MEGHNAD SAHA

A GREAT SCIENTIST AND A VISIONARY

Lectures Delivered at the 125th Birth Anniversary Celebration of Professor Meghnad Saha

Viva

Editors
Ajoy Ghatak
Anirban Pathak

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Front Cover: A group photograph taken at the end of the 125th birth anniversary celebration of Dr Meghnad Saha at Allahabad.

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राष्ट्रीय विज्ञान अकादमी, भारत

The National Academy of Sciences, India
5, Lajpatrai Road, Prayagraj (Allahabad) - 211002

Dr G. Padmanaban
President

Message

The National Academy of Sciences, India (NASI) celebrated the 125th birth anniversary of its Founder President Professor Meghnad Saha in a befitting manner – by organizing a 2-day seminar dedicated to the life and works of Prof. Saha and their impact on the society. The event was unique in the sense that along with a large number of eminent Indian scientists, about 400 school and college students participated in this seminar.

I am glad to know that the proceedings of the above-mentioned seminar, which was very well organized by Dr Ajoy Ghatak and Dr Manju Sharma in close collaboration with Dr Anil Kakodkar, Past President, and the entire NASI team is now ready for publication as a book. This book is a collection of the chapters based on the talks delivered by the experts during the seminar. It documents historical aspects of Prof. Saha's life and works along with an excellent discussion on the relevance of his contributions to the modern society. I am sure the readers will find this collection inspiring and keep it as a guide for the future. I hope that young readers will be motivated by the works of Saha and follow his footsteps to do their best for the society through science.

(G. Padmanaban)

राष्ट्रीय विज्ञान अकादमी, भारत

The National Academy of Sciences, India
5, Lajpatrai Road, Prayagraj (Allahabad) - 211002

Dr Anil Kakodkar
Past President, NASI
Chairman, Rajiv Gandhi Science & Technology Commission

Message

Almost 90 years back, in 1930, the first science academy of India started its journey as **The Academy of Sciences of United Provinces of Agra and Oudh** which was later renamed as **The National Academy of Sciences, India** (NASI). It was conceptualized and founded by the legendary Indian physicist Prof. Meghnad Saha with the objective to provide opportunities for exchange of views among the Indian scientists. First president of the Academy was Prof. Meghnad Saha, who was born on October 6, 1893.

To commemorate the 125th birth anniversary of its founder and first president, NASI organized a 2-day seminar on October 6-7, 2018 at Prayagraj (Allahabad). It was my privilege to be present there as the President of NASI at that time. The distinguished speakers present at the seminar revealed many interesting aspects of the life and works of Prof. Saha. It was an enriching experience for those who were present there. I am glad that Prof. Ajoy Ghatak and Prof. Anirban Pathak have taken an initiative to ensure that those who were not present in the seminar can also get enriched by the information shared in the 2-day seminar in the form of this book. All the speakers who have taken efforts to convert their talks into chapters of this book have done a great job as this book will be of great inspirational value and guidance to the future researchers and students of science.

I hope that this book will encourage young readers to find scientific solution of social problems being faced by our country by following Professor Saha's footsteps.

(Anil Kakodkar)

राष्ट्रीय विज्ञान अकादमी, भारत

The National Academy of Sciences, India
5, Lajpatrai Road, Prayagraj (Allahabad) - 211002

Dr Manju Sharma
NASