 \rightarrow 2O_2$		

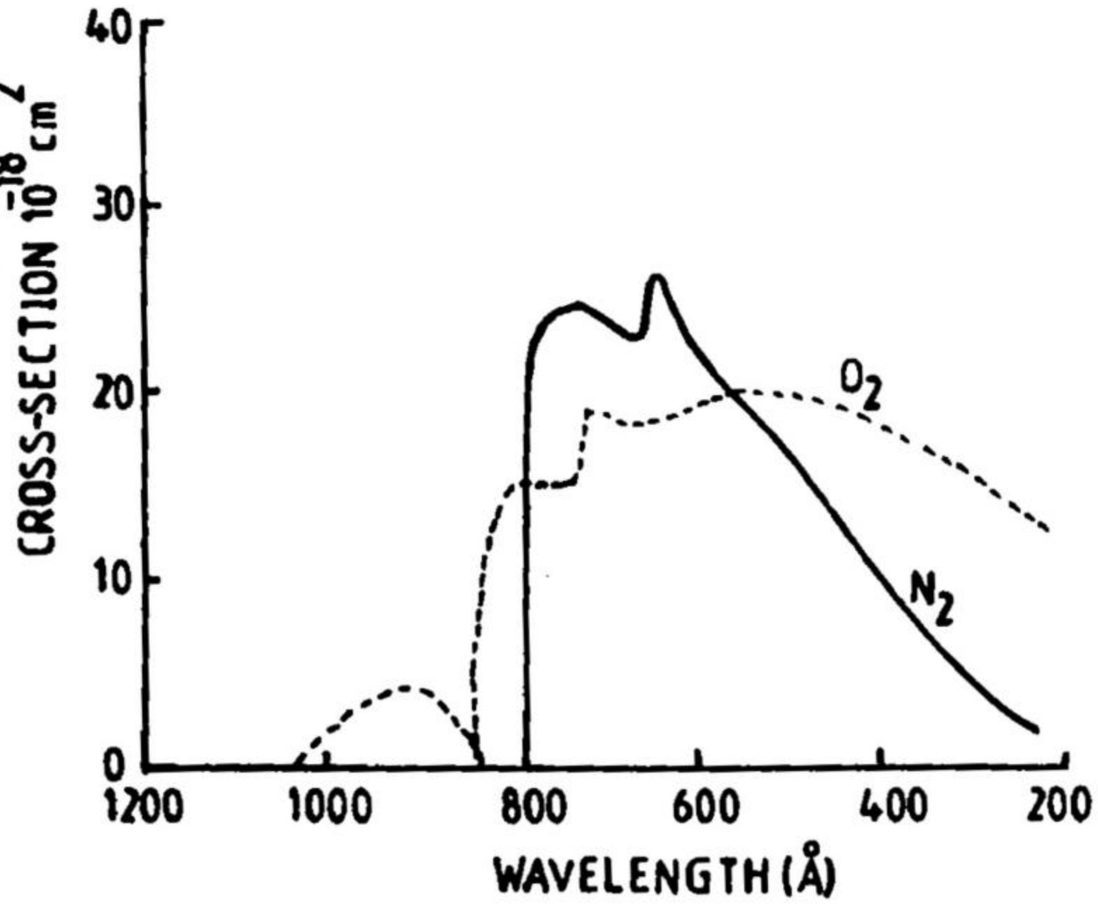


Fig. 8. *Absorption continua of O_2 and N_2 [21].*

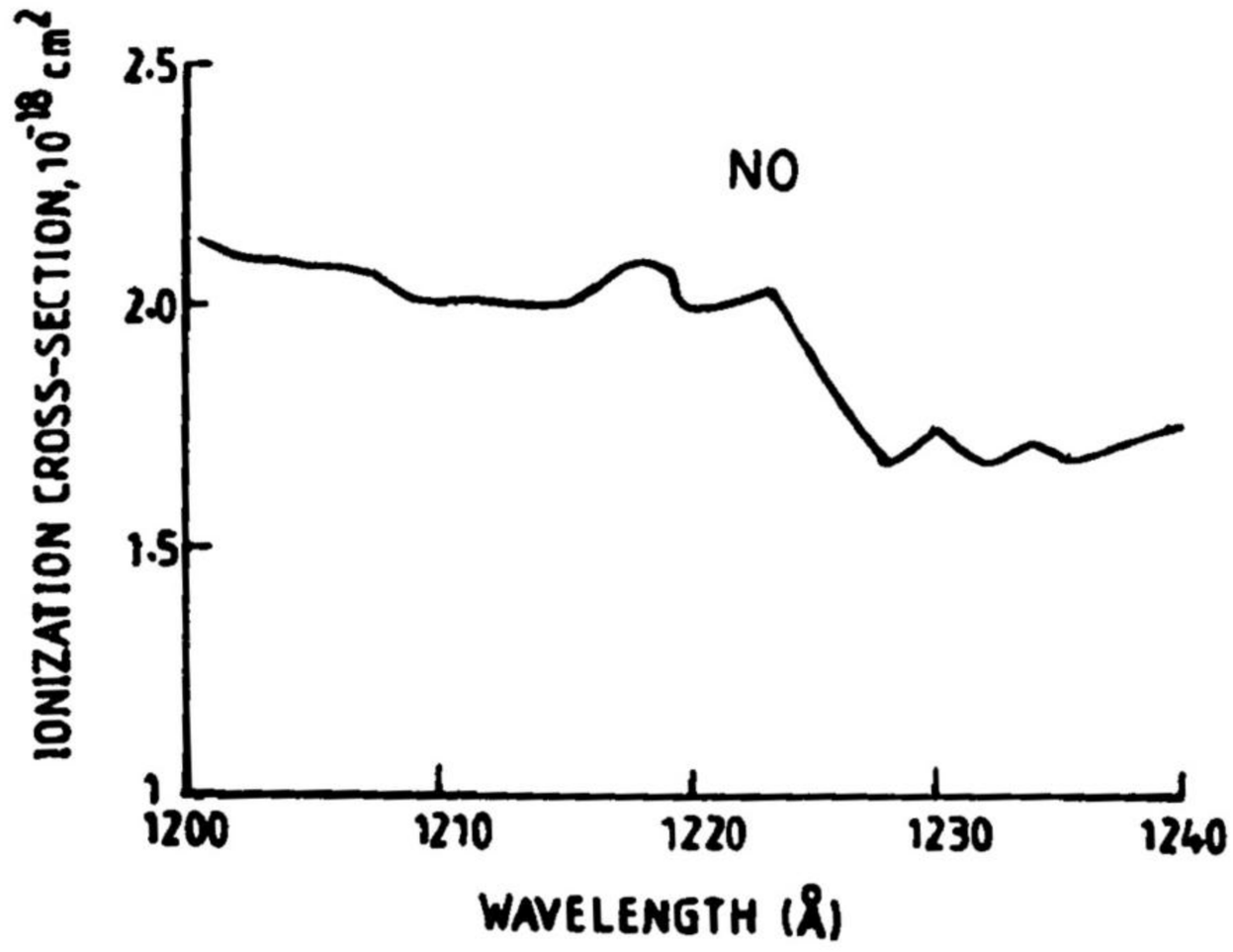


Fig. 9. *Laboratory experiments showing the absorption of NO by UV radiations between 1240 and 1200 Å* [22].

Saha was a passionate believer in science and the important role it could play in lives of common people of India. He truly believed that

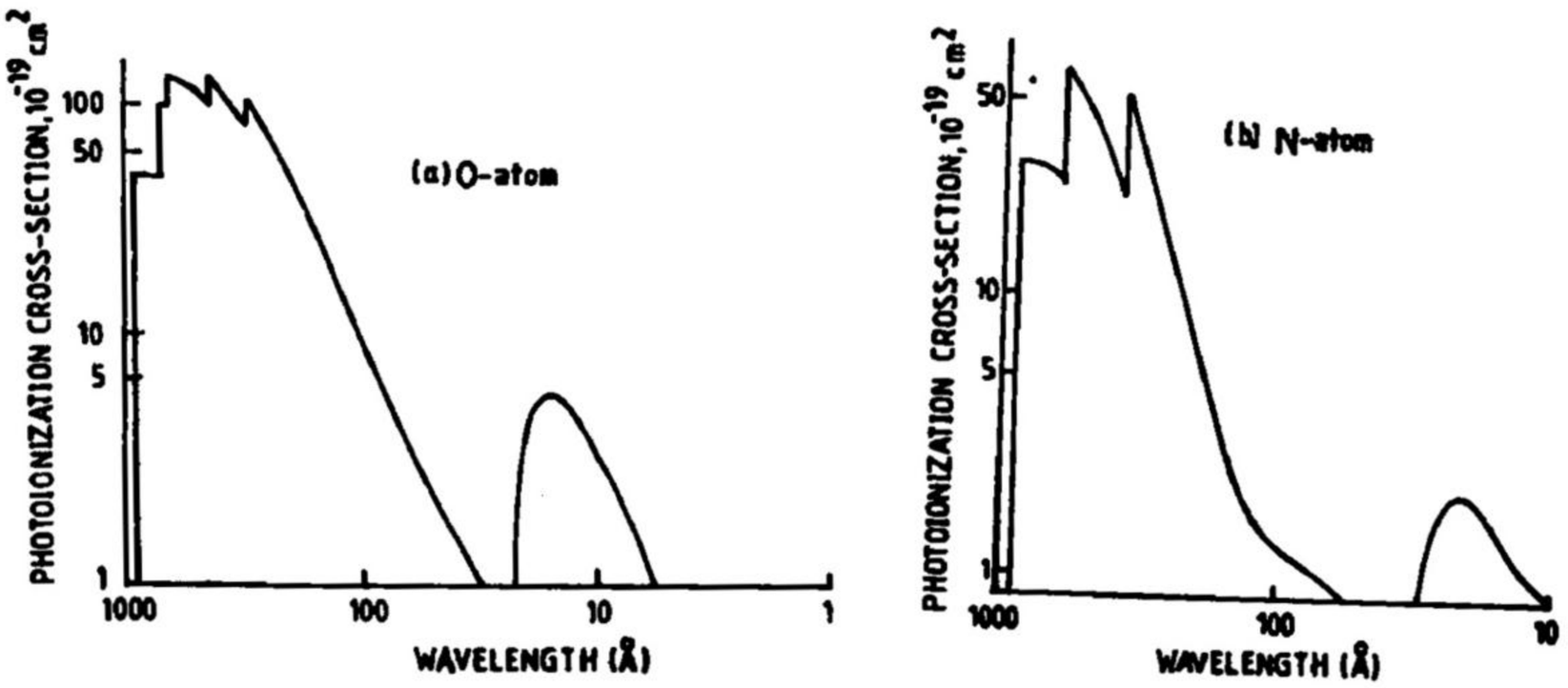


Fig. 10. *Laboratory experiments showing absorptions of EUV radiations and X-rays by (a) O atoms and (b) N atoms [23].*

by taking science to the common man—not only the facts of science but also its methods—India could progress to a great extent. He was firmly of the opinion that a great country like India, with high tradition of scholarship, individual thinking and great cultural heritage, should be able to participate fully in the march of science and then develop herself immensely. He strongly believed that by applying science suffering of the common people could be relieved and India could be redeemed from underdevelopment and poverty.

During World War II, Sir Stafford Cripps was sent to India on a goodwill mission by the-then prime Minsiter of England, Mr. W. Churchill, so that India would support the British war effort whole-heartedly. As a part of the mission, Sir Stafford proposed to take Indian scientists to the U.K. and U.S.A. to show them the latest scientific developments and involvements of scientists of these countries in war efforts. Saha, Mitra, Bhatnagar and others were included in the team. They visited England and saw klystrons, radars and other scientific items being developed. Thereafter they went to the U.S.A. and visited the Radiation Laboratory and also other laboratories where war efforts were being carried out.

When they were in the U.S.A., they were asked if they wanted to meet Einstein. The team welcomed it gladly. They went to Princeton, the place of residence of Einstein. He enquired from the party about Gandhi, India's struggle for freedom and some other general topics of India and her people. Afterwards Saha requested Einstein to clarify certain aspects of specific heat of solids. Einstein gave a quiet but surprising answer. I quote the conversation :

Einstein : *I did not work in the field.*

Saha : *Sir, your work in the field is most fundamental.*

Einstein : *I have forgotten it.*

On hearing this, Saha stopped his discussion on this topic. Afterwards they bade him goodbye. On the way back, Saha talked to Slater, Head of the Department of Physics, M.I.T., U.S.A., who escorted Indian scientists to Princeton, and the conversation went as follows :

Saha : *Why did Einstein say that he had forgotton about his research on specific heat of solids ?*

Slater : *Whenever Einstein takes a problem for investigation, he thinks over it for days, months and even years.*

Saha : *What about answering a particular question ?*

Slater : *He forgets every other problem except the particular item of research he is then carrying out. His attention is wholly focussed on this single problem. Any other discussion is then distraction to him.*

This year, the birthday centenary of Prof. M. N. Saha, a great son of India, is being observed. The author pays his deepest regard, respect and homage to him under whom he pursued his studies in the post-graduate classes, carried out research and participated in scientific discussions on many occasions.

Acknowledgement

The author wishes to thank Dr. Prasenjit Saha for supplying copies of Appleton's letter and its reply by Saha referred to in this paper.

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MILLIMETER WAVES : SOLAR EMISSION AND VARIOUS APPLICATIONS

A. K. SEN

ABSTRACT

Professor Meghnad Saha's studies on solar radio emission are mentioned. The paper is basically divided into two parts, the first part dealing with solar radio emission at millimeter waves and the second part concerning millimeter wave technology and various applications of millimeter wave systems. In the first part solar millimetric radio noise is discussed. Radiometers at 53 GHz and 94 GHz developed at the Institute of Radio Physics and Electronics, University of Calcutta, are described, and the results on solar emission at these frequencies are presented. Solar microwave emission at 4 GHz, as recorded in the Institute, is also reported. In the second part millimeter wave technology is reviewed, particularly in the context of strategic electronics. Various applications of this technology are discussed in the national perspective.

Introduction

I am sincerely thankful to the organisers of the Centenary Seminar for giving me an opportunity to present this paper and pay my respectful homage to the memory of Prof. M. N. Saha, a great scientist and visionary. It is well known that Prof. Saha carried out interesting work on the origin of radio waves from the sun and the stars, which led him to predict the existence of the 21 cm line of hydrogen [*Nature*, **158** (1946) 6]. He also worked on the conditions of escape of radio waves and microwaves from the sun [*Nature*, **158** (1946) 549 ; *Ind. J. Phys.*, **21** (1947) 199]. He was of the opinion that experimental work on radio astronomy should be initiated in this part of the country, and when he visited the Ionospheric Research Laboratory at Haringhata, which was jointly being run fruitfully

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by the Calcutta University and CSIR, Govt. of India, he expressed the hope that a Radio Astronomy Section would be added to the Laboratory (vide Annexure).

Emission of microwaves and millimeter waves from the sun has attracted a considerable amount of attention in recent years. Our studies in this field are reported in Part I of this paper. We have considered the sun as a broad band point source of angular width of about 0.5° and with a blackbody temperature varying from 6,000 to 7,000 K, depending on the wavelength used. A number of millimeter wave radiometers were, in fact, developed for the purpose with their 0.5° – 1° antenna beams arranged to track the sun. Some of interesting results of measurements of the millimetric radio emission from the sun made by these solar tracking radiometers are reported.

Millimeter wave technology has been advancing fast in recent years. Part II of the paper presents this technology, particularly in the context of strategic electronics, and covers various civil and defence applications, indicating their scope in India in the next decade and beyond the year 2000.

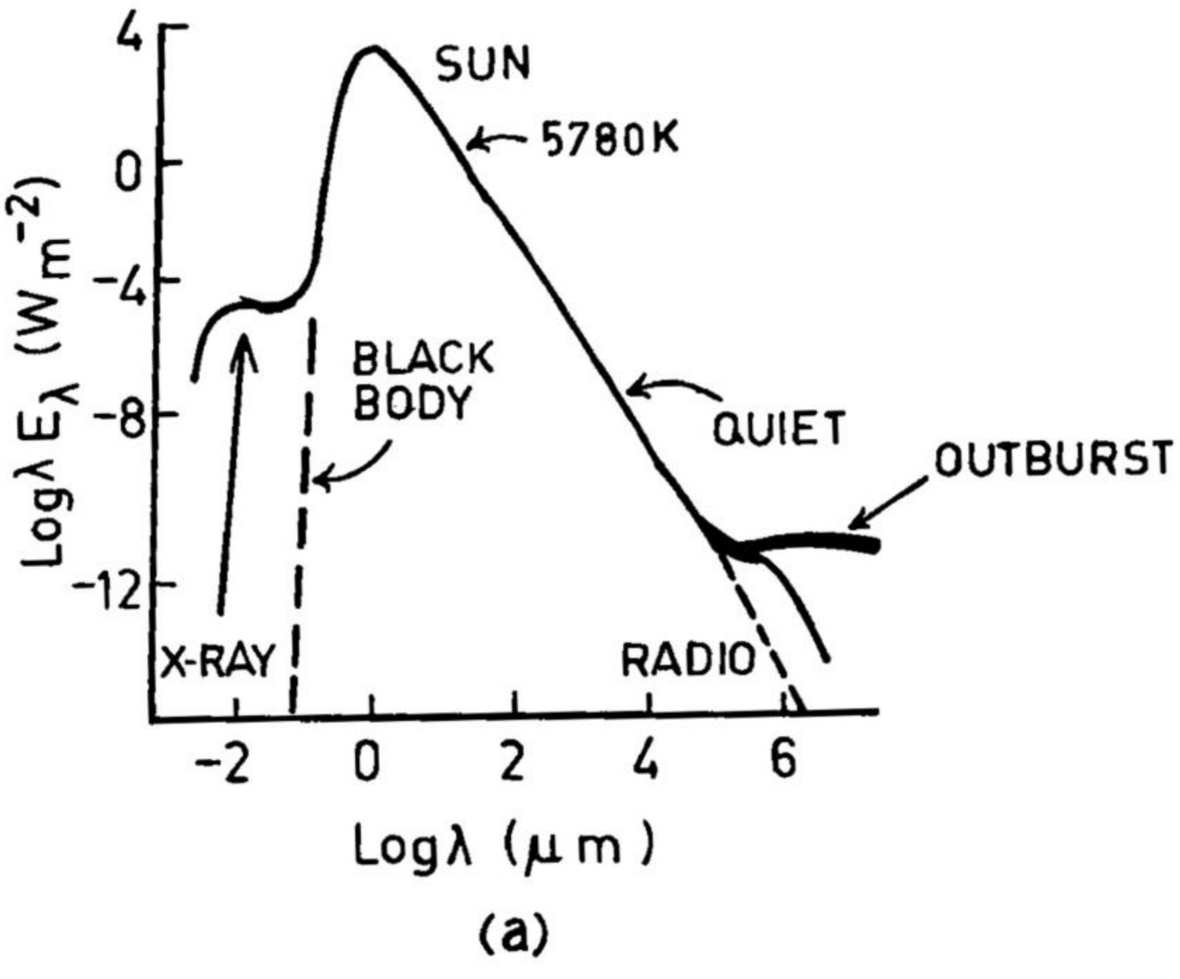
PART I

SOLAR RADIO EMISSION AT MILLIMETER WAVES

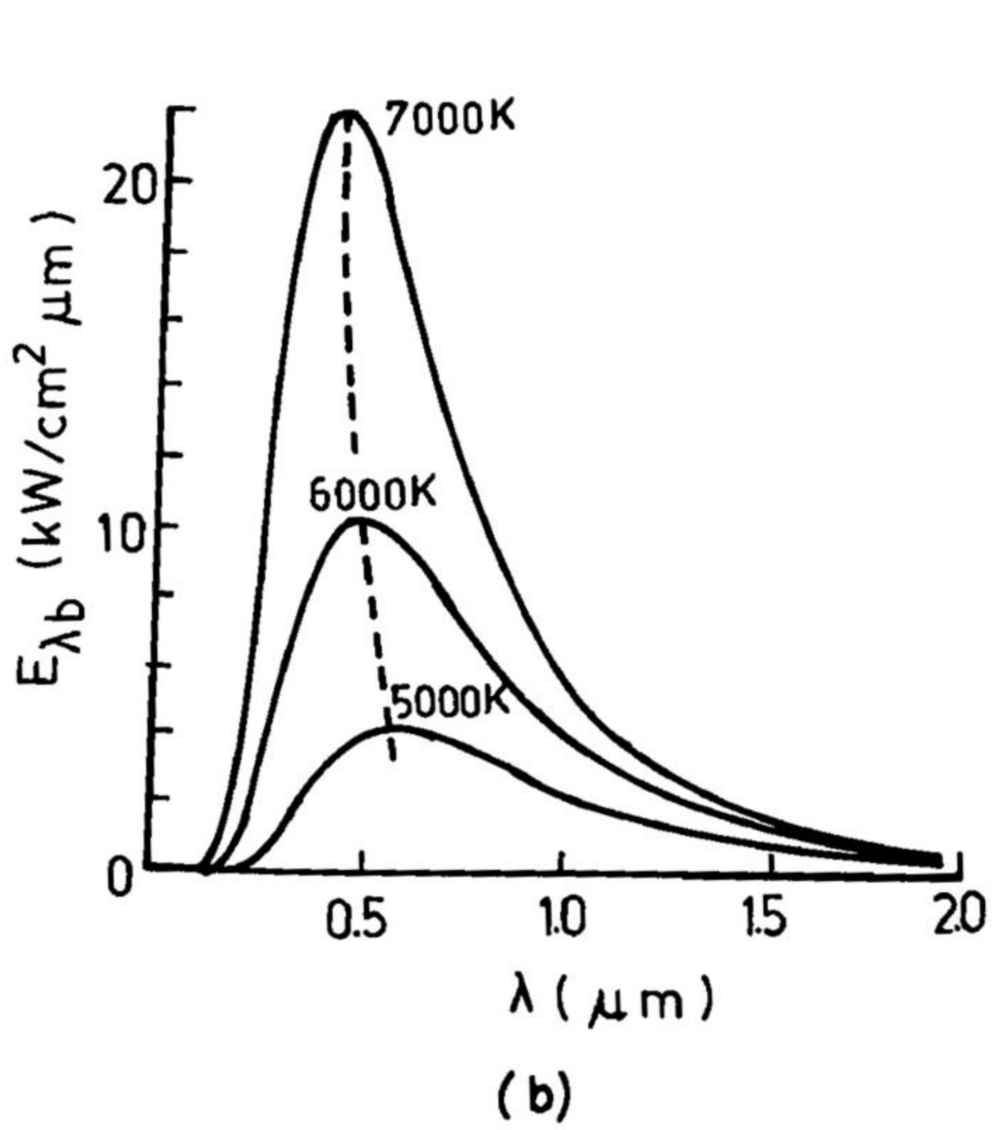
Historical Background

Radio noise emission from the sun was discovered accidentally in February 1942 during World War II by a British Admiral, J. S. Hey, who was the leader of the British Army Operational Research Group. He, in fact, noticed a severe jamming noise in his operational radars on the day and initially took it to be some powerful jamming noise radiated by their enemy, the Germans. When he analyzed all these events of apparent radar jamming, he discovered that every time the antenna beam happened to be pointed towards the sun and that the sun was at that time disturbed with sunspot activity. The discovery was, however, kept secret until after the War, and in 1945 this first well-documented example of solar radio noise was published by Appleton and Hey. Subsequently, the problem was taken up, and Radio Astronomy was thus born. It is now known

that the Sun is a strong emitter of microwave and millimeter wave radio noise originating from the entire solar disc acting as a blackbody radiator. Occasionally, additional burst-like radio noise in the microwave and millimeter waves also originates from different layers of the solar atomosphere and they act as signposts of gamma-ray bursts from the sun.



(a)



(b)

Fig. 1 (a) *Variation of apparent brightness of the sun with the wavelength.*
(b) *Brightness of a blackbody radiator.*

Background Information about Solar Millimetric Radio Noise

The apparent brightness of the sun varies with wavelength as shown in Fig. 1(a), while Fig. 1(b) shows the brightness of a blackbody radiator for temperatures 5000 K, 6000 K and 7000 K. From Fig. 1(a) it is clear that the equivalent blackbody temperature of the sun is 5780 K ~ 6000 K in the visible and infrared wavelength ranges. However, the temperature appears to increase at both ends of this range exhibiting appreciable increases at higher microwaves and millimeter waves as well as at the ultraviolet & X-ray ends of the spectrum.

Studies of the solar radio noise by the radio astronomer indicated a wide variety of mechanism occurring in the solar atmosphere, producing solar radio noise flux densities at the earth which varies with wavelength as shown in Fig. 2. From the figure it is evident that below 10 cm

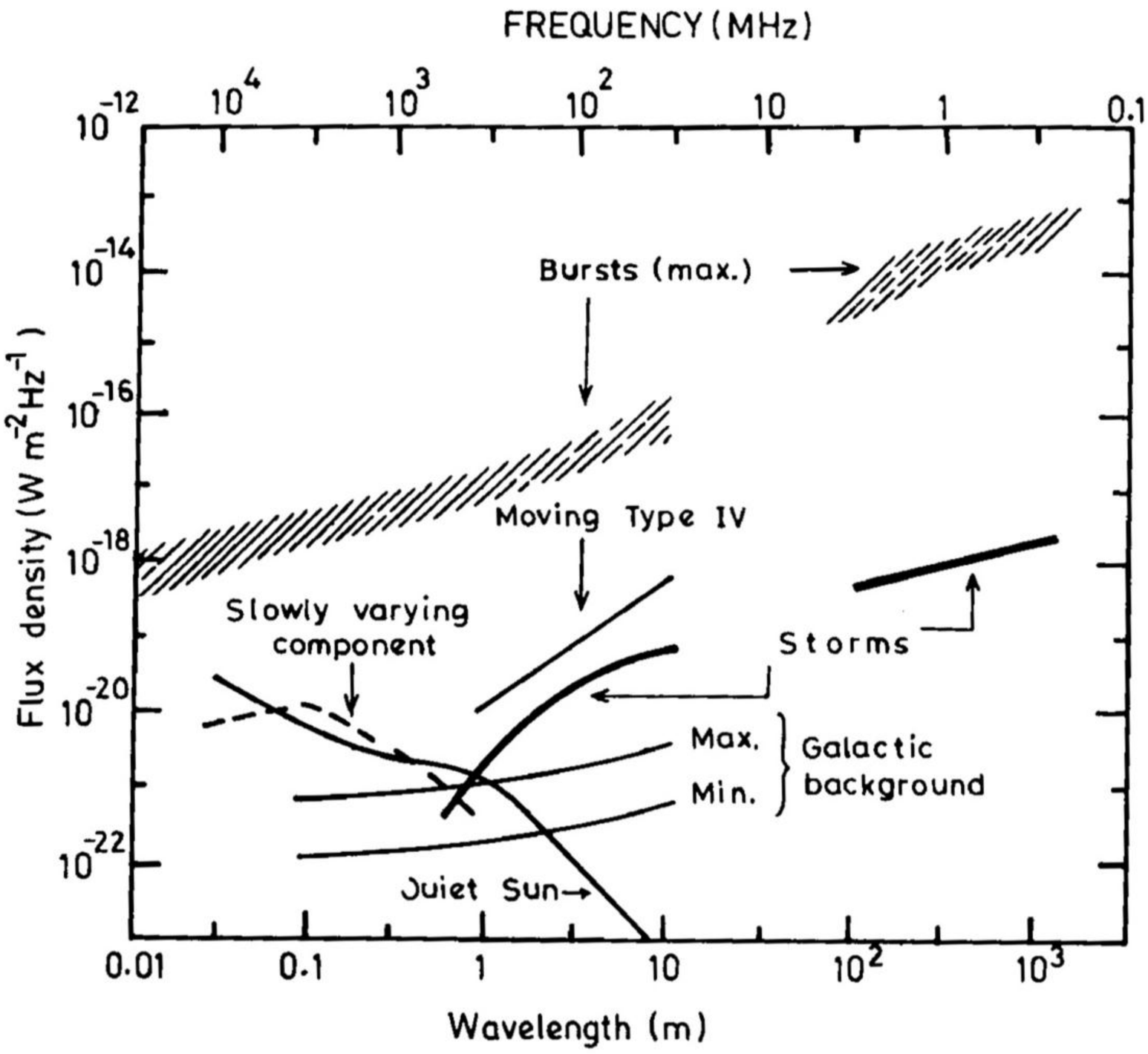


Fig. 2. *Flux densities of the quiet sun (at sunspot minimum) and of large solar bursts of several types. Also shown is the range of the galactic background flux (20^0 beamwidth is assumed).*

wavelength the background flux from the quiet sun dominates the situation with occasional bursts in the 3-30 GHz range exceeding the quiet sun level and a slowly varying component varying cyclically with the solar rotational motion about its own axis. Above 30 GHz the burst component becomes progressively smaller with increasing frequencies compared with the background flux from the quiet sun, while the slowly varying component also tends to become negligible. The situation at millimeter waves for frequencies exceeding 30 GHz will be more clear by referring to Fig. 3. The curve 'a' shows the relative variation of the solar radio noise in the microwave and millimeter waves between the two extreme situations, sunspot miximum and sunspot minimum. It is evident

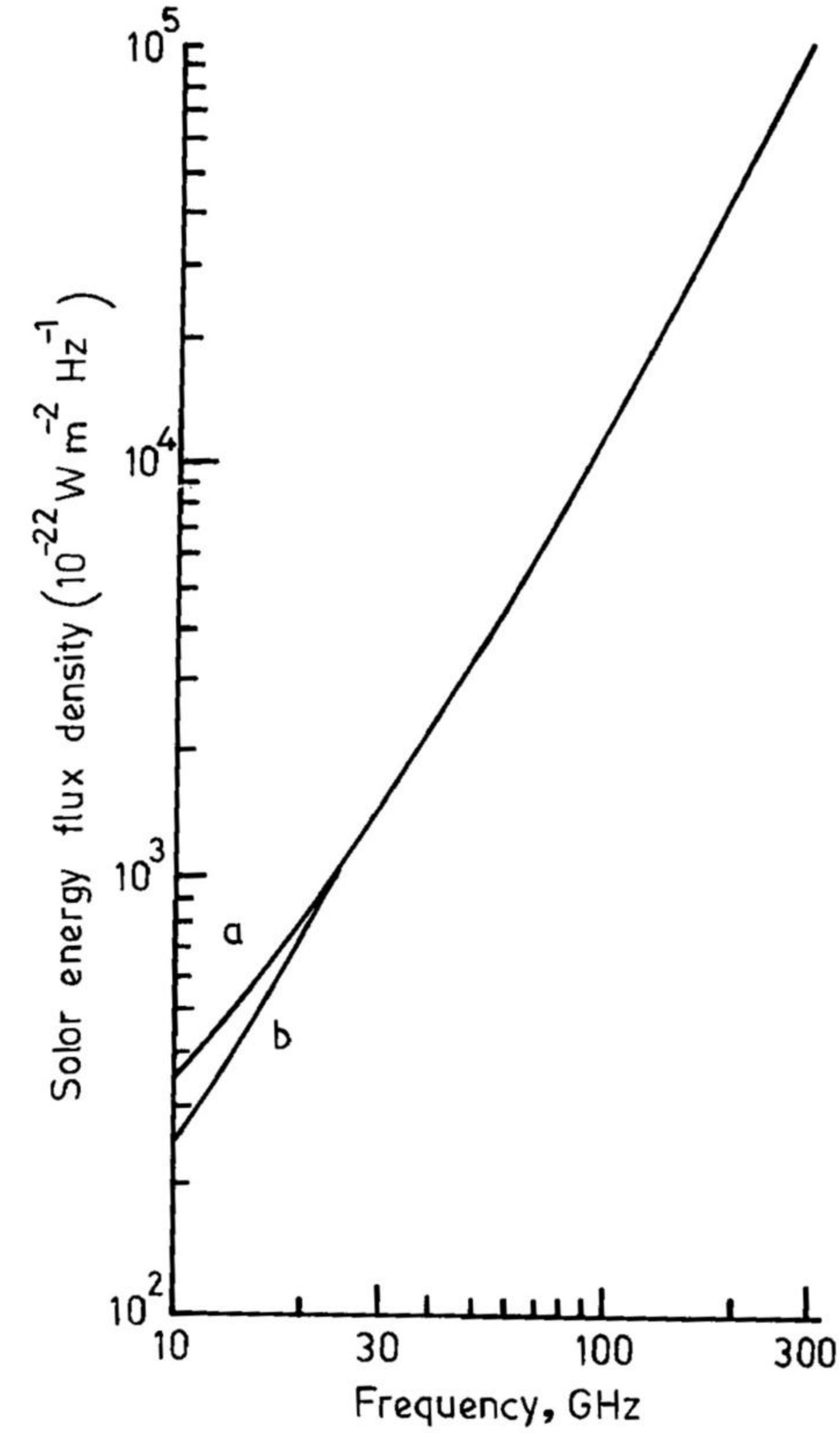


Fig. 3. *The quiet sun emission as a function of frequency for (a) sunspot maximum and (b) sunspot minimum.*

from this figure that the sunspot cycle variation is non-existent at frequencies above 30 GHz. This is also borne out by the curve 'b' which shows how the solar radio noise flux received at the earth's surface increases rapidly with frequencies in the millimeter wave region. Here also, above about 30 GHz, no sunspot cycle variation is observed.

The millimeter wave bursts are submerged in the powerful millimeter wave emission from the solar disc except during outstanding events. The visibility of solar millimeter wave bursts at various millimeter wave frequencies for different intensities of bursts are shown in Fig. 4, from which

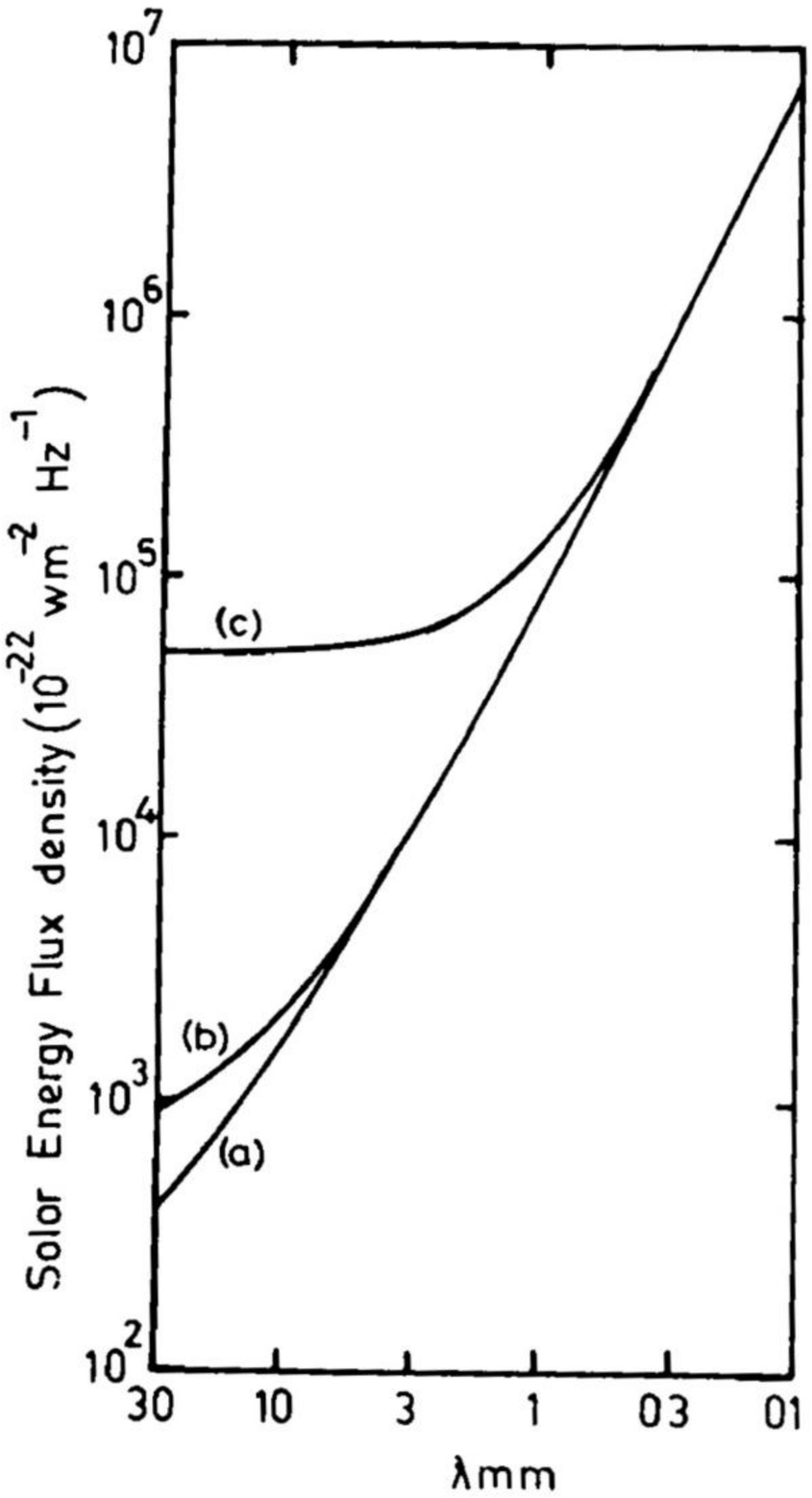
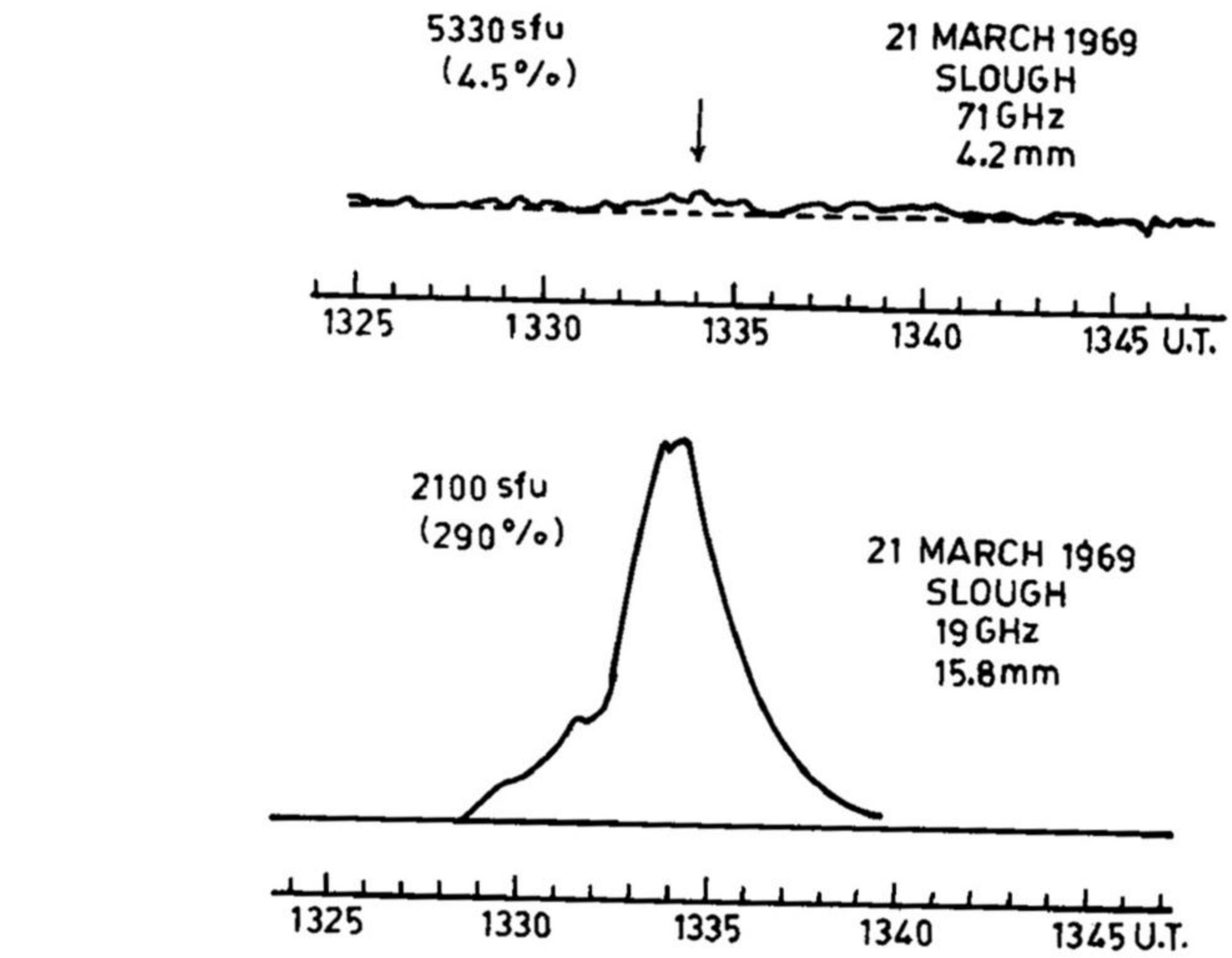


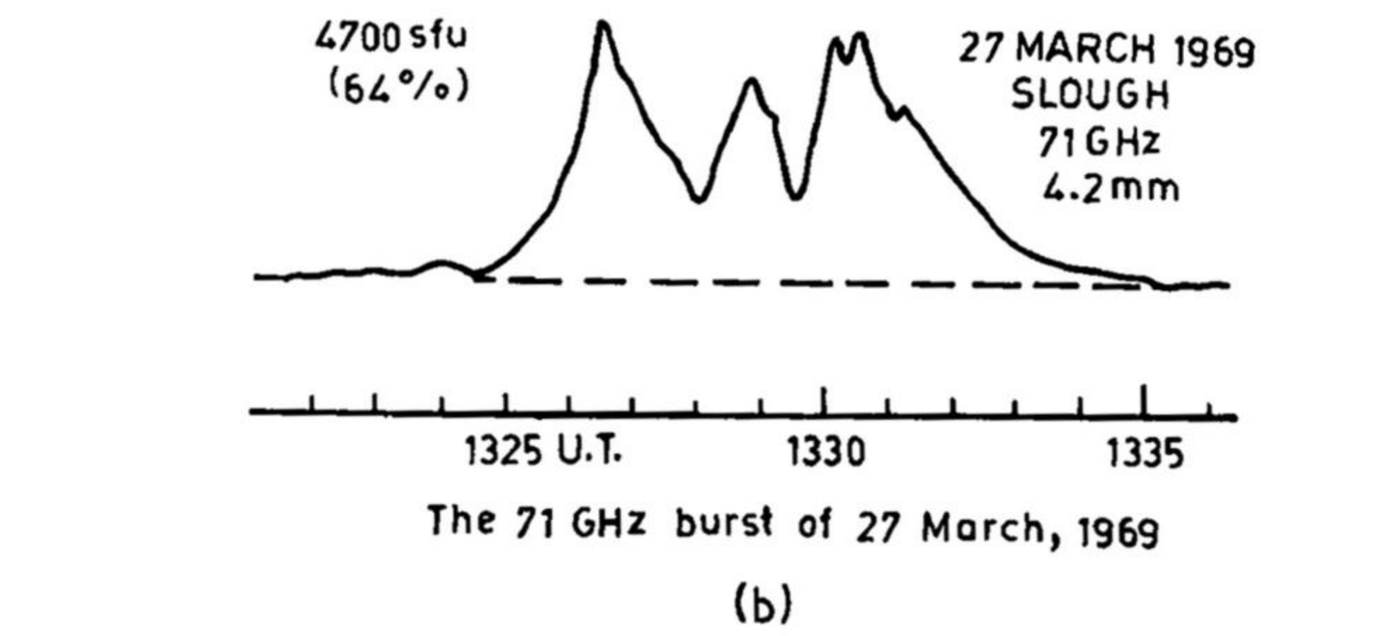
Fig. 4. *The potential enhancement of solar flux due to flare events.*
(a) Quiet sun emission
(b) Enhancement due to burst of 500 sfu peak increase.
(c) Enhancement due to burst of 50,000 sfu peak increase.

it appears that only the most powerful millimetric bursts, having intensities exceeding a few thousand solar flux units (sfu) would be able to rise above the background flux due to the sun. One solar flux unit (sfu) corresponds to a flux of 10^{-22} watts/m^2/Hz. Some examples of such outstanding millimeter wave bursts recorded by Dr. D. L. Croom of the Rutherford Appleton Laboratory in U.K., are shown in Fig. 5. Such



The 19GHz burst of 21 March, 1969.

(a)



The 71 GHz burst of 27 March, 1969

(b)

Fig. 5. *19 GHz and 71 GHz bursts.*

occurrences are, in fact, rare events and are likely to occur in the vicinity of the sunspot maximum years. Fig. 5(a) shows peak flux of 2100 sfu at 19 GHz observed on 21 March 1969 which was a sunspot maximum year, while a 4700 sfu peak flux level was observed at 71 GHz 6 days later on 27 March 1989 [Fig. 5(b)]. All these bursts originate from the gyrosynchrotron mechanism occurring in the solar atmosphere and the frequency of maximum emission, f_{max}, of the burst spectrum is governed by the magnetic field H in the source region on the sun, as given by

$$f_{max} = 3.5\, f_H = 9.8\, H \ \text{MHz} \qquad (1)$$

where f_H = gyrofrequency
and H is in gauss.

From the relation (1), with H = 10,000 gauss, f_{max} turns out to be 100 GHz.

Solar Radiometers at Millimeter Waves

Millimeter wave radiometers at 53 and 94 GHz wave were developed at the Institute of Radio Physics & Electronics, University of Calcutta, for the studies of millimeter wave propagation in the atmosphere. The total power radiometers are, however, subject to sizeble drifts which warrants frequent calibrations. All those radiometers were, therefore, subsequently converted to Dicke switched radiometers when the Ferrite Dicke switches became available to us. A dicke radiometer is more sensitive and it is also free from drifts, which reduces the need for frequent calibration.

A special problem in solar radiometry is that if the solar flux corresponding to the equivalent blackbody temperature T_s of the sun is more than an order of magnitude higher than the radiometer is to be used for the measurement of the night sky noise temperature T_{sky}, which is lower than T_{ref}, there will be a problem of phase reversal of the 1000 Hz detector output, depending on whether the antenna temperature is higher (T_s) or lower (T_{sky}) than the reference temperature (T_{ref}). A phase sensitive detector may cater for this phase reversal and its output will change its sign accordingly. However, the dynamic range of the recorder needed for the purpose would be prohibitively large, ranging from T_s (6000–7000 K) to T_{sky} (50–150 K). A linear recorder scale would hardly be able to accommodate such a wide dynamic range. A logarithmic amplifier would be

a solution. However, it will greatly complicate the subtraction of the background solar flux from the measured solar noise flux, during the estimation of the excess radio noise flux of a solar burst. Under the circumstances, we tried to devise a new technique to cope with the large dynamic range, as indicated in the following section.

Wide Dynamic Range Detector

A wide dynamic range was achieved by a special synchronous detector which is insensitive to phase reversal of the low frequency signal. In the phase lock loop configuration the VCO phase tracks the phase of the LFA output by the phase lock keeping a constant 90° phase difference between the two. The output of the synchronous detector is, therefore, always of the same sign irrespective of the phase of the low frequency signal from LFA. With this detector the recorded level initially increases steadily with antenna temperature, T_{sky}, attaining a maximum value at T_{sky} reaching T_{ref}, such as may occur during heavy rains. For a further increase of antenna temperature due to the sun creeping into the antenna beam, for instance, the recorded level begins to come down again till the full sun is received by the antenna. What happens is that the amplitude of the LFA output drops from a large value, for low values of T_{sky}, passing through a maximum output for $T_{sky} = T_{ref}$ and increasing thereafter for a futher increase of T_a due to intercept by the sun.

Records of Solar Drift Across the Antenna Beam

Two typical solar drift curves recorded, respectively, by the 53 GHz and 94 GHz radiometers are reproduced in Figs. 6(a) and 6(b). In each of the figures the recorded level increases steadily as the sun encroaches the antenna beam until the level reaches a maximum value T_{ref}, beyond which the recorded level starts decreasing again, reaching a maximum value T_s when the Sun completely fills the antenna beam. The recorded level reverses the cycle, tending to produce a mirror image of the variations observed upto T_s. The effective dynamic range is thus equal to $(T_s - T_{ref}) + (T_{ref} - T_{sky}) = (T_s - T_{sky})$. If T_{sky} is adjusted to start from the zero level, then $(T_{ref} - T_{sky}) = (T_s - T_{ref}) = a$. Therefore, $(T_{ref} - T_{sky}) + (T_s - T_{ref}) = 2a = 2(T_{ref} - T_{sky})$. In this way, the dynamic range is increased by a factor of 2 from a to 2a, compared with what is possible with a phase sensitive detector in which the output d.c. level

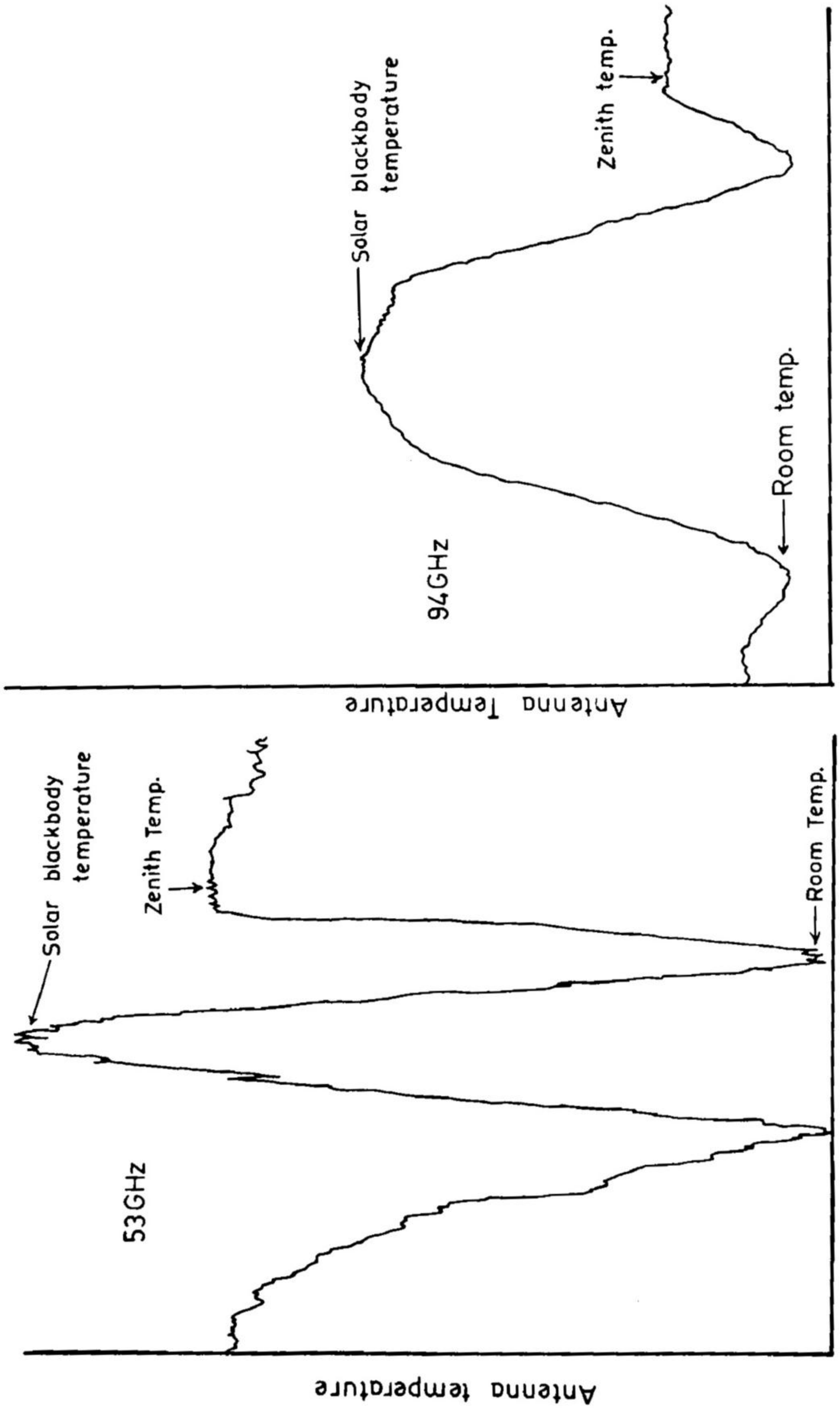


Fig. 6 *(a) Solar drift curve of March 13, 1992, at 53 GHz. (b) Solar drift curve of August 1, 1991, at 94 GHz.*

changes sign with a range of only "a" instead of "2a". Like the non-phase sensitive detector the envelope detector also produces output of the same sign irrespective of whether the phase of the low frequency input is 0° or 180°. However, in this case the detection is incoherent and non-synchronous as no local oscillator is needed for the detection process, with the result that the S/N ratio is lower than that with coherent detection.

Solar Radiotelescope at Microwaves

A Solar radiotelescope in the microwave band around 4 GHz was also developed at the Institute for the studies of microwave bursts from the sun. A typical record of the solar radio emission under a quiet condition of the sun, recorded on 16.3.93 at the Institute, is reproduced in Fig. 7.

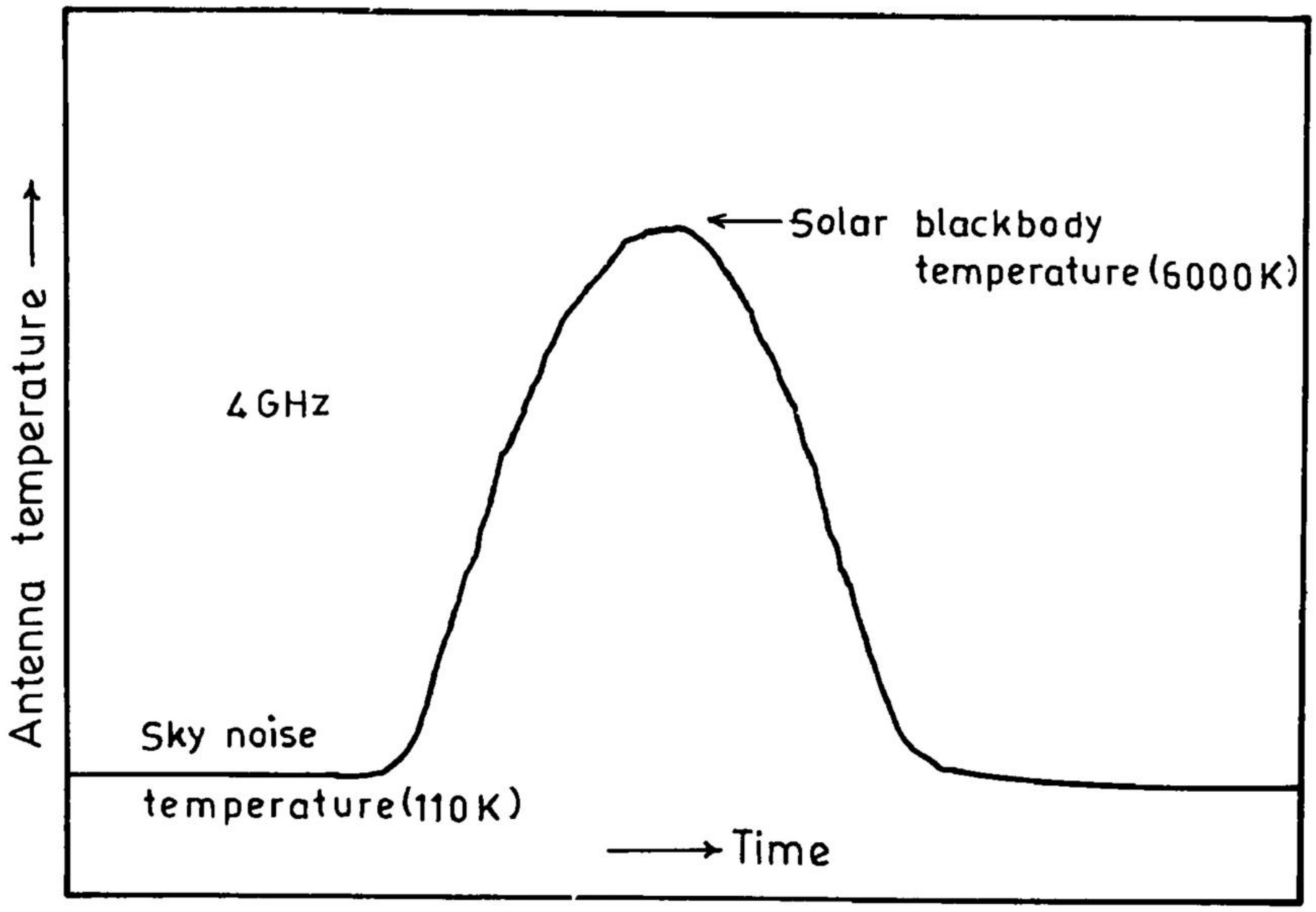


Fig. 7. *Solar radio. emission at 4 GHz*

PART II

MICROWAVE TECHNOLOGY AND VARIOUS APPLICATIONS

Historical Background

Millimeter waves were generated about 100 years back in 1895 in India at Calcutta by Acharya J. C. Bose, who developed the world's first wireless radio communication link at millimeter waves, well before Marconi could dream of a practical radio communication system, which he did in 1901 at longer wavelengths. However, the difficulty of generating millimeter waves and, apparently, its limited propagation distance shifted the interest from millimeter waves to wavelengths longer than a meter. Subsequently, an attempt to build a radar at 10 mm wavelength range was made at M.I.T., Radiation Laboratory, U.S.A., during the early stage of World War II. But it was a disappointment apparently due to a wrong choice of the exact operating frequency near the water vapour molecular resonance absorption line, causing the radar range to be curtailed severely. This damped the driving force to develop radar technology for frequencies above 30 GHz.

During World War II, J. H. Van Vlock made a theoretical prediction of a strong atmospheric absorption line around 60 GHz. However, this work was given security classification because of its military significance. Work was then initiated at NRL, U.S.A., to exploit the 60 GHz line for secure communication services in military applications leading further to the development of millimeter wave technology.

After World War II millimeter wave work continued at NRL for military applications and at Bell Telephone Laboratories (BTL) for telecommunication applications. In 1950s, Hughes Aircraft company successfully extended the frequency range of coupled-cavity travelling wave tubes to millimeter waves. During 1960s, intensive work in millimeter wave technology was done at BTL on the development of solid state components required in the development of underground repeaters using low loss millimeter waveguide lines of the overmoded type. In 1970s, Hughes began manufacturing a solid state sweep generator, which apparently triggered a chain of development, in Hughes, of a full range of devices, components and instruments covering 18 to 160 GHz with the

work continuing later to extend the frequency range to higher frequencies in the millimetric wavelength ranges.

Millimeter Wave Technology and Strategic Electronics

The term "Strategic Electronics" encompasses a very wide range of electronic systems and applications which are of strategic importance for a country's defence services as well as for developments in the civilian sectors. Computers and Supercomputers are, for instance, well known areas under Strategic Electronics apparently because of their great impact in both the civil and defence services. In recent years, the Millimeter Wave Technology emerged as one of the most powerful Strategic Electronics areas. In fact, the recent success by the western block in the Gulf War in minimising drastically losses of human life and property during battle-field operations and eventually preventing the outbreak of a 3rd World War has proved, beyond doubt, the impact of Millimeter Wave and Infrared Technology and there has been a renewed interest in the area, both for its civil and defence application potentials. Some of the unique advantages of millimeter waves include :

1. Small size and weight of the equipment allowing it to be mounted in mobile vehicles in land or water and also in missile seekers.
2. Sharp beamwidth and fast scan rate of millimeter wave antennas allowing high angular resolution and fast tracking capabilities of radars required to lock on to supersonic aircrafts.
3. Broad Communication bandwidth allowing video conferencing and high capacity intracity trunk telephony using roof top antennas and reflectors.
4. Very high range resolution due to short pulse generation being feasible at millimeter waves, allowing three dimensional radar imaging.
5. Low voltage power supply requirement.
6. Ruggedness and reliability of equipment.
7. Low probability of interception by the enemy because of the sharp beamwidth.

One of the major drawbacks of Millimeter Wave Technology was, perhaps, the high fabrication cost. Recently, this has also been reduced

drastically with the advent of Monolithic Millimeter Wave Integrated Circuits (MMIC).

The MMIC technology is based on microstrip and finline structures and facilitates large scale and repeatable production of the various millimeter wave components, subsystems and systems fabricated in a very small size at a low cost. MMIC is going to render the conventional Millimeter Wave Technology of 1970s based on waveguide structures obsolete. During the 1980s a combination of waveguide and microstrip structures called Hybrid Millimeter Integrated Circuit (HMIC) have started coming up. Hughes is now manufacturing low noise GaAs MMIC chips upto 35 GHz, of which about 100-1000 are produced at a time on a single substrate. Similar mass production techniques are being tried to develop GaAs power amplifiers upto 35 GHz and efforts are being given to go to higher frequencies upto 94 GHz.

Specific Strategic Electronic Items Based on Millimeter Wave Technology

Some of the specific strategic electronic items based on Millimeter Wave Technology, which may be of great national importance are highlighted in the following sections :

A. Defence applications

(a) Fast scan battle-field surveillance radar
(b) Anti-aircraft weapons systems
(c) Missile seekers
(d) Beam riders
(e) Radiometric imaging of tanks from aircraft
(f) Active radiometric imaging of tanks and battle fields
(g) Imaging radars

B. Civil applications

(a) Dual polarisation Doppler radar celiometer for cloud maping and micrometeorological studies.
(b) Collision avoidance and obstacle warning radars for cars and locomotives.

(c) Video conferencing, intracity trunk telephony and TV rediffusion.

(d) Secure communication at the strong absorption bands of millimeter waves.

(e) Remote sensing for earth resources survey and limb sounding of atmospheric environment.

(f) Radio astronomy for studies of high energy solar physics, organic molecules in space and maser lines from the cosmos.

(g) Thermography for thermal insulation assessment and fire monitoring and tomography of human body.

It is well known that most of the high-tech developments in strategic electronics area usually start off from acute defence needs and later on the technology is transferred from the warfare to the welfare of mankind with grand success. One such example is the area of Radar, which was developed to detect and fire enemy aircrafts. It is now being widely employed for air traffic control and storm detection to avoid aviation hazards. Storm detecting Meteorological Radars are also being employed by the IMD in forecasting severe thunderstorms including cyclonic storms. Sometimes, developments motivated by physical research have also led to high-tech innovations, which were later on exploited for defence applications. For instance, the microwave radiometers were originally developed in 1942 for physical research requiring measurement of thermal emission noise and another physical phenomenon, the line emission of atomic hydrogen at 21 cm wavelength (1420 MHz) from the intersteller hydrogen atoms due to electron spin reversal. In recent years, the microwave and millimeter wave radiometers are being employed widely for several strategic application areas : (1) passive radiometric sensing of the earth and its atmosphere, (d) missile seekers to avoid glint in the final phase, and (3) imaging application for seeing through clouds and fogs. We also know, how the first artifical earth satellite, Sputnik, launched in 1957, meant for observing our atmosphere from a space platform, promptly found application in strategic electronics areas.

National Perspective in Millimeter Waves and Their Applications

The phenomenal development of strategic electronics systems in recent years, and their rapidly growing deployment in civil and defence applications prompted us to study critically how India can exploit the

art for national interest. Keeping in mind that India with its vast population needs special attention to mass communication by radio and TV broadcasts, telecommunication, visual communication, disaster and environmental monitoring and warning gadgets, remote sensing of agricultural fields, soil condition and water resources and collision avoidance of fast vehicles, besides a host of defence applications, we were prompted to study the case one by one and tried to look into the prospects of their development in the Indian context.

(a) Mass communication

A recent trend of mass communication is to employ audio visual media like TV broadcasts, video recorded messages, large screen TV displays, Outside Broadcasting Vans (OBV) for field broadcasting using satellites like INSAT. In India we now have the National Satellite in orbit, INSAT-ID, for the purpose. To expand the activities the need for Very Small Aperture Satellite Terminal (VSAT), using a small dish of 0.6 m diameter, was felt and ISRO has already taken up a project to develop VSAT for operation in the Ku band at 14/12 GHz. Direct Broadcasting Satellite (DBS) service to homes using the VSAT receiving system has, in fact, started already in many countries at a cost per unit of only 400 US $ (Rs. 12000/-), as a result of which the DBS receiving system is fast becoming popular. DBS has many other related applications. These include High Definition Television (HDTV), business television (BTV) and educational television (ETV). The 1988 Seol Olympics were telecast live in HDTV using INTELSAT-8 and BS-2B satellites for viewers in Japan. Likewise, HDTV transmission of the Barcelona Olympic of 1992 was made in European HDTV format using the Astra satellite of Europe for viewers in those areas.

In a future Indian programme involving INSAT-II-C satellite with a Ku-band transponder, ISRO has a plan to provide DBS services. Another DBS satellite called GRAMSAT is also planned by ISRO, with eight high powered transponders which can disseminate region and culture specific programmes in each of the regional languages. The GRAMSAT concept is illustrated in Fig. 8. The introduction of video compression technique to reduce the bandwidth allows 4 picture signals to be accommodated in each transponder, resulting in a total of $4 \times 8 = 32$ video channels for the 8 transponders, of which 6 are for C-band operation with 1.2 m dish

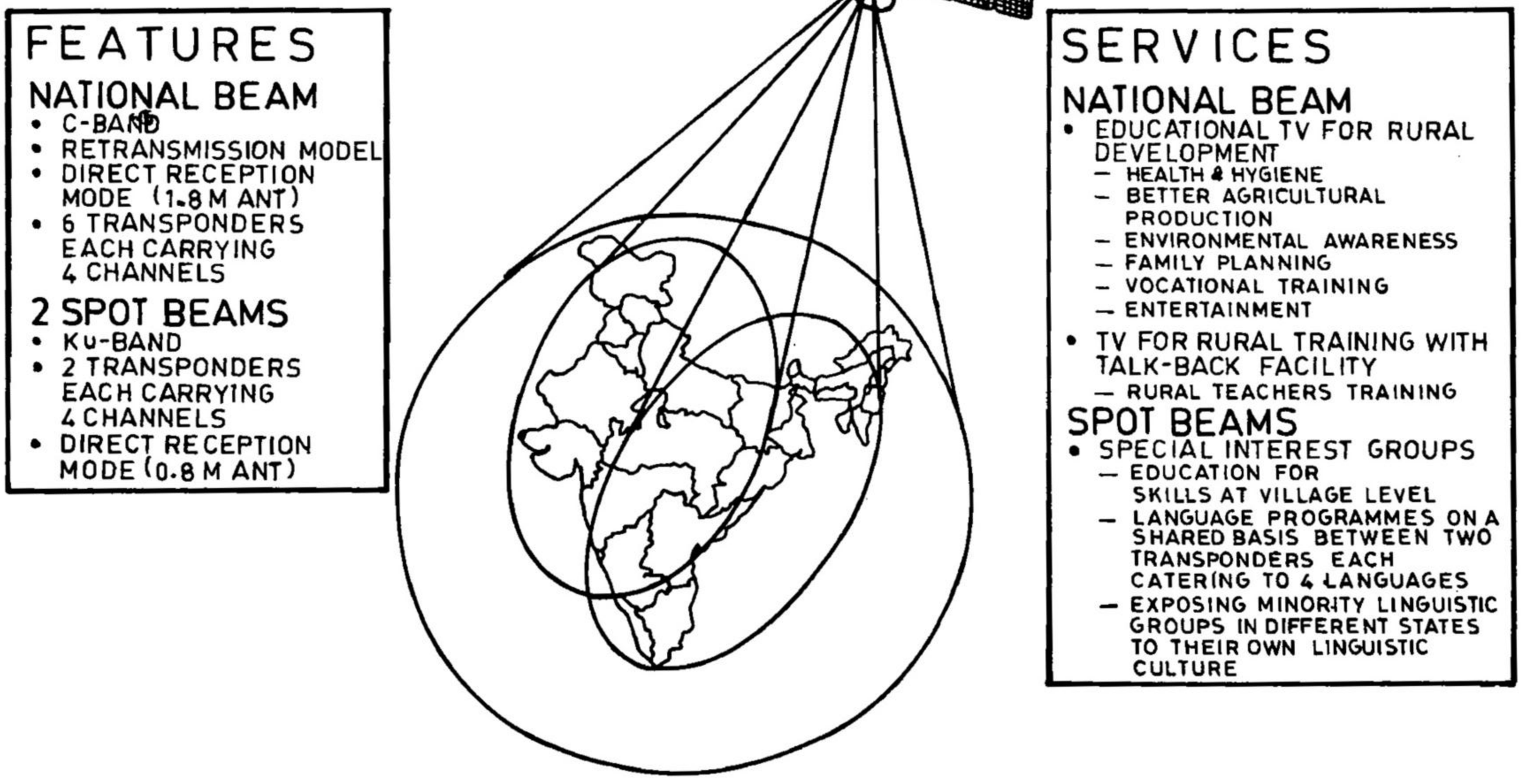


Fig. 8. *GRAMSAT Concept.*

at the receiving terminal and 2 units are designed for Ku band to generate spot beam for reception with only a 0.8 m dish. The GRAMSAT is expected to cover 90 percent of the national population, reaching individual homes and villages within the next 5 to 6 years. The viewer has to tune his TV set to the local channel of rebroadcast to receive the relevant national programme in his own language via the GRAMSAT signal received in a central C-band very small aperture terminal, with a 1.8 m dish. At the same time direct reception facility is provided by the 2 Ku-band transponders to receive the GRAMSAT signal directly with only a 0.8 m dish.

It may be mentioned here that in Europe and elswhere, HDTV in the 30/20 GHz band is becoming popular apparently for the wider bandwidth available at these higher frequency bands and also for the smaller antenna dimension for DBS receiver in the band. However, the system will not be suitable for Indian conditions where the outrage due to rain attenuation in the Ku band (26.5 – 40 GHz) is sizeable to affect the up link at 30 GHz. Nevertheless, considerating the advantages of the Ku band, plans are underway to push the transponder power up, to make the HDTV signal survive even in the worst tropical rain conditions.

(b) Telecommunications

INMARSAT

One of the fast developing telecommunication services is, perhaps, the INMARSAT system, which is a maritime communication system of the International Maritime Satellite (INMARSAT) Organisation. It came into being in 1979 to facilitate telex, telephone, facsimile, 2.4 kb/s data and high speed data of 56 kb/s services between a Coast Earth Station (CES) and a Ship Earth Station (SES) via a geostationary satellite. The CES employs 6/4 GHz link with a geostationary satellite while the SES uses 1.6/1.5 GHz link. India has already been a member of this fast growing telecommunications Organization with a full fledged earth station for the purpose installed in Pune.

INMARSAT–C

The most popular low cost variety of land mobile earth terminal for

INMARSAT follows a standard C specification using 1.6/1.5 GHz satellite link. The specifications of the standard-C mobile earth station may be summarised as follows :

Minimum G/T (5)		– 23 dB/K
Minimum EIRP (5)		12 dBW
Modulation : BPSK		1200 symbols/second
Information rate	:	600 bits/s
FEC coding forward	:	1/2 rate convolutional encoding interleaving
return	:	1/2 rate convolutional with interleaving for the SES message channel
1st generation satellite	:	The return channel transmission rate is 300 bits/s for all services.
Operational bandwidth	:	TX 1626.5 – 1646.5 MHz (B = 20 MHz) RX 1530 – 1545 MHz in 5 kHz steps (B = 15 MHz)

INMARSAT–P

A new generation of INMARSAT service called INMARSAT–P has come up to cater for Group III facsimile and data services at 2.4 kb/s, in addition to providing for duplex voice. INMARSAT–P terminal design provides for a dual-mode feature : (1) Operating as a normal cellular phone when within the range of a celluar system, or (2) as a satellite phone. The terminal will incorporate high-penetration paging facility for services such as call for voice mail altering or for displaying the number of a caller. INMARSAT–P terminal can be acquired at a price of US $ 1500 (Rs. 45,000/-) with a satellite retail usage charge $ 200 (Rs. 6000/-) for a minute.

INMARSAT is currently investigating advanced network designs to support INMARSAT–P service features such as cellular-satellite interworking and mobility management. INMARSAT is, in fact, working to ensure that personal mobile satellite communications services function with other existing and evolving communication systems as an integral part of the wordwide communication infrastructure. Satellite-cellular in-

terworking for briefcase INMARSAT–M and the handheld INMARSAT–P are under consideration. INMARSAT–P system based on 3 satellite configuration is expected to usher in a global handheld mobile telephone service in the 1998-2000 time frame.

In India, manufacture of INMARSAT-C earth terminal has already been taken up by private companies for internal use as well for exports and these companies have acquired sufficient expertise to face the future challanges of developing INMARSAT-P and INMARSAT-M. In fact, the Indian Space Research Organisation (ISRO) and 11 other companies responded to a global tender by INMARSAT on January 4, 1993. Separate contracts are to be awarded : one for a satellite configuration in geostationary orbit, another for intermediate circular orbit and a third for a satellite in the low earth orbit.

(c) Disaster monitoring and warning gadgets.

A programme for the International Decade of Natural Disaster Reduction (IDNDR) was initiated in 1991 by the UNDP. Natural Disaster Reduction is comprised of three phases : (1) monitoring (2) warning and (3) recovery. Of these, the first two phases, monitoring and warning, are largely dependent on strategic electronics systems. For instance, monitoring of cyclonic storms are now being made on a continuous basis by orbiting meleorological satellites like NOAA (National Oceanic and Atmospheric Administration) and also by the geostationary satellite INSAT–ID, while local severe storms and microbursts are effectively monitored by meteorological radars in the S, C, X, Ka and W bands. Doppler and dual polarisation facilities in these radars allow raindrop size distribution and the departure of a raindrop from the spherical shape for high rain rates, to be determined effectively. Introduction of the dual polarisation facility, in fact, helps in identifying the ice and rain clouds from the differential reflectivity data of the raindrops and ice pellets. The world's largest dual polarisation doppler radar at S-band, using a 25 m steerable dish antenna, installed at Chilbotton, U.K., is capable of monitoring rain drops and their distribution out to a radial distance of 50 km and a vertical height of 10 km. The millimeter wave dual polarisation Doppler radars in the Ka and W bands have been developed to monitor the overhead cloud patterns and microbursts in and around airports upto a height about 10 km, when the radar acts as "ceilometers".

At the moment, there is not a single Doppler Radar or a Dual Polarisation Radar, nor a combination of the two, in any of the IMD stations or in any other organisation in India. It is high time to develop such a radar or at least try to convert existing meteorological radars to Dual Polarisation Doppler Radar by changing the antenna feed and some portions of electronics in the radar, in order to make forecasting of microbursts and local severe storms with a higher reliability.

Regarding the warning of disasters like cyclones, local severe storms and microbursts, monitored by meteorological radars and satellites, a highly reliable telecommunication network must be utilised for dissemination of the disaster informations. INMARSAT network is one possibility. In regions disconnected from the rest of the world by the disaster, the mobile INMARSAT–C or INMARSAT–P terminals may be transported to the affected area by carrying it to the site by a helicopter. Even a 30/20 GHz mobile earth terminal could be easily transported by a helicopter to set up telecommunication within an hour or so.

(d) Environmental monitoring of greenhouse and ozone depleting gases.

The problems of global warming of the climate due to accumulation of greenhouse gases from the industrial affluents and the use of nitrogenous fertilizers, and also the depletion of our ultraviolet protecting screen of ozone layer in the stratosphere, arising from the widespread use of choloroflurocarbons in the form of (1) disposed refrigerants, (2) aircraft exhausts and (3) deordants have, in recent years, aroused worldwide concern for our future generations. They may not have a habitable planetary environment if we fail to start taking corrective measures right now. The famous Brazil conference on the environmental problems and its spontaneous worldwide participation of scientists, engineers and political leaders initiated apparently a renewed awarness in the environmental problems round the world.

The remote sensing techniques have been used, in recent years, for the monitoring of the ozone depleting molecules like chlorine monoxide (ClO) and hydroxyl group (OH) in the stratosphere together with that of ozone (O_3) at stratospheric heights. The occurrence of 'ozone hole' in the polar regions and its close association with chlorine monoxide abun-

dance has been established by satellite remote sensing measurements with millimeter wave radiometers tuned to the prominent absorption lines of the respective gases, which are at 204.352 GHz for ClO and 206.132GHz for O_3. Because of the fact that the concentrations of these gases are very small, their detection at stratospheric heights requires the radiometer beam to scan tangentially to the stratospheric heights so that the total number of molecules viewed by the beam may be sizeable and detectable. Such measurements are referred to as limb sounding or limb scanning. Besides the above, millimeter wave limb scaning spectrometers covering the range 200-640 GHz have been used successfully to monitor the temperature upto 85 km, pressure upto 50 km and wind upto 38 km and also other minor constituents like H_2O, HCl, CO, HCN, N_2O, CH_3Cl and HNO_3 .

All these studies of minor constituents in the stratosphere as well as in the troposphere may be initiated in India in a phased manner with the expertise in millimeter wave radiometry at the Institute of Radio Physics & Electronics, University of Calcutta, in collaboration with the Space Application Centre, ISRO, Ahmedabad and the National Physical Laboratory, New Delhi. These studies will, no doubt, be of great significance by the year 2000 and beyond.

(e) Remote sensing of agricultural fields, soil and water resources

The Indian Remote Sensing Satellite Bhaskara I and II carried microwave and millimeter wave radiometers at 19.35, 22.235 and 31.4 GHz bands for studies on sea surface temperature (1) to locate warm regions where fishing will be prospective and (2) to distinguish between sea and land, desert and vegetative areas. The more recent Indian Remote Sensing Satellites, IRS–I and IRS–II, however, did not incorporate such radiometers but was fitted instead with multiwavelength imaging sensors in the visible and infrared wavelengths, to obtain razor sharp images of the earth's surface from which sea or land, desert or vegetative fields, rivers, lakes, hills and snow covers are clearly distinguished. The only limitation of the optical and infrared wavelengths is that visibility will be very poor through cloud cover or fog in which case microwave and millimeter wave radiometric remote sensing is the only solution. The next generation Indian remote sensing satellites, are, therefore, planned

to incorporate microwave and millimeter wave radiometric sensors at a number of frequencies to monitor and study the earth and its environment even in adverse weather conditions. By suitably choosing the operating frequencies, soil conditions including its salinity and water content, can also be sensed besides the assessment of the condition of growth of different kinds of vegetation including their diseases, if any.

(f) Collision avoidance radar

Millimeter wave Doppler radars at 94 GHz have come up for avoidance of collision between cars in highways, through sensing of the relative speed between two consecutive cars to control the speed, with a view to maintaining a safe distance between the cars. In our country a more important use of the collision avoidance radar may be in the railways to avoid collision between two trains. In foggy weather the visibility in the northern part of India often becomes too poor to obstruct the views of the driver in which case millimeter wave Doppler radar will be a tremendous aid to the locomotive driver in seeing through the fog and locating any unwanted target on its path, from a sufficient distance, at which breaks can be effective to avoid an impending collision with it. Often, due to the failure of the signalling a train may be approaching another train standing on its tracks, which cannot be detected visually in the presence of fog. Millimeter wave collision avoidance radar would be the only solution to mitigate such problems.

Besides the applications of microwaves and millimeter waves indicated above, there are a number of other civilian applications. These include railway telecommunication links for information transfer, signalling and administration. The Eastern Railways have already installed microwave links in the 18 GHz band, which is at the lower boundary of millimeter waves for interconnecting the entire chain of railway stations between Mughal Sarai and Gaya and the next phase of development is underway to cover the distance between Gaya and Howrah. For, getting additional frequency allocation for the purpose, they have to go to frequencies higher than 18 GHz, perhaps, upto 23 GHz to avoid mutual interference between the different microwave digital links of the Eastern Railways. Manufacture of link equipments for the purpose has also been taken up at WEBFIL at Calcutta, a WEBEL group of industries controlled by the State Government of West Bengal.

In view of the above civilian applications as well as a number of defence applications, there is an urgent need for the development of microwave and millimeter wave components, subsystems and systems in the country. In the microwave area some success has already been achieved in India due to efforts in both the private and public sector undertakings and plans are underway to initiate a similar trend at millimeter waves through the public sector, with a view to going into HMIC and MMIC developments of components based on GaAs technology in collaboration with Universities like Calcutta University, Jadavpur University and Burdwan University. A gigantic GaAs facility is, in fact, being created at DRDL, Hyderabad and at a few other locations of India. These facilities will provide a major boost in the development of MMIC chips for microwave and millimeter wave applications, with a great export potential as well.

(g) Visual communications systems

Recent technological progress has improved image reproduction quality and transmission efficiency to a level where audiovisual communication systems may become a part of everyday life. NTT of Japan has taken up the project of "VI and P" (Visual, Intelligent and Personal Communications services) for its long term vision towards the 21st century. Visual communication services including the audio channel will, no doubt, assume an important place among these services.

Typical amounts of image data for still pictures used in telecommunication and broadcasting are about 6 M bits/s for a full colour image. A colour photograph is, in fact, encoded at about 500 × 500 pixels of normal television monitor resolution. It takes about 100 seconds to send one colour photograph through a 64 kb/s line. Moving pictures require scores of times more data per second, perhaps about 100 Mb/s transmission rate for the normal NTSC television signal. Moving on to High Definition TV (HDTV), an even large amount of data transmission rate is needed, which may be about 600 Mb/s for transmission quality and 1.2 Gb/s for studio quality. The conventional analog telecommunication network system has been unsuccessful in transmitting at such large data rates. Recently, with the increasing sophistication of digital image compression and processing technologies, greatly improved image quality and transmission efficiency are becoming possible to allow conventional telecommunication

network to be utilised for the purpose. The development of image compression and processing technologies are shown in Table I.

Table I—Image Data and Compression

	Amount of Data		*Compression ratio*					
	Analog	Digital	1/2	1/4	1/10	1/100	1/1,000	1/100
Audio Signal	4kHz	64kb/s	32kb/s	16kb/s	8kb/s			
NTSC Signal	6MHz	100 Mb/s	32Mb/s		6.3 Mb/s	1.5Mb/s	384Kb/s	64kb/s
HDTV Signal	60MHz	1.2Gb/s	600Mb/s		150Mb/s			

Visual communication services can be broadly classified by (1) format of connection between the centre and terminals into interactive (1:1), collective (n:1), conference (n:n) and retrieval and broadcasting types (1:n). The application of these visual communication services is expected to expand to various areas, including video phones, education, training, art, fashion and shipping.

The video conference system is an end-to-end audio visual communication system that connects conference rooms by overmoded waveguide lines, fibre optic lines or by millimetric wave radio links using roof-top antennas. For longer distances Ku or Ka band satellite links can be utilised.

The need for video conferencing systems is growing today in Japan where many companies locate branches across the country and have to operate the business effectively. Video conference systems enable them to hold meetings with members sitting in their respective offices, thus reducing business trip expenses. Various image coding schemes have been studied and individual companies have developed their own conference systems. To standardise the image coding schemes an international standardisation recommendation was established in 1990. In India, the recent trend of rapid industrialisation with open market policy calls for an urgent need for video conferencing system to be developed. The acute shortage of fuel for vehicles can be largely overcome by video conferencing systems, which effectively reduce the number of business and management trips for meetings and conferences.

(h) TV rediffusion

A Multipoint Video Distribution Service (MVDS) with 20-30 channels of television are planned to be broadcast in U.K., in the 40-42 GHZ band over a radius of 2-3 km. The domestic receivers in this band use small 15 cm diameter roof-top antennas and a small MMIC receiver with a total cost of only £ 200 or Rs. 8000, which is about the same as a satellite TV receiver. Such MVDS systems may be tried in several areas of India for satellite TV rediffusion.

(i) Defence applications

Defence application of microwaves and millimeter waves for numerous strategic electronics areas have been undertaken in India. These include missile seekers, RCS measurement systems for light Combat Aircrafts, Earth/Space communication links etc. One of the major considerations in these R & D activities is, perhaps, the propagation characteristics of the microwaves and millimeter waves through the atmosphere. While the database for the propagation of microwaves upto about 10 GHz is quite comprehensive, the database at millimeter waves is too meagre. Some studies at the Institute of Radio Physics & Electronics indicated that the conventional millimeter wave window frequencies such as those at 35 and 94 GHz are really significantly lower in frequency over the Indian subcontinent, the exact amount of shift in the window frequency depending on the climatic conditions of the region involved.

Besides studying the propagational aspects, the R & D activities in a few other emerging strategic application areas may be considered for defence services. These include the following :

(1) Millimeter wave covert communication systems in the 40-70 GHz band.

(2) Mobile earth terminal in the 30/20 and 44/30 GHz bands.

(3) Dual mode missile seeker head with the radar switched into the radiometric mode during the final phase of descent, for avoiding errors due to glint.

(4) Chirp radar in the seeker head with wide chirp bandwidth of 1 GHz to avoid glint while maintaining the high range resolution by dispersive filter processing of the echo.

(5) Radiometric imaging of scences from aircrafts and helicopters for seeing through dense fog.

(6) Radar imaging with signal processing at Near Millimeter waves (NMMW) in the 100-800 GHz band, using quasi-optical components, for battle-field operations in dense fog.

(7) Very high resolution 3/D radar imaging at millimeter and submillimeter waves using sub-nanosecond pulses.

Shift of Millimeter Wave Window Frequency over the Indian Subcontinent and Choice of Frequency

Using the latest model of millimeter wave propagation due to Liebe 1989, the window frequencies over the Indian subcontinent were estimated by the millimeter wave group at the Institute of Radio Physics & Electronics, University of Calcutta (Sen et. al. 1992), and from the results it is evident that the optimum window frequencies over the Indian subcontinent should be centered around 31.5 GHz, 77 GHz and 125 GHz in place of the conventional windows at 35, 94 and 140 GH_Z respectively. If we stick to 94 GHz instead of the shifted window frequency around 77 GHz, for instance, we suffer from an extra attenuation of the order of 0.25 dB/km under clear weather conditions. Under conditions of rain the extra attenuation due to sticking to 94 GHz would be 1 dB/km. If we also consider that the available source power at 77 GHz will be more than that at 94 GHz, the net improvement in C/N would be about 2 dB/km, which is quite significant,—about 20 dB for a link of path length of 10 km. In view of the window shift it is suggested that all future R & D activities should take note of realistic window frequencies over the Indian subcontinent.

ANNEXURE

A COPY OF THE COMMENTS BY PROFESSOR M. N. SAHA IN THE VISITOR'S BOOK OF THE IONOSPHERIC FIELD STATION AT HARINGHATA

We had the pleasure of visiting the Ionospheric Research Laboratory at Haringhata which is jointly run by the Calcutta University and the Council of Scientific and Industrial Research, Govt. of India. It is the fruition of long years of devoted work by my colleague, Prof. S. K. Mitra, and the devoted band of workers he has trained. I am glad to note that the Laboratory is now in full working order, in a field important alike to the Nation, and to Science.

I hope that the Laboratory will not remain satisfied with the work already started. It ought to have a Radio Astronomy section.

I wish the Laboratory a good future and many years of successful work.

M. N. Saha
Aug 21-1955

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RADIO ASTRONOMY AND IONOSPHERIC EFFECTS*

A. DASGUPTA

ABSTRACT

Professor M. N. Saha's studies of ionospheric effects on wave propagation are mentioned. Ionospheric effects may continuously interfere with or may constrain or limit radio astronomical observations. The present paper discusses some of the phenomena which may seriously disturb signals passing the earth's ionosphere, with special reference to the performance of the Giant Metre-Wave Radio Telescope (GMRT). The perturbations imposed by the ionosphere mainly derive from the ambient ionisation and irregularities in electron density distribution, which depend on the time of the day, season, solar activity, geomagnetic condition and the location. The equatorial ionosphere contains the most intense electron density and irregularities which may seriously impair observations in the VHF, UHF and Microwave bands. In view of the location of the GMRT and the frequencies of operation, some of the ionospherics effects are too serious to be overcome.

* The paper was presented at the Seminar but the full manuscript has not been received.

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Meghnad Saha and River Research & Calendar Reform

PROF. MEGHNAD SAHA AND RIVER MANAGEMENT

A. C. RAY

ABSTRACT

The critical study made by Prof. M. N. Saha on the problems of Indian rivers is briefly reviewed. The emphasis laid correctly by him on river research is elucidated. His considered views and valuable comments on multipurpose development schemes of rivers, particularly in the context of planning for the Damodar Valley, are discussed.

The rivers of India have contributed to the development of India's civilization from the days of paleolithic and neolithic living. Places by the side of the Narmada, Luni, Tapti, Godavari, Brahmani, Baitarini and Mahanadi and other rivers have been the sites of oldest settlements of India. The rivers provided

— water for drinking and other use
— fish for gatherers and hunters
— transportation
— natural protection as barriers

In the process of development, major cities like Pataliputra by the side of the Ganges, Tamluk on the confluence of the Ganges and Bay of Bengal and similarly cities like Vaishali, Ujjain etc. came up. The Ganges, Narmada, Tapti, Kaveri and Krishna had been the mainstay of India's habitation and growth over centuries.

In Rajasthan, with drying up of the Saraswati and Ghagra, the prosperous settlements by their sides languished and the people moved to the upper Ganga reaches in the Punjab and Uttar Pradesh.

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Prof. Meghnad Saha was a keen observer of the role of a river in human civilization and development. His study of irrigation in ancient India shows the depth of his insight. His article 'The Problems of Indian Rivers', written in 1938, dealt with various problems related to Indian rivers. In this article he made a comparative study of the irrigation systems in the ancient times in Egypt, Babylon, China and India. He observed that India had scientific knowledge which helped the country to harness the rivers for the benefit of men. River courses changed and men took river training measures. He wrote :

"The work which has been done by the engineers in recent times in the Punjab may be summed up by saying that they have tried to restore the waterways which existed in former times."

He said : "The wide changes are characteristic of all the rivers in the whole of Bengal and in Assam and Orissa. Are these changes partly due to some deep-seated forces or due to the natural surface action of the rivers which, unable to carry their heavy load of silt, go on depositing it on their bed and banks and are utlimately forced to seek new channels? Scientists will take a long time in answering such questions, but it is needless to say that these changes have caused great dislocation of human life—old cities have been eroded, prosperous areas have been washed away, swamps have been formed and regions once populous have been ravaged by malaria. Can this been controlled at all ?"

He sounded a note of caution : Will Calcutta go the same way as Pataliputra and Gaur ? Its level has gone down in two hundred years by 2-4 feet below the surrounding country and the drains can no longer discharge their refuse matter to the surrounding river without pumping. No satisfactory solution has been found to this problem.

He brought public attention to the fact that planning of canals, bridges and railway lines have not always been made on scientific lines and many mistakes have been committed, causing obstruction to easy flow of river and affecting the surrounding rural area. In this context he stressed the necessity of having more river physics laboratories.

He concluded that if we have to fight poverty, remodel our society and renew the springs of our civilization and culture, we must utilize

our resources, harnessing the energy of our rivers, reclaiming deserts and swamps on scientific lines.

Many schemes have been rushed through without proper examination and survey. His following observation in the Parliament was prophetic : "I think in the Damodar Valley Project, the irrigation projects will lag a long time behind the completion of the canals".

He also very rightly desired that we should grow upon not only the experiences of America but also those of Russia, who had successfully trained the mighty Volga river.

In the context of current emphasis on hydel power network of irrigation canals and extensive inland water transportation through rivers, one remembers Meghnad Saha's great contribution to the field of river research. His emphasis on avoidance of repetition of past mistakes, development of river research laboratories and multipurpose development of river resources along scientific lines have great significance today.

Scientific development of river research is essential as the biotic pressures on river resources are increasing. There must be sustainable development, so that the resources are not squandered away. Man's symbiotic relationship with the river has to be preserved and respected. In the Ganga, Yamuna, Brahmaputra, Narmada, Indravati, Kosi and all other rivers scientific development with environmental concern is the need of the day and a must for the future.

In his article 'Need for a Hydraulic Research Laboratory' Prof. Saha suggested that studies should be organised in the following manner :

— Creation of a hydraulic research laboratory for research in river training in Bengal.
— Creation of a statistical department for continuation of studies undertaken by Prof. P. C. Mahalanobis.
— Undertaking uptodate hydrographic surveys of the entire river system of Bengal.

Prof. Saha advocated that the hydraulic research laboratory should undertake studies in river training, flood, irrigation, navigation and water-

power development in Bengal. The basic objectives should be to study the physics of great rivers, preparation of plans and their testing in laboratory models. Besides, there should be a department for field service for undertaking hydrographic surveys of the rivers of Bengal.

In his papers entitled 'Damodar Floods of 1935' and 'Irrigation Research in Damodar' Prof. Saha again emphasised the need for river physics laboratory in Bengal and on regional basis.

In his article, 'Flood', Prof. Saha warned us about the menacing trend of the river Damodar moving eastwards, continuous rise of river-bed due to silt deposition and persistent decrease of spilling capacity to the right which might endanger the very existence of the city of Calcutta. He advised the Government to take lessons from the measures adopted by the Government of USA in this direction. His article 'Training of the Tennessee River' is an amplification of his latent ideas to train the river Damodar in the model of the Tennessee River in USA. Prof. Saha personally inspected the Tennessee River Valley Project in USA.

In his articles, 'Planning for Damodar Valley' and 'The Damodar Valley Reclamation Scheme', Prof. Saha put forward a thesis for a planned reclamation of Damador Valley, converting 'a destructive river system into a beneficial agency, producing large amount of electrical power, ensuring water for irrigation and flushing of the lower basins throughout the year, removing the eternal menace to rail and road communications and guaranteeing public health'. He was of the view that 'nature, vested interests and thoughtless management made a once prosperous valley a wilderness' but he was confident that 'the nature, man and science can again make it a smiling garden'. He made a comparative assessment of different sites for dams, advocated for afforestation for control of soil erosion, considered problems of siltation in the reservoirs and prospects of extracting hydel power from the scheme. In his article, 'Multipurpose Development of Indian Rivers', Prof. Saha delineated different stages needed for finalising multipurpose development schemes of rivers. The steps, he recommended, were :—

(i) Survey of the inherent characters of the land and the natural resources—water, minerals, soil and vegetation.

(ii) Integrated planning, combining power, nevigation, irrigation, land-use and flood prevention.

(iii) Design

(iv) Construction with systematic research support

(v) Optimum utilisation

In a number of debates in the Loksobha, Prof. Saha, as an M.P., projected the proper management of the Damodar river. Optimum utilisation of the river resources of our country was a dream of Prof. Saha. It was virtually through his efforts and persuasion that the DVC project was planned and executed although in a truncated manner.

Prof. Saha's anxiety for proper river management is particularly relevant in the context of water resources development in the country. Although the country is flushed with water during the monsoon, during the lean season there is scarcity of water. Erosion, primarily because of lack of tree cover, is causing tremendous loss of precious top soil. There is shortage of drinking water in vast areas of the country. All these problems can be tackled with proper river management as envisaged by Prof. Meghnad Saha.

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RIVER RESEARCH IN THE CONTEXT OF POWER GENERATION

B. K. BANERJEE

ABSTRACT

A scheme for a systematic and comprehensive study of Indian rivers, as envisaged by Prof. M. N. Saha in the light of his first-hand experience of the devastating floods in Bengal, is described. His views on various aspects of river management, namely, flood control, irrigation, industrial use of water and power development, are presented. His extensive investigation on the Damodar River System and the Damodar Basin Scheme suggested by him on the basis of his acquaintance with the successful work of the Tenessee Valley Authority are highlighted. The power generation scenario in a river basin, as reviewed by Prof. Saha, is narrated. His valuable suggestion regarding post-implementation studies of multi-purpose river development projects such as the DVC project in the context of future national planning is discussed.

It is indeed a privilege to participate in the birth centenary seminar of Professor Meghnad Saha, which is a part of the year-long programme for paying homage to this great son of India, who had worked untiringly for the development of the nation. This part of the programme is devoted to discussion on the life and works of Prof. Saha, which, I am sure, is always quite rewarding because, when we look back on a life so illustrious and so completely dedicated to the welfare of the country, we find important directions that help us organise ourselves in our respective fields of work and illuminate our mind.

Prof. Saha was undoubtedly a colossus of his times. His genius worked over many diverse fields, and wherever he had found it necessary to involve himself, the outcome had always been marked with a touch

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of class and brilliance which was the hallmark of his works right from the beginning till end.

It is well known that Meghnad Saha was among the all-time greats in the fields of science and he was aptly regarded as one of the pioneers of modern science in India. However, his contributions in other fields, which are perhaps not so widely known, were no less outstanding. He was the driving force behind the setting up of the National Planning Committee in the pre-independence days. The principal objective of this Committee was the formulation of techno-economic development plans which could be implemented when the nation became free. Prof. Saha was a member of the Core Committee and also the Chairman of two Sub-committees, one of which dealt with the vital areas of power and fuel. For him, power was not only an index of development but also one of the most significant inputs. Therefore, development of power, especially hydropower, was one of the areas in which he was very deeply involved.

However, River Research in the context of power generation, which is one of the topics for this morning's discussion, forms only a part of water resources development in this country. Therefore, while talking about river research and hydro-power, it would be appropriate to discuss Prof. Saha's works in the field of river management and water resources development also.

However, his contribution in this field is so immense and spectacular that within the short span of time at our disposal, we can only take a passing glance on some of his works. While doing that, we will, no doubt, realise that the motivation and thought-process that had involved him so intimately in this field had deep roots in humanitarianism, nationalism and highly organised mental capabilities.

His familiarity with rivers goes back to his childhood days in Eastern Bengal (now Bangladesh) where it was quite common for him as a child to row his boat to school and back. Besides that, there were floods. The devastation that accompanied them must have set his mind to work even in those early days.

Problems of Flood

Prof. Saha was initially quite besieged with the problem of floods. He had horrifying memories of the 1913 flood of the Damodar, when, as a student, he had worked as a volunteer for relief works and witnessed destruction and misery all around. Quite obviously, he was very deeply moved by the suffering of the people.

In 1922, he worked as a Publicity Officer in Acharya P. C. Ray's Relief Committee for the flood victims of North Bengal. There he could realise that the main reason for widespread flooding in North Bengal was human interference on the river system, which was in the form of railway embankments with inadequate waterway.

Hydraulic Research

It was now clear to him that human interference could be very serious unless it was well planned and comprehensively studied. He was quite amazed to see that there was very little data available on the river systems and hardly any investigation at all. He was convinced that a beginning had to be made for systematic and comprehensive study of rivers. So, he was quite vocal about the creation of a hydraulic research laboratory along with hydrographic survey of the system. The need for creation of a statistical department for recording and processing of information was also highlighted by him. He realised that river problems varied widely from region to region and it was necessary to set up a number of regional laboratories rather than a central one.

There was another devastating flood in Bengal in 1931, and Saha decided to make an in-depth study to inquire into the causes of floods and suggest remedial measures. He was quite convinced that the main cause of flooding in those areas was the catastrophic changes in the river system caused by the deposition of silt year after year. It was therefore quite clear to him that proper remedy would involve restoration of the river. But before taking up any such works, it was essential to make systematic studies.

From 1932 onwards, Saha wrote a number of papers on setting up of what he called 'River Physics Laboratories' in Bengal. He drew references to opinions expressed by Sir Spring in 1903 and urged the authorities

to implement his suggestion in that direction. He was quite pained to see that while science was being applied to every walk of life, the problem of river control was never properly studied in the country. According to him, this was the reason why the engineers had gone on blundering and benefitting rather by chance than by design.

Saha was quite convinced that forces of rivers could certainly be controlled but he was also quite aware that Nature to be commanded must have to be respected. The rivers represented great forces of nature and therefore they needed careful study for effective control and management.

He studied the establishment of river physics laboratories in a number of countries abroad and urged the authorities to set up such laboratories in different regions of India.

Irrigation

Saha's concern for farmers of Bengal was quite well known. He was quite aware that peasants of Bengal depended fully on their land. These lands required protection from floods and also perennial irrigation for agriculture. To Saha, irrigation was not merely supplying the fields with water but manipulation of water resource of the country to its best possible interests. He was aware of the varying scenario of the vast country, and the different types of problems faced in different areas. He was also quite aware of the failures in the past in the design of irrigation systems mainly because they were not studied in relation to the local conditions. Therefore, he was extremely conscious about the need for irrigation research in India. He was of the opinion that research laboratories would be required for study of the various types of problems in irrigation as well as river training.

Problems of Rivers

Saha knew very well that rivers were essential for agricultural communities and this was the reason why human civilization since time immemorial had chiefly centred around river basins. However, changes in rivers in the past had brought great suffering to the people and therefore, these changes were required to be controlled.

He realised that one of the main problems with Indian rivers was change of course. In Pubjab, rivers tended to move westwards due to either some deep-seated tectonic action or change in monsoon tracks of rain clouds. In the Ganga-Brahmaputra system the changes were mainly due to heavy load of silt depositing on the beds and banks of the rivers. These changes caused destruction of human lives, erosion of cities, formation of swamps and spread of diseases.

He acknowledged the work of engineers in Punjab who had tried to restore the waterways by well-designed control works and were able to fight the tendency of aridification of lands. He sounded a word of caution by citing examples of the ancient city of Patliputra which lay buried under large deposits of sediment and the city of Gaur in Bengal that turned into swamp giving rise to catastrophic epidemics and rapid decadence.

Industrial Use of Water

Saha was fully aware of the needs of modern times. He was quite upset with the state of poverty in the country. This, according to him, was mainly due to the fact that India had a very large population of farmers. His description of the state of poverty of the farmers was remarkably intimate and came from the bottom of his heart :

"And do the peasants enjoy a good living ? A few huts, mostly without doors & windows, a few mats & rags, a few half starved animals, hunger, debt & frequent disease—this is all they have to enjoy."

Saha felt that industrialization was the only solution to the poverty problem. He was of the opinion that agriculture could provide food supply but this was the least part of the demand. Other demands like better house, better education and better enjoyment could come mainly from industry.

However, setting up of industry required cheap electric power. India had sufficient power resource but it was not developed. Saha felt that not only had the power resource not been developed but also the available power was extremely dear. This, according to him, was the root cause of India's backwardness in industrialization.

Power Development

Saha knew that the prestige of a nation depended largely on the industrial muscle-power, and for setting up industries, power development was a basic necessity. India had plenty of resources but its distribution was quite uneven. Coal was available in the eastern parts. Therefore, coal-based power plants would not be suitable for other areas of the country. Moreover, coal was an exhaustible resource. It was, therefore, quite clear to Saha that it was essential to develop water power adequately. The country had excellent potential of this renewable resource and Saha identified the upper reaches of the Ganga and the Indus for setting up hydro-power plants. However, he found it essential to take up extensive studies relating to various aspects of hydro-power generation including construction of storage reservoirs. He was quite impressed by the progress made by the Russians within a short span of time which helped them in passing from an agricultural state to an industrial state. He was sure that India could do the same thing, but what was needed was systematic utilization of the resources and moulding the nature of the people both in its industrial and social aspects.

Association with Damodar Valley

Works of Saha on the Damodar River System are considered by many as his masterpiece in water resources planning. Here, the modern thinker in Saha was seen in full blossom. In fact, in the light of his studies, some radically new concepts of water management emerged. It was no more a piece-meal planning for either irrigation or flood control but a comprehensive development plan for the system as a whole, taking into account the various beneficial uses such as irrigation, flood control, hydro-power etc., all taken together.

Saha had seen catastrophic floods of the Damodar in 1913 and analysed the problems of flooding after the 1935 floods. Floods in the Damodar were not unexpected events and occurred almost every year in July-August and sometimes in September-October also. The catastrophic floods were, however, rare. But when they came, they spelt disaster to the countryside. In fact, when they occurred, it was always with a fatality. Saha looked back in history to find that flood control and irrigation had always gone hand in hand with civilization. They were required to be considered together in the case of the Damodar River also.

After the flood of 1943, which was a comparatively small flood but which caused extensive damages, the Government of Bengal had set up a Committee known as the 'Damodar Flood Enquiry Committee' to study the problem in detail and suggest remedial measures. Saha, who was then a Professor of Physics in the University of Calcutta, made important contributions to the Committee as one of its Members. It is here that he elaborated the importance of dams in control of floods and in providing perennial water supply for assured agriculture.

He cited a radical solution that was suggested way back in 1920 by E. L. Glass and Addams-Williams after intensive field work over a number of years. Their recommendation for construction of flood detention dams on the main river and the tributaries was not, however, implemented. Had the measures been undertaken then, the fury of the floods in 1943 could have been satisfactorily curbed and damage to life and property avoided to a large extent.

At this point of time, Saha became quite familiar with the wide ranging complexities of water resources management not only from the engineering point of view but also on account of its impacts over various interest groups. The Damodar Scheme suggested by Glass and Addams-Williams was halted by coal interest and Saha made stern remarks that read as follows :

"It now appears that Government had almost decided to build the dams at Parjori on Damodar and Palkia on Barakar and preliminary works were started, when a small bird appears to have whispered into the ears of coal magnets in Calcutta that dams would spoil their mines."

Basin as a Whole

While studying the problems of the Damodar, Saha pointed out that after the great Miami floods in 1913, the US Government undertook and completed a large number of dams and river-training works with the policy of regarding the whole river basin as a unit and coordinating plans for irrigation, hydro-power, navigation etc. He also made a detailed study of the Tenessee River Scheme in the USA, and found striking similarities between this system and the Damodar. Saha was greatly impressed by the multipurpose development of this multi-reservoir project and was

convinced that such a solution would be appropriate for the Damodar Basin also. He was quite amazed to find that in 1941, energy generated by the Tenessee Valley Authority was around 60% more than the whole energy produced in India. He was equally impressed by the fact that cheap power supplied by TVA had helped in rural electrification, opening of small mills, factories and small industries. These were exactly what the Damodar Valley needed.

The TVA success story was intently analysed by Saha and he found, above all, the over-riding importance of a strong political will in setting up such large projects with far-reaching consequences. Such projects, he was sure, helped in the development of a country and in its socio-economic transformation.

Saha suggested in a paper written in 1944 a TVA-like scheme for the Damodar Basin considering the whole valley as a unit in order to explore the fullest possibilities of the river system for a multipurpose, multi-objective development. Concept of optimal utilisation of water resources of a basin stems from this suggestion. It is interesting to note that the Government of India have quite recently considered basin-wise planning as an essential element in the National Water Policy while Saha could realize its importance many years ago.

While planning for the Damodar basin, he could realise that hydro-power available from each project would be secondary in nature, being available mainly during the monsoon. But if a number of reservoirs were built, he argued, a large part of the power could be made primary, that is, available throughout the year. This was an essential requirement for industrialization in the area and in fact, it was also quite necessary to set up auxiliary thermal power units to firm up power generation. This added a new dimension on power generation scenario in a river basin considered as a well-integrated socio-economic entity.

Saha also recommended afforestation of the upper catchments of the Damodar for preventing erosion of soil, improving channels and enhancing life of reservoirs. Clearly, this was a further step ahead in water resource planning from the concept of multipurpose projects to multi-objective schemes.

Damodar Valley Project

The report of the Damodar Flood Enquiry Committee was signed in March, 1944. In the same year, Saha brought out an article in which the planning details of the multipurpose scheme were worked out.

The Central Government took up the planning for the Damodar Valley on the basis of recommendations of the Damodar Flood Enquiry Committee. Services of W. L. Voorduin who had worked for the planning of the Tenessee Valley Scheme were utilised. The planning details of the scheme were brought out as the 'Preliminary Memorandum for Unified Development of Damodar River' in August, 1945. The recommendations made in this report closely agreed with the suggestion made by Saha about a year back.

However, the implementation of the project was quite a different thing. It involved inter-state matters requiring a great amount of political manipulations. Saha expressed the hope that the scheme would be pushed through energetically and neither civil service, politicians and experts nor provincial jealousy would be allowed to impede its speedy execution. He had also cautioned against haste and light-hearted approach and warned that schemes like this could not be erected overnight but needed careful planning and detailed investigation. He also indicated the different stages leading to the finalization of the schemes such as survey, planning, design, construction and utilization. He was also quite eager to set up a firm basis for the fullest development of natural resources for the country and stressed on optimization of utilization which, he thought, could be achieved on the basis of balanced development of the entire unit.

The Damodar Project was taken up in due course and Saha was keenly associated with the activities of the project even as a Member of the Parliament. The project was no more a dream but a reality taking shape. Implementation of the scheme and the resulting transformation in the socio-economic scenario is a part of history the nation could be proud about.

National Planning

The Damodar Project had striking similarities with the TVA Scheme but it was much smaller in size. Such projects and, in fact, much larger

ones were required to be set up for the overall development of the country. So, Saha identified other projects such as Rihand, Sulej and Koyna. However, before launching such gigantic projects it was necessary to have feedbacks from the smaller ones. Damodar could ideally provide that. It is true that it was not meant to be an experimental project and was indeed worked out in great details. But the dynamics of the planning process demanded that real-life projects like Damodar were carefully studied in the post implementation stage so that future projects could stand on better footings. In a way, Damodar had provided ample real-world information and research material for integrated river valley schemes, and the country could now draw upon these materials in the planning and development of other projects to come.

Conclusion

We have now seen the wide-ranging contribution made by Prof. Maghnad Saha in the field of water resources in India. He had, in fact, revolutionized the way of thinking in project planning in this country. He had worked tirelessly for water resources development because he could realise that this was the most important area where rapid development was called for so that proverty could be removed and prosperity could be ensured for all. He laid bare the various types of complexities in the field and gave important guidelines in dealing with each one of them. So, on this day, when we pay homage to this great architect of modern India, let us resolve to be guided by his ideals and try our best for the prosperity of the nation.*

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* The paper was presented by Shri S. K. Ray, Executive Engineer (Civil), Floor Forecasting Unit, DVC, as Shri B. K. Banerjee could not attend the Seminar due to unavoidable reasons.

PROFESSOR M. N. SAHA'S CONTRIBUTION TO CALENDAR REFORMS

AMALENDU BANDYOPADḤYAY

ABSTRACT

This paper brings out salient features of Prof. M. N. Saha's contribution to calendar reforms. The Indian scenario has been discussed in detail. In India people have taken for granted a large diversity of calendaric systems, with the result that there has been a great calendar confusion in the country. Some of the calendars are based on the movement of the Sun, known as solar calendars, while some others are based on the lunar month related to the solar month, known as the luni-solar or simply lunar calendar. But different conventions are adopted in different States for determining the first day of the year and also of the month and all these differences have resulted in more than 30 varieties of Calendars being now in vogue in India. Another significant deficiency of the Indian Calendars is the erroneous length of the year upon which the calendars are based. Moreover, compilers of ancient Hindu Siddhāntas *were ignorant of the phenomenon of the precession of equinoxes. Saha studied all these problems of our calendars and after independence, at his initiative, the Government of India in 1952 appointed a Calendar Reform Committee, of which he was the Chairman. Saha Committee recommended in 1955 for a uniform civil calendar which is known as the National Calendar. The introduction of the National Calendar was an important and bold step taken by the Governmnt for introducing a uniform and scientific system of calendar making in the country. But it should always be kept in mind that this was a significant achievement of Saha in his efforts for reformation of our divergent systems of calendar. The Report of the Calendar Reform Committee edited in this connection by Saha jointly*

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with Nirmal Chandra Lahiri, is regarded as a vade makum *for research workers on calendaric astronomy.*

Panchangs, i.e., religious calendars are widely used in our country. It contains some astronomical parameters viz. tithi, nakshatra, positions of the Sun, the Moon and the planets. It has been observed that the calculations of these astronomical elements of Panchang are very often considerably in error, as they are computed on the basis of the tables given in Surya-Siddhānta, *an ancient astronomical treatise, composed in about 500 A.D. Saha struggled hard for the adoption of the most modern scientific methods of computation of these elements by indigenous panchang-makers. With a view to supplying correct astronomical elements to panchang-makers of our country, it was Saha who founded in 1955 the Nantical Almanac Unit at Calcutta. This small Unit was within the administrative jurisdiction of the Indian Meteorological Department of the Government of India. Ultimately this small unit developed in 1980 into an international centre named Positional Astronomy Centre (PAC). PAC is the only institute of its kind in the whole of India, concerning the discipline of positional astronomy. In reality, PAC is the consequence of Saha's farsightedness for the development of various disciplines of science in our country.*

Gregorian Calendar, which is now used internationally for civic and adminstrative purposes, is an unscientific system of time-reckoning. Its main defects have been discussed. The defects of this Calendar were sought to be taken care of by the World Calendar, which was being advocated by the World Calendar Reform League for acceptance as an International Civil Calendar by the U.N.O. The salient points of the World Calendar have been described. As a result of a request from the Government of India, the proposal of the World Calendar Reform was taken up as a subject of discussion at the eighteenth session of the Economic and Social Council of the U.N.O. at Geneva in June–July, 1954. The Government of India deputed Saha to attend this meeting. Saha delivered an unforgettable speech in support of this proposal, but ultimately the proposal could not find acceptance by the United Nations due to stiff opposition from the Jewish community. Saha's efforts for the world calendar reform will be remembered long.

I have been assigned the task of giving an outline of Professor Meghnad Saha's contribution to calendar reforms. I feel much pleasure in doing this job, as I have been closely associated with the work of calendar reforms in our country for a long time.

The magnitude of Saha's contribution to calendar reforms is of high order. In this field also, he may claim originality. Before telling you about his specific contribution in this field, let me narrate the Indian scenario of calendars very briefly.

Calendar Confusion in India

Perhaps in no other country have the people taken for granted such a large diversity of calendar-systems as in India. The result is that there has been a great calendar confusion in the country. Even at the present time, there is a large variety of indigenous calendars, as is evident from the different kinds of Panchangs (Almanacs) in use in differnt parts of the country. There is a great divergence in the indigenous calendars used for the purpose of numbering civil days of the month in different regions of the country. Some of the calendars are based on the movement of the sun from one zodiac sign (*Rashi*) to the next, and are known as solar calendars. Some others are based on the lunar month related to the above mentioned solar month ; they are known as luni-solar or simply lunar calendars.

Even in different solar calendars in use, there are differences of one or two days in the commencement of the same month in different States. This is because different conventions are followed in different States for determining the first day of the month on the basis of the time of transit of the sun (*samkranti*) which may occur at any hour of the day. For example, in Bengal when a *samkranti* takes place between sunrise and midnight of a civil day, the solar month begins on the following day and when it occurs after midnight, the month begins on the next following day, i.e., on the third day. In Orissa, the solar month begins on the same day (sunrise to next sunrise) as the *samkranti,* irrespective of whether this takes place before or after midnight. In Tamil Nadu the rule is that when a *samkranti* takes place before sunset, the month begins on the same day, while if it takes place after sunset the month begins on the following day. The rule observed in Kerala is that, if the *samkranti* takes place between sunrise and 3/5th of the duration of day from sunrise, the month begins on the same day, otherwise it begins on the following day. The names of the solar months also differ from one State to another. Similarly, in other parts of the country where the lunar calendar is used for purposes of reckoning civil dates, there is a similar lack of uniformity of practice. Some count the month from the day following the new moon (*Sukladi* system), while others count the same month from the day following the preceding full moon, i.e., 15 days earlier (*Krishnadi* system). The year beginnings, both in the solar and luni-solar calendars, differ in different States. In West Bengal, Assam, Orissa, Punjab, Haryana and Tamil Nadu

the regional solar year usually starts from 14th or 15th April, whereas the solar year of Kerala begins from 17th August. The lunar year in vogue in U.P., M.P., parts of Rajasthan, Andhra, Karnataka and Maharashtra usually begins from near about 22nd March, whereas the lunar year in vogue in Gujarat and parts of Rajasthan, starts from near about 13th November. There are also similar differences in the eras used with these calendars in different parts of the country. All these divergences have resulted in the evolution of more than 30 varieties of calendars now in vogue in India.

Erroneous Year-length of Indian Calendars

The significant deficiency of the Indian calendars is the erroneous length of the year upon which the calendars are based. The year of the Indian calendars consists of 365 days 6 hours and 12.6 minutes, whereas the correct length of the tropical year or the "year of seasons" is 365 days 5 hours and 48.8 minutes. The year of the Indian calendar is thus 23.8 minutes longer than its correct value. The result of this erroneous value of the year-length has been that the Indian year, which in 500 A.D. used to commence at the moment of the sun's crossing the vernal equinox, now starts about 23 days later. Consequently the seasons, being connected with the equinoxes and solstices, are gradually receding at the rate of about one day in 60 years or a month in 1800 years. Thus originally solar *Asvina* and *Kartika* constituted the *Sarat Ritu* (autumn), but now autumn falls in the months of solar *Bhadra* and *Asvina* ; and after a few hundred years, solar *Sravana* and *Bhadra* would constitute this season.

The compilers of the Hindu *Jyotisha Siddhantas* of 500 or 600 A.D. (Aryabhata, Brahmagupta and others), who first introduced the erroneous length of the year in the calendar, could not anticipate the difficulty brought about by the precession of the equinoxes (which finds no mention in their treatises). This fact, the shift of the equinoctial day, came to the notice of later astronomers some 400 or 500 years after Aryabhata, but they did not incorporate any correction factor.

The makers of our *Shastras* ordain that the Hindu religious festivals should be observed in the prescribed seasons. From what has been stated above, it is clear that in order to secure this conformity the tropical year (in which seasonal correspondence is maintained) should be taken as the

year-length in the calendar and not the year-length of the *Surya Siddhanta,* nor even the correct sidereal year (which is the time of revolution of the earth in its orbit round the sun).

The State's Role

India is a secular State. As such, it is not directly concerned with the question of reforming the Indian calendars which are used mainly for religious purposes. The reason why the Government has come into the picture is that both the Central and the State Governments have to prepare annually a list of holidays of religious, social and national significance, which they have to declare in advance. Since there is normally no uniformity about these days according to the existing Indian calendars, the Government has had to take the responsibility for the preparation of a standardised calendar. Also, since the preparation of a unified national calendar is an issue affecting all classes of people, it is thought that the task can be effectively accomplished only at the State level. Still another reason for the Government undertaking the task of standardisation is the fact that the preparation of a uniform national calendar will, by acting as a social cementing force, usher in a new element of unity in the country which became politically united after independence.

Elements of a Panchang

Uptil now, I have told you about the various systems of calendar, which are in vogue in India, and their basic defects. Now I tell you about the astronomical elements usually published in *panchangs* all over the country. What is a *panchang* ? How was the name *'Panchang'* derived? The ancient Indian *Siddhantas* lay down rules for compiling almanacs which were called *panchangs* or five-limbed ones, so called because they had to give, for every day of the year, the five astronomical elements in addition to the days on which the solar month was to be started, viz. (1) *Vara* (2) *Tithi* (3) *Karana* (4) *Nakshatra* (5) *Yoga*. The significance of each of these elements may now be explained. *Vara* gives the name of the week-day (i.e. Monday, Tuesday etc.) to which the date corresponds. Next comes the most important element of a *Panchang,* viz. *Tithi* which is an indigenous conception and is found in *Vedanga Jyotish* literature. There it was defined in a loose, but convenient way and the *Siddhantic*

astronomers gave it a strict mathematical definition. It is defined as the time period when the moon gains successive 12° on the sun, beginning from the moment when conjunction of the moon with the sun is completed. They are then enumerated by the ordinal numbers, the first, second etc. In other words, a *Tithi* is completed when the longitude of the moon gains exactly 12° or its multiple on that of the sun. A difference in longitude of 12° indicates the ending of the 1st *Tithi*, 24° that of the 2nd *Tithi* and so on. There are altogether 30 *Tithis* in a lunar month, the first 15 belonging to the waxing half (*Shukla Paksha*) and ending in full moon and the second 15 belonging to the waning half (*Krishna Paksha*) and ending in new moon. The mean duration of a *Tithi* is 0.98 of a day, but actual duration may vary through 0.98 ± 0.19 days on account of irregularities of the motion of the sun and the moon. In each *Tithi* there are two *Karanas* covering the two halves of the time period of the *Tithi*. A *Karana* is therefore completed when the moon gains every 6° on the sun.

Nakshatra is regarded as the next important element of a *Panchang* after *Tithi*. For the purpose of calculation of *Nakshatra*, an initial point which occupies a fixed position on the ecliptic has been adopted in Indian astronomy as the origin for the measurement of longitudes. The position of this initial point coincides with the vernal equinoctial point of 285 A.D. The tropical longitude of this fixed initial point for any day is known as *ayanamsa*. The longitude of a celestial body measured from this initial point is known as *nirayana* longitude. A *Nakshatra* is completed when the *nirayana* longitude of the moon as measured from the above initial point attains a value of 13° 20′ or a multiple thereof. When this longitude is 13° 20′, the 1st *Nakshatra* ends, and so on. There are thus 27 *Nakshatras* in a sidereal month such as *Asvini, Bharani, Krittika* etc. and the *Nakshatra* divisions occupy fixed position in the sphere of stars. *Nakshatra* can be regarded as the lunar asterism in which the moon is found on the day. The last element *Yoga* which literally means the addition, is the time-period in which the combined motions of the sun and the moon amount to 13° 20′. A *Yoga* is obtained from the sun of the *nirayana* longitudes of the moon and the sun and divided into 27 parts of 13° 20′ each. Like *Nakshatras*, there are 27 *Yogas* viz. *Vishkumbha, Priti, Ayushman* etc.

In addition to the five elements mentioned above, the *Panchang* gives

details of positions of the sun, the moon and planets, sunrise sunset timings, moonrise moonset timings from day to day and also of important astronomical events like solar and lunar eclipses, astronomical phenomena, *nirayana* longitudes of the sun, the moon and planets etc.

One can have now a clear idea of how the five main elements of a *panchang* are calculated and from this it will be more than evident that the science of astronomy is the basis for calculation of these elements. Moreover, computation of sunrise sunset timings, moonrise moonset timings, daily planetary positions and eclipses also entirely depend upon the science of astronomy. It may also be pointed out that the dates and moments of all Hindu religious observances and auspicious days, which are published in any *Panchang* are determined on the basis of the ending moments of *Tithi, Nakshatra* and *Yoga*, which are calculated on the conception that our earth is a point in the solar system. Consequent conclusion is that the ending moment of any particular *Tithi* on any day shown for any station of this earth like Calcutta, Delhi, Moscow or Tokyo should be the same. But it can be noticed that the different *Panchangs* published even from Calcutta itself may show different timings for ending moment of a particular *Tithi* on any day. Why is it so ? The reasons behind such difference may now be analysed.

Two Classes of Panchang

There are distinctly two classes of *Panchang* published in our country. In one type of *Panchang*, the calculated positions of the sun, the moon and planets, as published, agree with their actual positions in the heavens. This system is known as *Driksiddha Panchang* which is correct and accurate. In the other system, the calculated positions of the heavenly bodies, as published, do not agree with the actual positions in the sky. This class is known as *Adriksiddha Panchang* i.e. they belong to the old and incorrect system.

Let me now explain the two systems of calculating the astronomical elements for these two different classes of *Panchang*. For calculating principal contents like *Tithi, Nakshatra* and *Yoga*, the old and incorrect *Panchang* makers depend for their calculations on the principles laid down in the old Indian astronomical treatise *Surya Siddhanta* (400 A.D.) which do not incorporate the corrections now required to be introduced into the for-

mulae, based on the latest accurate astronomical observations made by means of the most modern instruments. The formulae used by the indigenous astronomers are not only inaccurate but also inadequate, as for example, in the case of the moon for which the *Surya-Siddhanta* does not give more than only one correction to its mean place, this conception can be taken as absurd in modern astronomy. It has been observed that the calculation of *Tithis* and planetary positions given by the old and incorrect *Panchang* makers are very often considerably in error, ending moments of *Tithis* differing from the correct timings sometimes by as much as 6 hours and the planetary positions by as much as 11 degrees. What is the cause of such grave error ? It is because the formulae about the motion of the sun and the moon which they follow were empirical, being based upon some kind of observations available about 570 A.D. These rules were accurate for a short while, but as time went on, they were found to be in error by small amounts and so more terms had to be added to the empirical formulae giving the motion, to make the rules conform to observed facts. Some of these terms were formed by Munjal (932 A.D.), Bhaskar II (1150 A.D.) and Sripati (1030 A.D.). About 1600 A.D., Raghavananda Chakravarty of Bengal introduced some corrections to the empirical formulae for agreement of the calculated positions of the planets with their observed positions in the heavens. At present, old and incorrect Panchang makers of West Bengal have been following such a set of rules. But still *Siddhantic* rules, even with later corrections, fail to give the correct timings of *Tithis*. This system of calculating astronomical parameters incorrectly is, at present, being followed by the authors of most popular *Panchangs* of West Bengal viz. 'Gupta Press' and 'P. M. Bagchi' which have the widest circulation. But these *Panchang* makers cannot afford to give the wrong data, though they may be *Shastric*, regarding eclipse dates and times as these are matters of direct observation and the times of eclipses calculated according to *Surya Siddhanta* come out to be wrong and if they prove to be wrong, people will lose all faith in them. At present, such *Panchang* makers have been taking all dates and timings for eclipses from the 'Indian Astronomical Ephemeris' prepared and published by the Positional Astronomy Centre of the Government of India. But in the case of calculation of dates and moments of religious observances, they can afford to profess to be guided by the *Shastras*, as these are not subject to any direct observational test. Moreover, the theory of

the precession of equinoxes which has been completely established on modern principles based on the laws of gravitation was completely unknown to the compilers of the Hindu *Jyotisa Siddhantas* and this was also a great handicap for them for calculating correctly the planetary positions.

Let me now turn to the system of calculations adopted by the *Driksiddha Panchang* makers. Computation of astronomical parameters required for a *Driksiddha Panchang* is done on most modern scientific basis. All astronomical elements necessary for the publication of a *Driksiddha Panchang* are at present computed with the help of electronic computers on the basis of most up-to-date astronomical formulae at the Positional Astronomy Centre (PAC) at Calcutta, which is the only centre of its kind in the whole of India. These astronomical data are published in advance for helping the *Driksiddha Panchang* makers in compiling their *Panchang*. It may not be out of place to point out that India is one of the eight countries of the world to compute and publish an astronomical ephemeris of her own. The other countries are U.K., U.S.A., U.S.S.R., France, Spain, Japan and China. The accuracy and correctness of the computed positions of the sun, the moon and planets of such astronomical centres are regularly checked and verified by astronomical observations of their positions in the sky through powerful telescopes all over the world and if any discrepancy is noticed, it is intimated to the International Astronomical Union (IAU) which is the highest international organization of astronomers. The IAU then introduces effective changes in the formulae of astronomy for determination of the orbital elements. Thus utmost careful watch is maintained by the IAU so that the computed position of any heavenly body completely agrees with its observed position. PAC of India is affiliated to the IAU and as such receives regularly necessary latest modifications for computing positions of the celestial bodies in the sky and thus astronomical elements of a *Panchang* computed by PAC are most authentic and accurate. *Driksiddha Panchang* makers all over India use the astronomical parameters supplied by PAC and as such there is cent percent correctness in the astronomical parameters published in their *Panchangs*.

Saha's Realisation

Saha realised the unscientific aspects of calendar-making and also of modes of computing astronomical parameters required for the publication of *panchangs* in our country. When most modern up-to-date formulae for

computing positions of the heavenly bodies are already available, *panchang* makers of our country are still using the tables of old and out dated treatise of *Surya Siddhanta,* an ancient astronomical treatise composed in about 400 A.D. This practice of our *panchang* makers used to give Saha much pain. Ultimately after independence, it was Saha who took the initiative, struggled hard and strongly advocated the adoption of a correct and unified calendar all over the country. He also advocated the adoption of the correct system of computing astronomical parameters of *panchangs* published from all corners of our country. Not only that, it was he, who brought this major problem of our calendar-making to the notice of the-then Prime Minister Jawaharlal Nehru. In fact, Saha requested Nehru so that the Government might take upon itself the task of bringing uniformity in the Indian calendars. And ultimately, with a view to introducing a scientific and uniform system of calendar calculation throughout the country, the Council of Scientific and Industrial Research of the Government of India appointed in November, 1952 a Calendar Reform Committee with Saha as the Chairman and six other eminent experts in this field as Members. The Secretary of this Committee was the late Nirmal Chandra Lahiri, the eminent calendaric astronomer. The committee was asked to submit proposals for an accurate and uniform calendar suitable for the whole of India. In this connection, Saha visited a good number of *panchang* making centres of India and critically studied different systems of calendar-making.

Report of the Calendar Reform Committee

The Committee submitted its report in 1955 with its recommendations for a uniform civil calendar and also laid down rules for the compilation of the religious calendar on scientific principles accepting the tropical year, or the year of seasons, as the length of the year with suitable luni-solar adjustments. The main points of the recommendations as regards National Calendar are as follows :

(i) The year of the calendar to be used for civil purposes will have its beginning on the day following the vernal equinox day.

(ii) The first month will be *Chaitra* which will start on the 22nd March in a normal year and on the 21st March in a leap-year when its duration also will increase from 30 to 31 days. The remaining months will have a fixed number of days.

(iii) The *Saka* Era should be used in the unified National Calendar, the year 1954-55 A.D. corresponding to 1876 *Saka*. *Saka* Era is recommended, as this is the era par excellence used by all Indian astronomers and had been used (and is still used for calendaric calculations all over India) since the days of the Ujjain astronomers (first century A.D.). Also this is the only era used in all Indian scientific treatises. The Indian almanac-makers, even today, use the *Saka* Era for calculations and then convert the calculations to their own system.

(iv) A normal year would consist of 365 days while a leap-year would have 366 days. After adding 78 to the *Saka* Era (as Zero-year of *Saka* Era is 78 A.D.) if the sum is divisible by 4, then it is a leap-year. But when the sum becomes a multiple of 100, it would be a leap-year only when it is divisible by 400, otherwise it would be a common year.

For the purpose of all calculations in connection with the religious calendar, one of the main recommendations of the Committee is that the longitudes of the sun and the moon should be obtained by applying the most up-to-date and complete equations of their motions, so that they may tally with their observed positions.

Thus the new calendar, both civil and religious, are based on the tropical year and as such its months would continue to conform to the present seasons for all time to come.

Introduction of the National Calendar

The Government of India accepted all the above recommendations of the Calendar Reform Committee and introduced for all India use the civil calendar with the Saka Era, with effect from the 22nd March, 1957, corresponding to 1st *Chaitra* 1879 *Saka* Era. It was also desired by the Government that the dates of the National Calendar of India should be followed in all civil work along with the dates of the Gregorian Calendar. As regards the religious calendar, the Government decided that *Panchangs* in different regional languages should be made available to the public, in which all the calculations will be shown according to the recommendations of the Calendar Reform Committee.

Some people believe that though the National Calendar has been introduced 35 years back, it has apparently not yet succeeded in attaining

the objective of the Government in its use as a standard calendar for the whole country by replacing the regional calendars. It has to be admitted that in a country like India where so many diverse traditions are prevalent, it is not possible to rush through in taking steps for imposing the National Calendar immediately. Under such circumstances the change and progress are bound to be gradual and slow.

It may not be out of place to mention that, originally, Pope Gregory XIII reformed the calendar on October 5 of 1582, but in Great Britain it was officially introduced only in 1752, i.e. after a period of almost 170 years. We have introduced our National Calendar only 35 years back. Nevertheless, there is need for a stronger drive for popularisation of the National Calendar by its constant use by all departments of the Central Government as well as all the State Governments, particularly in their dealings with the public.

In this connection Saha jointly with Nirmal Chandra Lahiri prepared the Report of the Calendar Reform Committee (which was published by the C.S.I.R. in 1955) and the part C of it contains the history of the calendar in different countries through the ages. This part of the report can be regarded as a monumental work of Saha in the field of the history of calendars and is still considered as a *vade makum* for research workers on calendaric astronomy. I must tell you the tragic fact that such a valuable book is, at present, completely out of print and that not a single copy of it is available for sale.

Positional Astronomy Centre

Another valuable recommendation of Saha Committee was that steps should be taken to publish an astronomical ephemeris by the Government of India. After the work of the Calendar Roform Committee (CRC) was almost over, Saha took up this case with Jawaharlal Nehru and explained that in ancient times, India was known for her advancement and contribution towards positional astronomy and that in course of time, this activity languished. Nehru readily agreed with Saha for revival of work of positional astronomy in India and accordingly the residual work of the CRC and also the preparation of an astronomical ephemeris was taken up from the Council of Scientific and Industrial Research by the India Meteorological Department on the 1st December, 1955. The Unit which

was functioning as the office of the CRC at the-then Institute of Nuclear Physics, Calcutta was attached to the Regional Meteorological Centre at Alipore, Calcutta as one of its sections named as 'Nautical Almanac Unit'. Ultimately this small unit was separated from the administrative control of the Regional Meteorological Centre in order to preserve its distinctive programme, identity and autonomy as much as possible, and the same developed in April, 1980 into an international centre named Positional Astronomy Centre (PAC) at New Alipore, Calcutta. PAC is the only institute of its kind in the whole of India, concerning the discipline of positional astronomy and is also one of the eight such centres of the world. The other countries are U.K., U.S.A., Russia, France, Spain, Japan and China. In reality, PAC is the ultimate consequence of Saha's vision and farsightedness for the development of the science of positional astronomy in India.

Defects of the Gregorian Calendar

I now come to Saha's role in calendar reform on the international scene. You are aware of the demerits of the existing Gregorian Calendar. Its main defects are :

(i) The months vary in length between 28 and 31 days quite arbitrarily ;

(ii) The year and month-beginning may fall on any week day and this causes serious inconvenience for civil and economic activities ;

(iii) The year beginning on the first January has no correspondence to the cardinal points of the year ; and

(iv) Though the Gregorian Calendar has discarded the moon as a time-keeper, it uses the lunar motions for defining the dates for holidays. This keeps the Good Friday and certain other holidays moving through an amplitude of 35 days.

World Calendar

In view of the above demerits, the Gregorian Calendar itself is in need of reform. These defects were sought to be taken care of by the Wordl Calendar (see Annexure) which was initially proposed by Armelin

in 1887. It was being advocated by the World Calendar Reform League (Head-quarters : New York) for acceptance as an International Civil Calendar by the League of Nations before the War and then by the U.N.O. The World Calendar proposes to prevent the wandering of the first day of the year. It is a very simple device. If from 1989, which starts on a Sunday, the last day of the year (i.e. Dec. 31) which would be under the present system a Sunday, is called the 'Worldsday', that is, no week-day denomination is attached to it, then 1990 also will start on a Sunday, and so will every year till the next leap-year 1992. On that year another additional day, the 'Leap-year Day' is inserted at the end of June and have the usual 'Worldsday' at the end of the year ; then 1993 will also start on a Sunday. So, by this simple device of having a 'Worldsday' at the end of every year and a Leap-year Day at the end of June every fourth year, both without any week-day denomination, every year can be made to start on a Sunday. This will prove to be an inestimable advantage for civilian use. This World Calendar is the same from year to year and so is of a perpetual character. Special merits of the proposed World Calendar are the following :

(i) Every year is the same ;

(ii) The quarters are equal ; each quarter has exactly 91 days, 13 weeks or 3 months. The first month in each quarter has 31 days and the other 30 days each ;

(iii) Each month has 26 week-days plus Sundays ;

(iv) Each year begins on Sunday, 1 January ; each working year begins on Monday, 2 January ;

(v) Each quarter begins on Sunday, ends on Saturday ; and

(vi) The calendar is stabilized and perpetual, at the same time retaining astronomical accuracy, by ending the year with a 365th day that follows 30 December each year, called 'Worldsday' dated 'W' or 31 December, a year-end world holiday. Leap-Year Day is similarly added at the end of the second quarter, called Leap-Year Day dated 'W' or 31 June, another world holiday in leap years.

Saha's Role in World Calendar Reform

At the strong initiative of Saha, the Government of India made a

request to the U. N. O. for taking up the proposal of the World Calendar Reform and as a result of this request, this proposal was taken up as a subject of discussion at the eighteenth session of the Economic and Social Council (ECOSOC) of the United Nations held at Genéva during June-July, 1954. Saha attended this ECOSOC meeting on behalf of the Government of India and delivered a burning speech in support of the Indian proposal for World Calendar Reform. He explained the utter desirability of the proposed reform, but ultimately the proposal could not find acceptance by the United Nations due to stiff opposition from the Jewish community.

Thus you can see that Saha's contribution to calendar reforms may be regarded as very valuable.

□□□

ANNEXURE

The World Calendar

JANUARY						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

FEBRUARY						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

MARCH						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

APRIL						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

MAY						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

JUNE						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30 W

JULY						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

AUGUST						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

SEPTEMBER						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

OCTOBER						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

NOVEMBER						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

DECEMBER						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30 W



Socio-economic Role of Meghnad Saha

SOCIO-ECONOMIC ROLE OF PROF. M. N. SAHA

TRIDIB CHAUDHURI

ABSTRACT

An appreciative account is given of Professor Meghnad Saha's role as a leader in the East Bengal Refugee Relief Movement and Famine Relief Movement in the early fifties. It is noted how his intimate association with the socio-economic planning by the All-India Congress Committee in the pre-independence era motivated him to enter the House of the People (Lok Sabha) as an Opposition Member, where he took an active part in exposing the defects and lacunae in the planning process formulated and implemented by the Government of the day.

I express my heartfelt gratitude to the Local Organising Committee for the Birth Centenary Celebration of Prof. Meghnad Saha for extending their kind invitation to me to speak about the socio-economic role of Prof. Saha. I am particularly grateful to the Committee because it gives me an opportunity to put on record my appreciation of Prof. Saha's unique personal contribution as a public man and a scientist to the solution of the problems faced by West Bengal in the early fifties on account of (a) great waves of refugee influx in the wake of the partition of the country, and (b) acute food scarcity accompanied by soaring price of foodgrains, particularly of rice and paddy at that time. I came in touch with Prof. Saha and worked under his leadership in the East Bengal Refugee Relief Movement and Famine Relief Movement during those days. I was of course acquainted with his name as a world-renowned scientist. But not being a student of science, I had not come in personal contact with him earlier. The East Bengal Refugee Relief Movement and the Food Movement of the early fifties, with both of which I was connected, brought me in close personal touch with him. Since then I got to know him intimately as a unique leader and great social worker. What struck me most about him at that time was the fact that in spite of his busy schedule

Shri Tridib Chaudhuri, M. P., is a renowned political figure.

as one of the top-most scientists, and a teacher and leader of science in the country, he could find time to take active part in and contribute to the solution of the urgent socio-economic problems faced by the country. He was intimately connected with the crystallisation of the idea of socio-economic planning of the All-India Congress Committee when he was posted at the Allahabad University, and he participated actively in the formulation of the schemes of socio-economic planning of the Congress in close association with Pandit Jawaharlal Nehrù and Netaji Subhas Chandra Bose. Actually it was his close connection with the idea of socio-economic planning that eventually persuaded him to contest the Parliamentary election and enter the House of the People (Lok Sabha) as an Opposition Member.

His ideas about planning were however very different from those of the official Congress Party, and he sought from his position of an Opposition M. P. to point out the defects and lacunae in the planning process as conceived and worked out by the Government of the day.

I had the opportunity of working with him in the Parliament in those days, and I was closely acquainted with his ideas. Unfortunately, I was soon cut off from him as I was arrested and detained in Goa in connection with the Satyagraha Movement there against the Portuguese colonial rule in 1955. Dr. Saha however suddenly expired in the year 1956 while I was in Portuguese prison in Panaji (Panjim), Goa.

What has always struck me most powerfully about the life and works of Prof. Saha is the fact that he always considered it to be his inescapable social obligation to participate in and search out the solutions of the most urgent current socio-economic problems of the country and to work for them. He was not a member of any particular political party as an M.P. I however knew from my discussions with him that he was a firm believer in socialism without being a partisan of any particular sect or school of socialist or communist thinking. He maintained an intimate personal and political relation with all the leftist and opposition parties, and his services and advice were available to all. I had seen him functioning as the President of the East Bengal Refugee Relief Committee and of the Food and Famine Relief Committee in Calcutta in perfect harmony with all sections of relief workers and members of different political parties. As a matter of fact, it was his unique personality and leadership quality which made these organisations work in perfect harmony with one another whether

in regard to collection of funds and relief materials or their distribution and disbursement. As far as I can remember, both the above organisations functioned under his leadership for about two years in perfect harmony and in mutual cooperation and amity, and they were wound up smoothly when their work was over. The great contribution that the personality and leadership of Prof. M. N. Saha made in their efficient functioning should be remembered with gratitude by all those who saw and bore witness to his work.

Prof. Saha was amongst the band of brilliant scientists and public social workers brought up and reared by Acharya P. C. Ray from amongst his students, and the contributions that all of them, including Prof. Saha, made to the development of the country's science and socio-economic life is a proud inheritance of our national life. The nation is beholden to all of them, Prof. Saha included, for this.

It is to be hoped that the contributions of Prof. Saha as a great scientist, teacher and public worker would be remembered gratefully by the present generation and those who would follow hereafter.

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REMINISCENCES ON MEGHNAD SAHA

HIRENDRA NATH MUKHERJEE

ABSTRACT*

In pre-independence days, when we were in anguish under an alien rule, we felt proud that we had amongst us eminent persons like Rabindra Nath Tagore, Abanindra Nath Tagore, Jadunath Sarkar, Jagadish Chandra Bose, Prafulla Chandra Ray, Satyendra Nath Bose and Meghnad Saha. Thanks to the opportunities created by Ashutosh Mukherjee in the University of Calcutta, Meghnad Saha was one of the few who secured for our country a top position in the research map of the world.

Inspired by his illustrious guru, Dr. P. C. Ray, M. N. Saha had great love and respect for the mother-land. I first met him—when I was hardly fifteen years old—in the office of the newspaper, 'Dainik Basumati' at 166, Bowbazar Street (now B. B. Ganguly Street), Calcutta, which I frequently visited along with my grandfather, one of the prominent journalists, in those days. Dr. Ray had brought Saha there in connection with some work of the Relief Committee which had been formed to mitigate the sufferings of the flood-stricken people in North Bengal and which had, besides Ray and Saha, Subhas Chandra Bose (later 'Netaji') in the leading role. Dr. Ray introduced Saha to the editor and staff of the newspaper by saying, 'Here is a greater man than Dr. Ray'.

In the forties, when fascism was on its onward march and the whole world was in turmoil, I visited Dr. M. N. Saha at the Science College from time to time in connection with our political work—for example, to request him to preside over a meeting or to have his signature on an appeal. We were then engaged in forming a Society of the Friends of the Soviet Union, and his sympathy and support were of great help to us. He visited the USSR in 1945 just after the Second World War, and on his return delivered a lecture at 46, Dharamtola Street (now Lenin Sarani), which I covered in our journal. It was not that he was in complete agree-

* The talk delivered in Bengali by Prof. Hirendra Nath Mukherjee, a renowned political figure and an ex-M. P., follows. An extended abstract of the talk is presented here in English.

ment with the Communist Party or the RSP but like communists he was in favour of an exploitationless society, i.e., a classless society.

Dr. Saha was well aware of various aspects of planning under experimentation in the Soviet Union. He was an important member of the National Planning Committee under the Chairmanship of Jawaharlal Nehru, which was formed in 1938 by the-then Congress President, Subhas Chandra Bose. Dr. Saha was in constant touch with the planning in our country. In fact, he collapsed and died on his way to the office of the Planning Commission which was then situated in an outhouse of the Rastrapati Bhawan in Delhi.

In the context of planning I recall an incident at a meeting in Calcutta addressed by Subhas Chandra Bose as the Congress President. Meghnad Saha asked him about the method he would like to adopt to ensure the advancement of our poverty-stricken backward country. In reply Bose advocated 'forced march'. Bourgeois democracy is good but one should remember the hard struggle people had to wage for achieving it. Morever, bourgeois democracy has its own limitations. For progress of our country some amount of social discipline and working of the people in unison is essential. This reminds me of Lenin's saying, 'There is nothing more authoritarian than revolution'. Misuse of the authority should be deplored but revolution must have authority to ensure progress. Saha was of the same view as Bose in regard to 'forced march', and this coincided with the view-point of the communists. This is why Saha maintained good relations with us, and we could work together till his death in 1956.

As Dr. Saha was elected as a Member of the Parliament with the support of the RSP, he proposed, on behalf of the Leftists, the name of Prof. K. T. Shah as the President of India, and we all supported him. But Dr. Rajendra Prasad, the Congress candidate, won the contest and became the first President of India. I vividly remember an event in the Parliament, which is worth mentioning. Exasperated by a speach made by Saha, Prime Minister Nehru, who normally behaved gently, burst out, saying that Dr. Saha should not have been involved in worthless affairs instead of keeping himself engaged in scientific activities. Dr. Saha retorted later, 'Scientific persons like Meghnad Saha would be remembered long after the politicians reigning today are totally forgotten.'

Dr. Saha had a liking for dynamic persons. He had great respect for Stalin. He used to tell us that the promises made by the Soviet Union in respect of India would surely be kept because Stalin had wished to maintain good relations with India. Saha himself was also a dynamic person. He did his best to apply science to the benefit of our society and to keep the planning in the right track. Many good reports on planning were published but nothing much has yet been implemented. The exhaustive work he carried out in planning the water resources of our country has been discussed in the present seminar. A number of decades have passed since then, but even drinking water is scarce in many villages of our country. In meetings organised to celebrate the 125th Birthday of Rabindra Nath Tagore the problem of water scarcity in villages was discussed, when I stated that a definite target to solve the problem ought to be undertaken so that it could be fulfilled in time. But nothing substantial has yet been achieved. In an essay entitled 'Crisis in Civilization' Rabindra Nath spoke of our civilization being engulfed in darkness. Evidently the phase of darkness is not yet over.

That Dr. Saha had a soft corner for his students was apparent to me from the way Dr. D. S. Kothari, an eminent scientist and a pupil of his, spoke of him with great regard. Saha had also a soft corner for the downtrodden people at large and wanted to make them science-minded in order that they could get out of the entanglements of superstitions and the hypocracy that thrives on them.

I am glad that the Saha Institute of Nuclear Physics, Calcutta University and Indian Association for the Cultivation of Science have organised this Seminar through a common Organising Committee for celebrating the Birth Centenary of Acharya Meghnad Saha. I understand that they have also some other programmes for the commemoration. But the centenary should have been celebrated all throughout the country. However, I thank the organisers of the Seminar, which would be of real significance if we follow, at least to some extent, the noble example set by Acharya Saha.

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মেঘনাদ সাহা স্মরণে

হীরেন্দ্রনাথ মুখোপাধ্যায়

আচার্য মেঘনাদ সাহার জন্মশতবার্ষিকী উপলক্ষে আজ যেখানে আলোচনার আয়োজন হয়েছে, স্থান-মাহাত্ম্য আছে সেই জায়গার — তাঁর বহু স্মৃতি বিজড়িত এই বক্তৃতা-কক্ষ। এখানে বসে তাঁকে আমরা স্মরণ করছি ; তাঁর গুণাঙ্কিত যে চরিত্র, তাঁর দীপ্তিমান যে কীর্তি, তাকে স্মরণ করছি।

তিনি চলে যাবার পর আমাদের জীবনে যে শূন্যতা এসেছিল, সে শূন্যতা আজও পূরণ হয় নি। সেই শূন্যতার কথা স্মরণ করে আমরা সকলেই যেন আবার মেঘনাদ সাহার অনুপস্থিতির যে বেদনা, তা অনুভব করছি। আমি বিজ্ঞানের ছাত্র নই, তবে নানা সুবাদে ডঃ সাহার জীবনের শেষ দিকে — অন্তত 15/16 বছর বা আরো কিছু বেশি, তাঁর সঙ্গে মাঝে মাঝে যোগাযোগের সুযোগ আমার হয়েছিল এবং সেজন্যেই তাঁর সম্বন্ধে কিছু বলবার অধিকার হয়তো বা আমি অর্জন করেছি। সামাজিক ও অর্থনৈতিক দিক থেকে তিনি আমাদের যা দিয়েছেন, তা নিয়ে বহু আলোচনা হতে পারে, তবে আমি আলোচনা করবো প্রধানত ব্যক্তিগত অভিজ্ঞতার ভিত্তিতে।

আমার মনে পড়ে আমার ছেলেবেলাকার কথা, যখন আমরা গর্ব করতাম ডঃ সাহার মতন ব্যক্তিকে নিয়ে। আপনাদের মধ্যে যাঁরা স্বাধীনতার পরে জন্মেছেন, তাঁরা পরাধীনতার গ্লানির কথা বুঝবেন না। পরাধীনতার যে বেদনা, পরাধীন দেশবাসী হয়ে থাকবার যে যন্ত্রণা, তাকে শুধু বিড়ম্বনা বললে মানায় না, অসম্ভব সেই কষ্ট। এই যে মর্যাদাহীন অবমাননা— যাঁরা অপেক্ষাকৃত বয়স্ক, যাঁরা প্রাক-স্বাধীনতার অনুভূতি স্মরণ করতে পারেন, তাঁদের মনে পড়বে সেই অনুভূতির কথা। যাঁদের স্মরণে নেই সেই কথা, তাঁরা জানবেন না পরাধীনতার বেদনা। তাঁরা বুঝবেন না যে, যতই অপূর্ণ হোক এই স্বাধীনতা আমাদের কাছে, যতই বিপন্ন হোক না কেন — বিশেষ করে আজকের দিনে — ভারতবর্ষের সার্বভৌমত্ব এবং তার স্বাধীনতা, তবুও 1947 সালে ক্ষমতা হস্তান্তরের মধ্য দিয়ে, দেশ বিভাগের দণ্ড দিয়ে, মূল্য দিয়ে আমরা দেশকে নিয়েছিলাম ইংরেজদের হাত থেকে ; 'Transfer of power' বা 'ক্ষমতা হস্তান্তর', এই কথা তারা ব্যবহার করেছিল। এই স্বাধীনতার ভিতর যত কিছু গলদ, যত কিছু অভাব থাকুক না কেন, তবুও অন্তত আমরা স্বাধীন। অন্তত কতকগুলো দিক থেকে — রাজনৈতিক দিক থেকে, নানান অনুষ্ঠানের দিক থেকে— আমরা সমস্ত জগৎ জুড়ে মাথা তুলে দাঁড়াতে পারি। পরাধীনতার যে বেদনা, সেই বেদনার দৈনন্দিন অভিজ্ঞতার যন্ত্রণা থেকে আমরা রেহাই পেয়েছি।

কিন্তু আমাদের ছেলেবেলায় তো এরকম ছিল না। তখন আমরা সেই সব প্রখ্যাত লোকেদের কথা ভাবতাম, ভেবে গর্ববোধ করতাম, যাঁরা জ্ঞান-বিজ্ঞানের জগতে পরাধীন ভারতবর্ষের মান তুলে ধরেছিলেন। রবীন্দ্রনাথ ঠাকুর, অবনীন্দ্রনাথ ঠাকুর, যদুনাথ সরকার, জগদীশচন্দ্র বসু, প্রফুল্লচন্দ্র রায়, সত্যেন্দ্রনাথ বসু, মেঘনাদ সাহা, জ্ঞানচন্দ্র ঘোষ— যশস্বী লোকের সংখ্যা তো তখন

অধ্যাপক হীরেন্দ্রনাথ মুখোপাধ্যায় প্রখ্যাত রাজনীতিবিদ ও লোকসভার প্রাক্তন সদস্য।

নিতান্ত কম ছিল না ! আজকের দিনে আমাদের মধ্যে এরকম দু'একটি মহৎ ব্যক্তির সন্ধান পাওয়াও কঠিন হয়ে দাঁড়ায়। আশুতোষ মুখোপাধ্যায়ের কাজের বিচার নানা ভাবে হতে পারে, তাঁর সম্পর্কে সমালোচনাও অনেক হতে পারে কিন্তু এ বিষয়ে কোন সন্দেহ নেই যে, কলকাতা বিশ্ববিদ্যালয়ে বিভিন্ন বিভাগে গবেষণার প্রবর্তন করে তিনি ভারতবর্ষের মর্যাদা অনেকাংশে পুনঃপ্রতিষ্ঠা করেছিলেন। তাঁর আমলে জগতের গবেষণার মানচিত্রে ভারতবর্ষকে প্রতিষ্ঠিত করবার ক্ষেত্রে প্রধান ভুমিকা যাঁরা নিয়েছিলেন, তাঁদের মধ্যে অন্যতম হলেন আচার্য মেঘনাদ সাহা।

সামাজিক অর্থনৈতিক দিক থেকে মেঘনাদ সাহার যে গুরুত্বপূর্ণ অবদান, তার পিছনে ছিল তাঁর দেশাভিমান, দেশ সম্পর্কে তাঁর আত্মমর্যাদাবোধ। একটা ইডিয়ম (idiom) খুব চালু ছিল তখনকার দিনের ভাষায়— 'স্বদেশী করা'। বিদ্যার্জনের মধ্যে নিমগ্ন থেকেও মেঘনাদ সাহা স্বদেশী করতেন, সত্যেন বসু স্বদেশী করতেন। তাঁদের অল্প বয়সে স্বদেশী আন্দোলনের দু' একটা পর্যায় ছিল, সেই সব পর্যায়ে উল্লেখযোগ্য ভূমিকায় যাঁরা নেমেছেন, সে সব মানুষের কারো কারো সঙ্গে এঁদের যোগাযোগ ছিল। গবেষণায় রত অবস্থাতেও এঁদের মধ্যে ছিল দেশাভিমান। সত্যেন বসু বিশ্ববিশ্রুত আইনস্টাইনের সঙ্গে পত্রালাপ করছেন, তখনো তিনি সত্যেন বসু, এম এস-সি, কলকাতা— ডিগ্রীর জন্যে কোন বিদেশী বিশ্ববিদ্যালয়ের দরজায় ধর্ণা দিতে যান নি। মেঘনাদ সাহাও ডি এস-সি, কলকাতা—প্রি-ডক্টরেট ফেলোশিপ হয়তো অনেক জায়গায় পেতে পারতেন কিন্তু তিনি ডিগ্রীর জন্যে কোথাও যান নি। এঁরা স্বদেশী করতেন নিজস্ব ধরনে। তখন আমাদের পরাধীন দেশের মানুষ প্রচন্ড দুর্দশার মধ্যে রয়েছে— সেই সব মানুষকে আপনজন ভাবতেন বলেই স্বদেশী করতেন। এঁরা ছিলেন আচার্য প্রফুল্লচন্দ্র রায়ের ছাত্র—তাঁর কথা বলতে গেলে তো মহাভারত লিখতে হয়। দেশের জন্যে তাঁর কত চিন্তা—দেশের সাধারণ মানুষের অবস্থা ভাল করে তোলা, নতুন জীবন এনে দেওয়া, বাঙ্গালীর মস্তিষ্কের অপব্যবহার বন্ধ করা, বাঙ্গালীকে নতুন করে গড়ে তোলা। 'রেখেছ বাঙ্গালী করে, মানুষ করো নি'— রবীন্দ্রনাথের এই যে খেদ, সেই খেদকে দূর করবার চেষ্টায় নেমেছিলেন আচার্য প্রফুল্লচন্দ্র। তাঁর মন্ত্রশিষ্য হিসাবে যে ক'জন এগিয়ে এসেছিলেন, তাঁদের মধ্যে অন্যতম ছিলেন ডঃ মেঘনাদ সাহা।

আমার মনে পড়ছে, প্রথম যখন আমি তাঁকে দেখি, তখন আমার বয়স বেশি নয়— 15/16 বছরও হয়নি তখন। আমি আমার পিতামহের সঙ্গে প্রায় প্রতিদিনই 'দৈনিক বসুমতীর' দপ্তরে যেতাম। ঐ দপ্তর তখন ছিল, এখনো আছে, 166 নং বৌবাজার স্ট্রীটে (বর্তমানে বিপিন বিহারী গাঙ্গুলি স্ট্রীট) আমার পিতামহ তাঁর প্রজন্মের প্রধান সাংবাদিকদের মধ্যে একজন ছিলেন। একদিন ডঃ প্রফুল্লচন্দ্র রায় বসুমতীর দপ্তরে একজনকে নিয়ে এলেন, পরিচয় দিলেন বসুমতীর সম্পাদক ও সাংবাদিকদের কাছে ঃ 'এই দেখ, here is a greater man than Dr. Ray', এই কথা বলেছিলেন আমার এখনো মনে আছে। ইংরেজিতে যাকে বলে cynical, সাংবাদিকরা সাধারণত সেইরকম একটু হয়ে থাকেন। যাঁরা রাজনীতি করেন, তাঁদের সম্বন্ধে সাংবাদিকদের এত খোঁজ-খবর রাখতে হয় যে, তাঁরা কারুর সম্পর্কেই খুব একটা উচ্চ ধারণা রাখেন না বা রাখতে পারেন না। যে ডঃ রায়কে সাংবাদিকরা শুধু আচার্যদেব বলে খাতির করতেন, তাঁর কথাতেও তাঁরা পরে একটু হাসি-ঠাট্টা করলেন ঃ 'শুনলেন, উনি বললেন যে, here is some one who is greater than Dr. Ray, অর্থাৎ Dr. Ray নিজেও great man, he is greater than Dr. Ray. সাংবাদিকরা যে ঠাট্টাই করুন, ডঃ রায় তো 'great man' বটেই। আমাদের মাপকাঠি অনুযায়ী মেঘনাদ সাহাও একজন 'great man', একজন বড় মাপের মানুষ, এ বিষয়ে সন্দেহ নেই। তাঁরা কিজন্যে বসুমতীর দপ্তরে

এসেছিলেন ? —উত্তর বাংলায় প্রচণ্ড বন্যা হচ্ছে, আর্ত মানুষদের সাহায্যের জন্যে তৈরি হয়েছে 'সংকট ত্রাণ সমিতি', সেই সমিতির কাজে। এই সমিতির সঙ্গে আচার্য প্রফুল্লচন্দ্র স্বাভাবিক ভাবে যুক্ত ছিলেন। সুভাষচন্দ্র বসু তখন যুবক — 'নেতাজী' হবার তাঁর তখনো সময় আসে নি — তিনিও ঐ সমিতির সঙ্গে যুক্ত ছিলেন। মেঘনাদ সাহাও যোগ দিয়েছিলেন এই সমিতির কাজে। দেশের সেবাকে জীবনের অঙ্গীভূত করবার তাঁর যে বাসনা, পরবর্তী কালে আমরা নানা ভাবে তার পরিচয় পেয়েছি।

চল্লিশের দশকে ভয়াবহ পরিস্থিতি ঘটেছে, দেশে দুর্দৈব চলেছে, সোভিয়েত ইউনিয়ন আক্রান্ত হয়েছে, ফ্যাসিজিমের অগ্রগতি অব্যাহত, চীন বিধ্বস্ত হয়ে গেছে ফ্যাসিস্ত জাপানের আক্রমণে। রবীন্দ্রনাথ যখন 1941 সালে জীবনান্তের ঠিক পূর্বে 'সভ্যতার সংকট' বলে ঘোষণা জানাচ্ছেন, সেই রকম সময় থেকেই মাঝে মাঝে আমাদের রাজনৈতিক কাজের একটা অনুসঙ্গ হিসাবে ডঃ সাহার কাছে যেতে হত। হয়তো তাঁর আশীর্বাদ চাই কোন একটা প্রচেষ্টায়, হয়তো তাঁর সাক্ষর চাই কোন একটা আবেদনে, হয়তো তাঁর উপস্থিতি চাই কোন একটা সভায় — এই সব কারণে তাঁর কাছে আমাদের যাতায়াত এই সায়েন্স কলেজে। সেই যোগাযোগে নানা বিষয়ে তাঁর সঙ্গে আমাদের আলোচনা হত। আমরা তখন সোভিয়েত সুহৃদ সমিতির পত্রিকার ব্যাপারে অগ্রণী হবার চেষ্টা করছি বলে নানা দিক থেকে বহুজনকে জানবার চেষ্টা করেছিলাম, এঁদের মধ্যে আচার্য মেঘনাদ সাহা ছিলেন একটি বিশিষ্ট স্তম্ভ। দ্বিতীয় বিশ্বযুদ্ধের অব্যবহিত পরে 1945 সালে তিনি সোভিয়েত ইউনিয়নে গেছেন, ফিরে এসে 46নং ধর্মতলা স্ট্রীটে (বর্তমানে লেনিন সরণি) সোভিয়েত সুহৃদ সমিতিতে বক্তৃতা করেছেন। তাতে নোট নিয়ে আমি তার রিপোর্ট ছাপিয়েছিলাম আমাদের কাগজে। আজ তার কোন হদিস পাই না, আমাদের কাগজপত্র পুলিশী অত্যাচারে এবং আমাদের অবহেলায় ও নানা কারণে হারিয়ে গেছে — আমাদের দেশে প্রায় কোন কিছুই ভাল ভাবে রাখা হয় না বলে হারিয়ে যায়। ডঃ সাহা সব বিষয়ে যে আমাদের সঙ্গে একমত ছিলেন, তা নয় ; কম্যুনিস্ট পার্টি বা আর এস পি-এর সঙ্গে পরিপূর্ণ ভাবে তাঁর মতের মিল ছিল না। কিন্তু আমরা যে শোষণবিহীন অর্থাৎ শ্রেণীহীন সমাজ প্রতিষ্ঠা করবার চেষ্টা করছি, সেই চেষ্টার সঙ্গে তিনি নিজেকে যুক্ত করেছিলেন।

তাঁর মধ্যে ছিল অজস্র জিজ্ঞাসা, সর্ববিধ উপায়ে জ্ঞান-বিজ্ঞানকে আত্মস্থ করবার অদম্য ইচ্ছা। সোভিয়েত ইউনিয়নকে গড়বার জন্যে তখন প্রচণ্ড উন্মাদনা চলেছে, তা নিয়ে স্বভাবতই তাঁর আগ্রহ হয়েছিল। প্ল্যান, পরিকল্পনা, যোজনা, যাই বলি না কেন, সোভিয়েত ইউনিয়নে নানারকম পরীক্ষা-নিরীক্ষার মধ্য দিয়ে এই বিষয়ে যে সব ধারণার প্রবর্তন হচ্ছিল, ডঃ সাহা সেগুলি সম্বন্ধে অবহিত ছিলেন। মেঘনাদ সাহা, সত্যেন্দ্রনাথ বসু, প্রশান্তচন্দ্র মহলানবিশ, এই যে তিনজন স্বনামধন্য বিজ্ঞানীর জন্মশতবার্ষিকী খুব কাছাকাছি সময়ে পালিত হচ্ছে, আমাদের দেশে পরিকল্পনার শুরুতেই এঁরা অত্যন্ত আশাবাদী ছিলেন। 1938 সালে কংগ্রেসের সভাপতি সুভাষচন্দ্র বসু যখন জাতীয় পরিকল্পনা কমিটি গঠন করলেন, জওহরলাল নেহেরু হলেন তার সভাপতি। সেই কমিটির একজন মুখ্য সদস্য হলেন মেঘনাদ সাহা। জীবনের শেষ দিন পর্যন্ত পরিকল্পনার কাজে তাঁর আগ্রহ ও উৎসাহ ছিল।

যখন দিল্লীতে তাঁর আকস্মিক মৃত্যু হয়, তখন আমি কলকাতায়। তাঁর মৃতদেহ আনবার জন্যে যাঁরা গিয়েছিলেন, আমি তাঁদের মধ্যে ছিলাম। কিভাবে তাঁর মৃত্যু হয় ? জীবনের শেষ মুহূর্ত

পর্যন্ত তিনি দেশের কাজে, পরিকল্পনার কাজে ব্যস্ত ছিলেন। রাষ্ট্রপতি-ভবনে যাবার পাথরের একটা উঁচু রাস্তা আছে। সেই রাস্তা দিয়ে যখন তিনি যাচ্ছেন, হঠাৎ একটা স্ট্রোক বা ঐ ধরনের কিছু হয়েছিল। তখন যোজনা-ভবন তৈরি হয় নি, এত হাজার-হাজার কোটি টাকা খরচ করে সব কিছু এত ফলাও করে দেখানো হত না। তখন রাষ্ট্রপতি-ভবনের মধ্যে একটা আউট-হাউসের একটি ঘরে পরিকল্পনা কমিশনের অফিস ছিল। ডঃ সাহা যাচ্ছিলেন সেই অফিসে সময় মত পৌঁছতে।

পরিকল্পনার কথা বলতে গিয়ে আমার মনে পড়ছে 1938 সালে সুভাষবাবু যখন কংগ্রেসের সভাপতি, তখন তাঁকে নিয়ে একটা সভা হয়েছিল, বোধহয় আশুতোষ হল বা ঐ রকম কোন একটা জায়গায়। জাতীয় পরিকল্পনা সম্বন্ধে সুভাষবাবু সেখানে বললেন। ডঃ মেঘনাদ সাহা তাঁকে প্রশ্ন করেছিলেন, 'আমাদের মতন অনুন্নত দেশে সাধারণ মানুষের জীবনের মানকে যথাযোগ্য ভাবে উন্নত করতে হলে কেমন ভাবে এগতে হবে বলে আপনি মনে করেন?' তখন সুভাষবাবু বলেছিলেন, 'আমাদের মতন দেশে যেখানে দুর্দশায় আকীর্ণ মানুষ মৃতপ্রায় হয়ে কর্ম করছে, সেখানে এগতে হলে there has to be a forced march, তা আমরা যতই গণতন্ত্রের কথা বলি না কেন।' বুর্জোয়া গণতন্ত্র অত্যন্ত দামী জিনিষ, কোন সন্দেহ নেই, তবে তার পরেও অনেক ভাল জিনিষ হয়। তাছাড়া বুর্জোয়া গণতন্ত্রকে জয় করে আনবার জন্যে জনসাধারণকে সংগ্রাম করতে হয়েছে কত শত বছর ধরে, সেটা ভুলে যাওয়া যায় না কিছুতেই। আবার বুর্জোয়া গণতন্ত্র যদি শুধুই নিছক বুর্জোয়া গণতন্ত্র হয়ে থাকে, তবে তার সীমাবদ্ধতা তো কিছুতেই অতিক্রান্ত হবার নয়। সেজন্যেই সুভাষবাবু বলেছিলেন যে, আমাদের মতন দেশে — যেখানে কোটি কোটি মানুষ অভাব এবং বুভুক্ষার মধ্যে চরম দুর্দশায় বাস করছে, যেখানে স্বাভাবিক ভাবে অগ্রসর হবার উপায় নেই, সেখানে জোর করে এগিয়ে যেতে হবে, এজন্যেই forced march-এর কথা। মনে পড়ে লেনিনের কথা : 'There is nothing more authoritarian than revolution' ; যদি বিপ্লব হয়, তাহলে বিপ্লবকে কর্তৃত্ব দিতে হবে। কর্তৃত্ব ব্যবহার করতে হবে। কর্তৃত্ব ব্যবহারে যদি কোন বিষাক্ত ফল হয়, তবে সেটা অন্যায় হবে। কর্তৃত্ব ব্যবহার করতে গিয়ে যদি অত্যাচার হয়, অন্যায় হয়, তবে তার প্রতিফল পরে পেতে হবে। কিন্তু কর্তৃত্ব ব্যবহার করতে হবে, কিছু পরিমাণে শৃঙ্খলা রাখতেই হবে। সামাজিক নিয়ন্ত্রণ, সামাজিক শৃঙ্খলা, সবাই মিলে একসঙ্গে এক ছন্দে কাজ করা — এইভাবে যে forced march, এ বিষয়ে লেনিনের সঙ্গে সুভাষবাবুর মতের মিল ছিল। যাঁরা কম্যুনিস্ট বা কম্যুনিস্টদের কাছাকাছি এ সব চিন্তা করেন, তাঁদের সঙ্গে ডঃ মেঘনাদ সাহার চিন্তার মিল ছিল। এ কারণেই লোকসভায় তাঁর সঙ্গে আমরা একসঙ্গে কাজ করতে নেমেছিলাম। কতকাল তাঁর সঙ্গে একত্র কাজ করেছি। উনি আমাদের কথা শুনতেন, আমাকে বলেছিলেন, 'তোমার কথা মন্ত্রমুগ্ধ হয়ে সবাই শুনবে'। ওঁর মত লোকের কাছ থেকে সেই কথা কত ভাল লেগেছিল — আমি তো ওঁর ছাত্র নই, কিছুই নই, ওঁর তুলনায় প্রায় কিছুই জানি না, তবু আমাকে বলেছিলেন ঐ কথা।

তিনি যে বিষয়ে বিশ্ববিশ্রুত বিজ্ঞানী, সে বিষয়ের সঙ্গে আমাদের কোন সম্পর্ক নেই, তবু তিনি আমাদের স্নেহ করতেন, আমাদের সম্পর্কে তাঁর প্রীতি ও উৎসাহ ছিল কারণ তিনি জানতেন আমাদের সকলকে একসঙ্গে এগতে হবে। যেহেতু তিনি আর এস পি-এর সমর্থনে লোকসভায় নির্বাচিত হয়েছিলেন, সেজন্যে রাষ্ট্রপতি পদের জন্যে বামপন্থীদের প্রার্থী অধ্যাপক কে টি শাহ্-এর নাম প্রস্তাব করলেন, আমরা সকলে সমর্থন করলাম। কংগ্রেসের পক্ষ থেকে ডঃ রাজেন্দ্রপ্রসাদের নাম প্রস্তাবিত হল এবং তিনিই ভারতের প্রথম রাষ্ট্রপতি হিসাবে নির্বাচিত হলেন। লোকসভায়

একটা ঘটনার কথা আমার বিশেষ করে মনে আছে। জওহরলাল নেহরু ডঃ সাহা সম্বন্ধে কটু মন্তব্য করেছিলেন, বলেছিলেন যে, বিজ্ঞান ছেড়ে তিনি এখন রাজনীতির বাজে আলোচনায় জড়িয়ে পড়েছেন। নেহরু মোটের উপর সভ্য ব্যক্তি ছিলেন, সৌজন্য থেকে সহজে বিচ্যুত হতেন না, বোধহয় ডঃ সাহার মতন বিশ্ববিখ্যাত ব্যক্তি তাঁর বিপক্ষে কথা বলায় খুব বেশি বিরক্ত হয়ে ঐ মন্তব্য করেছিলেন। তবে তিনি ছিলেন একজন প্রতিষ্ঠিত ব্যক্তি, তাঁর ঐরকম মন্তব্য করা উচিত হয় নি। যা হোক, ডঃ সাহা উত্তরে বলেছিলেন যে, অনেক রাজনীতিবিদদের কথাই লোকে মনে রাখবে না কিন্তু মেঘনাদ সাহার মতন বিজ্ঞানীর কথা পৃথিবীর অনেক লোকই মনে রাখবে। গর্ব করে তিনি এ কথা বলতে পেরেছিলেন কারণ এ কথা বলবার ক্ষমতা ও অধিকার তাঁর ছিল।

করিৎকর্মা লোকেদের প্রতি ডঃ সাহার বেশ একটু সমীহ ছিল। স্ট্যালিনকে উনি খুব সমীহ করতেন। ভারতকে দেওয়া সোভিয়েত ইউনিয়নের প্রতিশ্রুতি সম্বন্ধে আলোচনা হলে উনি আমাদের বলতেন, 'আমি জানি এ প্রতিশ্রুতি ওরা রাখবেই কারণ স্ট্যালিনের নিশ্চয় হুকুম হয়েছে যে, ভারতের সঙ্গে ওদের সদ্ভাব এখন দরকার।' ডঃ সাহা নিজেও সক্রিয় ছিলেন, কত কর্মসূচী রচনা করেছেন। তখনকার দিনে জাতীয় পরিকল্পনা কমিটি থেকে যে সব রিপোর্ট বেরিয়েছে, এম এন রায়ের পক্ষ থেকে 'People's Planning' নামে যে সব রিপোর্ট বেরিয়েছে, সেগুলিতে বহু রকম কর্মধারার কথা আলোচিত হয়েছে কিন্তু আজ পর্যন্ত কিছুই প্রায় রূপায়িত হয় নি।

ডঃ সাহা নদীর বিষয়ে, জলের বিষয়ে কত পরিকল্পনা করেছিলেন, সে সব তো আজ আলোচিত হল। কিন্তু আমাদের দেশে এখনো অনুন্নত বলে চিহ্নিত এমন অনেক জায়গা আছে — যেমন বিহারে চম্পারণ, পশ্চিমবঙ্গে বাঁকুড়া ও পুরুলিয়া — যেখানে পানীয় জল পর্যন্ত ঠিক মতন পাওয়া যায় না। রবীন্দ্রনাথ ঠাকুরের 'সভ্যতার সংকটের' কথা মনে পড়ে। তিনি এরকম বলেছিলেন, 'ইংরেজ শাসকদের কোন রকম সার্টিফিকেট দেবার প্রবৃত্তি আমার নেই কারণ ইংরেজ শাসন 200 বছরে কি করেছে, তা আমি জানি। একসময়ে আমি ইংরেজদের অনুরাগী ছিলাম, এখনো পর্যন্ত আমি ব্যক্তিগত ভাবে বহু ইংরেজকে ভক্তি-শ্রদ্ধা করি কিন্তু ইংরেজদের উপর সাধারণ ভাবে আমার সমস্ত শ্রদ্ধা-ভরসা চলে গেছে কারণ 200 বছরে শিক্ষা ও জনস্বাস্থ্যের দিক থেকে আমাদের দেশকে যে জায়গায় তারা টেনে এনেছে, তা আমি ক্ষমা করতে পারি না। আমাদের দেশে এমন অনেক এলাকা আছে, যেখানে মায়েদের প্রায়-অখাদ্য তুলে দিতে হয় ছেলেমেয়েদের মুখে, পানীয় জল বয়ে আনতে হয় বহু দূর থেকে।' ক'বছর আগে যখন রবীন্দ্রনাথের 125তম জন্মবার্ষিকী হল, তখন পশ্চিমবঙ্গের মুখ্যমন্ত্রী সভা ডাকলেন কর্মসূচী স্থির করবার জন্যে। আরো কত সভা-সমিতি হল, আমাকেও সেখানে যেতে হয়েছে। আমি বলেছি, জল সরবরাহের জন্যে একটা নির্দিষ্ট টার্গেট নিতে হবে। হাজারটা টার্গেট নিলে কোনটাই হবে না। এখনো পর্যন্ত তেমন কোন কাজ হল না। গান্ধীজীর মৃত্যুর পর সভা হল, জগজীবন রাম মন্ত্রী হিসাবে বললেন, অনেক গ্রামে এখনো পায়খানার ব্যবস্থা নেই, মাথায় করে মল বয়ে নিয়ে যেতে হয়, এটা বন্ধ করতে হবে। কিছু কিছু চেষ্টা হল কিন্তু সমস্যার সম্পূর্ণ সমাধান আজ পর্যন্ত হয় নি। কলকাতাতেও তো কত সমস্যা — সে সবের কি তেমন সমাধান হচ্ছে ? আমরা রবীন্দ্রনাথকে নিয়ে গর্ব করি, সত্যজিৎ রায়কে নিয়ে গর্ব করি, কিন্তু আমরা বেশির ভাগই কর্মবিমুখ, কাজ করতে চাই না। আচার্য মেঘনাদ সাহার দৃষ্টান্ত থেকে তাহলে আমরা কী শিক্ষা পেলাম ?

ডঃ সাহা যে পরিপূর্ণ মানুষ ছিলেন, তার দৃষ্টান্ত হিসেবে ছাত্রদের প্রতি তাঁর দরদের কথা

বলতে পারি। তাঁর এক সময়ের ছাত্র, রক্ষণ মন্ত্রকের মুখ্য বৈজ্ঞানিক উপদেষ্টা, ডঃ ডি এস কোঠারিকে তিনি নিজে আমার বাড়িতে নিয়ে এসে পরিচয় করিয়ে দিয়েছিলেন, বলেছিলেন, 'এ আমার সবচেয়ে ভাল ছাত্র'। কোঠারির সঙ্গে পরে আমার অন্তরঙ্গ বন্ধুত্ব হয়েছিল। ডঃ সাহা সম্বন্ধে আলোচনা হলে কোঠারি হাত তুলে নমস্কার করতেন, নিজেকে উজাড় করে বলতেন তাঁর কথা। ডঃ সাহা যে কতখানি ছাত্রবৎসল ছিলেন, তাঁর কাছ থেকে তা জেনেছিলাম। আচার্য প্রফুল্লচন্দ্র রায়কে দেখেছি, তাঁর হাতের চাপড় খেয়েছি পিঠে, কিন্তু তাঁকে তত ভাল করে জানতাম না। তবে তাঁর শিষ্য-প্রশিষ্যদের কাছ থেকে জানতে পেরেছি — প্রকৃত ছাত্র-দরদী বলতে যা বোঝায়, তিনি ছিলেন তাই। মেঘনাদ সাহা হয়তো ততটা ছিলেন না, কিন্তু কোঠারির সঙ্গে তাঁর যে সম্পর্ক দেখেছি, তাতে তাঁকেও নিঃসংশয়ে যথেষ্ট ছাত্রবৎসল বলা চলে।

মেঘনাদ সাহা পরিপূর্ণ মানুষ ছিলেন বলে, দেশের মানুষের প্রতি তাঁর দরদ ছিল বলে তিনি দেশে বিজ্ঞানমনস্কতা আনতে চেয়েছিলেন। বিজ্ঞানমনস্কতা তৈরি করা চ্যালেঞ্জের কাজ ; এটা ঘরের কাজ নয়, অফিসের কাজ নয়, পারমাণবিক বিজ্ঞানের কাজ নয়, উচ্চতর গণিতের কাজ নয়, এর সঙ্গে সব কাজ জড়িত — এটা তিনি এড়িয়ে যেতে পারতেন কিন্তু এতে তিনি আত্মনিয়োগ করেছিলেন। বিজ্ঞানের সাধনা, জ্ঞানের পিপাসা, জানবার ইচ্ছা — এ সব তিনি ছড়িয়ে দিতে চাইতেন। যত জানবো, তত বুঝবো। জানলে হেতু জানতে পারবো, কার্যকারণ সম্পর্ক জানতে পারবো। বিজ্ঞান আপনা আপনি আমাদের মনে প্রতিষ্ঠিত হবে। তখন নানারকম বুজরুকি, নানারকম ভাঁওতা — যা এখনো আমাদের দেশে প্রচণ্ড মাত্রায় রয়েছে — সে সব আর চলবে না।

সাহা ইনস্টিট্যুট অব নিউক্লিয়ার ফিজিক্স, কলকাতা বিশ্ববিদ্যালয় এবং ইণ্ডিয়ান অ্যাসোসিয়েশন ফর দ্য কাল্টিভেশন অব সায়েন্স-এর তরফ থেকে যুক্ত ভাবে আচার্য সাহার জন্মশতবার্ষিকী উপলক্ষে অনুষ্ঠান হচ্ছে, আরো হয়তো কিছু হবে কিন্তু সমস্ত দেশ জুড়ে তো এটা সাড়ম্বরে পালিত হওয়া উচিত। আজকাল মানুষের মন কোথায় যেন হারিয়ে গেছে, মানুষের হৃদয় বলে বস্তু যেন নেই, মানুষের কলজেটা কোথায়, তার কোন ঠিকানা নেই। এরকম একটা ভয়ঙ্কর রাহুর গ্রাসের মধ্য দিয়ে চলছে আমাদের সভ্যতা। 1941 সালে 'সভ্যতার সংকটে' রবীন্দ্রনাথ এই 'রাহুগ্রস্ত সভ্যতার' কথা বলেছিলেন, সেই রাহুর গ্রাস থেকে সভ্যতার এখনো মুক্তি হয় নি।

মেঘনাদ সাহাকে স্মরণ করবার জন্যে আপনারা যে আলোচনা-চক্রের আয়োজন করেছেন, সেজন্য আপনাদের ধন্যবাদ জানাই। তাঁকে স্মরণ করলে কৃতার্থ আমরা কিছু পরিমাণে হব, তবে স্মরণ করে তাঁকে যদি আমরা অন্তত কিছু পরিমাণে অনুসরণ করবার চেষ্টা করি, তাহলেই এই ধরনের অনুষ্ঠান সত্যিকারের সার্থক হবে।

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APPENDICES

APPENDIX I

BIO-DATA OF MEGHNAD SAHA

1893 : Born of a lower middle class family, the fifth child of Jagannath Saha and his wife, Bhubaneswari, in the village of Sheoratali, 45 km away from Dacca in the-then East Bengal (now the capital of Bangladesh), on 6 October.

1905 : Stood first in the Dacca division in the Middle School Examination from a school in the village of Shimulia, and obtained a scholarship. Joined the Dacca Collegiate School, from which he was expelled soon afterwards because of his participation in a nationalist demonstration.

1909 : Appeared at the Entrance Examination from Kishorilal Jubilee School and stood first among all the candidates from the-then East Bengal.

1911 : Stood third in the I.Sc. Examination from the Dacca College, and joined the Presidency College in Calcutta.

1913 : Stood second in the first class in the B.Sc. Examination, with honours in mathematics, from the Presidency College. Participated in the relief work for the people afflicted by the flood in the river Damodar.

1915 : Stood second in the first class in the M.Sc. Examination in mixed mathematics from the Presidency College.

1916 : Joined the University of Calcutta as a Lecturer in the Mathematics Department, and got himself transferred to the Physics Department a few months later.

1917 : Published his two first research papers in two renowned journals, namely, *Philosophical Magazine* and *Physical Review*.

1918 : Obtained the D.Sc. degree from the University of Calcutta on the basis of his thesis on radiation pressure and electromagnetic theory. Published, jointly with his colleague S. N. Bose, English translations of a few articles on the theory of relativity by A. Einstein and H. Minkowski, written in German. These were the first English translations of the remarkable articles and were published by the University of Calcutta in the form of a book with an introduction by P. C. Mahalanobis, a member of the faculty of the Presidency College.

1920 : Put forward his famous theory of thermal ionization and demonstrated its important applications in the field of astronomy, which led to the foundation of modern astrophysics. Communicated from Calcutta a series of four papers on the subject to the *Philosophical Magazine*, two of which entitled 'Ionization in the Solar Chromosphere' and 'Elements in the Sun' were published in the same year. Proceeded to Europe on obtaining the Ghosh Travelling Fellowship, and joined A. Fowler's laboratory in the Imperial College of Science and Technology in London.

1921 : Withdrew the fourth paper of the series of four papers communicated from Calcutta, revised it and published it under the title, 'On a Physical Theory of Stellar Spectra' in the *Proceedings of the Royal Society*, while the third paper entitled 'On the Problems of Temperature Radiation of Gases' had, in the meantime, been published in the *Philosophical Magazine*. Met eminent scientists like J. J. Thomson, A. S. Eddington and E. A. Milne in Cambridge. Joined W. Nernst's laboratory in Berlin in February and carried out preliminary work on the experimental verification of the theory of thermal ionization. Had discussions with renowned scientists like A. Einstein, M. Planck and M. von Laue in Berlin. Gave an invited talk in München at the request of A. Sommerfeld. Returned to India on an invitation from A. Mukherjee, the-then Vice-Chancellor of the Calcutta University, to accept the post of the Khaira Professor in the Physics Department, and joined the University in November.

1922 : Participated, under the leadership of Acharya P. C. Ray, in the relief work for the flood-stricken people in North Bengal.

1923 : Joined the University of Allahabad as the Professor and Head of the Physics Department.

1926 : Presided over the Mathematics and Physics Section in the Session of the Indian Science Congress held in Bombay.

1927 : Had the distinction of being elected a Fellow of the Royal Society (FRS). Visited many laboratories in Europe. Took part in an expedition in Norway on the occasion of a total solar eclipse on 29 June. Attended an International Congress on Physics held at Como, Italy in September on the occasion of the Death Anniversary of A. Volta.

1931 : Founded the U. P. Academy of Sciences (renamed later as National Academy of Sciences) at Allahabad. Wrote, jointly with B. N. Srivastava, the renowned text-book entitled *'A Text-book on Heat'*, which was later renamed *'A Treatise on Heat'*. Started fabricating a demountable vacuum furnace, with financial assistance from the Royal Society of London, for experimental verification of the theory of thermal ionization.

1933 : Founded the Indian Physical Society at Calcutta.

1934 : Elected General President of the Indian Science Congress Session held in Puna. Carried out important research on beta-ray activity in the field of nuclear physics. Wrote, jointly with N. K. Saha, a text-book entitled *'A Treatise on Modern Physics'*.

1935 : Founded the National Institute of Sciences at Calcutta (transferred later to Delhi and renamed Indian National Science Academy). Established also the Indian Science News Association, and started editing its journal, 'Science and Culture'.

1936 : Made significant discussion on magnetic monopole in a paper published in the Indian Journal of Physics.

1937 : Elected an Overseas Fellow of the Carnegi Trust of the British Empire. Made an extensive tour of the United States of America, Germany and England. Emphasised correctly the need of a stratosphere solar observatory in a lecture delivered in a special convocation of the Harvard University. Attended an important conference on nuclear physics at Copenhagen. Initiated research on ionospheric wave propagation at Allahabad.

1938 : Joined the University of Calcutta as the Palit Professor in the Physics Department. Nominated as a Member of the Planning Committee set up by the Indian National Congress. Acted as the Chairman of the Sub-committees on 'Power and Fuel' and 'Technical Education'.

1939 : Published interesting articles, in Bengali, on modern science vis-a-vis Hindu religion in the magazine 'Bharatbarsa'.

1940 : Introduced nuclear physics in the M. Sc. physics syllabus of the Calcutta University. Initiated research on nuclear physics and cosmic rays at the Palit laboratory in the Physics Department. Started taking steps for building a cyclotron, the first of its kind in the country, around which nuclear physics could grow.

1944 : Visted U. K., U. S. A. and Canada as a Member of an Indian Scientific Mission. Published a valuable article in the Science and Culture, laying the foundation of the Damodar Valley Project in the context of river management in India.

1945 : Represented the Government of India in the Annual Function of the Soviet Academy of Science, held in Moscow.

1946 : Elected as the President of the Governing Council of the Indian Association for the Cultivation of Science and also as the President of the Asiatic Society.

1947 : Deeply involved in the problem of rehabilitation of the refugees from the-then East Pakistan.

1948 : Nominated as a member of the Education Commission set up by the Government of India. Encouraged research on biophysics and construction of an electron microscope (the first of its kind in India) in his laboratory.

1950 : Founded the Institute of Nuclear Physics at Calcutta, which was opened by Madame Irene Joliot-Curie on 11 January.

1951 : Became the honorary life-long Director of the Institute of Nuclear Physics, Calcutta while he was still the Palit Professor in Physics in the University of Calcutta. (The Institute was named Saha Institute of Nuclear Physics after his demise as a token of respect to his memory).

1952 : Elected a Member of the Parliament as an independent candidate from the North-west Calcutta constituency. Nominated as the Chairman of the Calendar Reform Committee set up by the Government of India.

1953 : Retired from the University of Calcutta. Joined the Indian Association for the Cultivation of Science as its Director.

1954 : Presented the Indian proposal for World Calendar reform in the 18th session of the UNESCO held in Geneva.

1956 : Collapsed and died suddenly on the way to the office of the Planning Commission in Delhi on 16 February.

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APPENDIX II

SCIENTIFIC PAPERS OF MEGHNAD SAHA

- On Maxwell's Stresses : *Phil. Mag.*, Sr. VI, **33** (1917) 256.
- On the Limit of Interference in the Fabry-Perot Interferometer : *Phys. Rev.*, **10** (1917) 782.
- On a New theorem in Elasticity : *Jour. Asia. Soc. Bengal,* New Sr. **14** (1918) 421.
- On the Pressure of Light (with S. Chakraborty) : *Jour. Asia. Soc. Bengal,* New Sr. **14** (1918) 425.
- On the Dynamics of the Electron : *Phil. Mag.*, Sr. VI, **36** (1918) 76.
- On the Influence of the Finite Volume of Molecules on the Equation of State (with S. N. Bose) : *Phil. Mag.*, Sr. VI, **36** (1918) 199.
- On the Mechanical and Electro-dynamical Properties of the Electron: *Phys. Rev.*, **13** (1919) 34 ; *Phys. Rev.*, **13** (1919) 238.
- On Radiation Pressure and the Quantum Theory, A Preliminary Note: *Astro Phys. Jour.* **50** (1919) 220.
- On the Fundamental Law of Electrical Action : *Phil. Mag.*, Sr. VI **37** (1919) 347.
- On the Equation of State (with S. N. Bose) : *Phil. Mag.*, Sr. VI, **39** (1920) 456.
- On Selective Radiation Pressure and the Radiative Equilibrium of the Solar Atmosphere : *Jour. Dept. Sci. Cal. Univ.*, **2,** (Physics), (1920) 51.
- Note on the Secondary Spectrum of Hydrogen : *Phil. Mag.*, Sr. VI, **40** (1920) 159.
- Ionization in the Solar Chromosphere : *Phil. Mag.*, Sr. VI, **40** (1920) 472.
- Elements in the Sun : *Phil. Mag.*, Sr. VI, **40** (1920) 809.
- On the Problem of Nova Aquila III : *Jour. Astr. Soc. Ind.*, **10** (1920) 36.
- On Electron-chemistry and its Application to Problems of Radiation and Astrophysics : *Jour. Astr. Soc. Ind.*, **10** (1920) 72.

- On the Problems of Temperature Radiation of Gases : *Phil. Mag.*, Sr. VI, **41** (1921) 267.
- The Atomic Radius and the Ionization Potential : *Nature*, **107** (1921) 682.
- On a Physical Theory of Stellar Spectra : *Proc. Roy. Soc. Lond.*, **A99** (1921) 135.
- Versuch einer Theorie der physikalischen Erscheinungen bei hohen Temperaturen mit Anwendungen auf die Astrophysik : *Zeit. f. Phys.*, **6** (1921) 40.
- The Stationary H and K-lines of Calcium in Stellar Atmospheres : *Nature*, **107** (1921) 488.
- On the Ionization of Gases by Heat (with P. Gunther) : *Jour. Dept. Sci., Cal. Univ.*, **4** (1922) 97.
- On the Temperature Ionization of Elements of the Higher Groups in the Periodic Classification : *Phil. Mag.*, Sr. VI, **44** (1922) 1128.
- On the Physical Properties of Elements at High Temperatures : *Phil. Mag.*, Sr. VI, **46** (1923) 534.
- On Continuous Radiation from the Sun : *Nature*, **112** (1923) 282.
- On an Experimental Test of Thermal Ionization of Elements (with N. K. Sur) : *Jour. Ind. Chem. Soc.*, **1** (1924) 9.
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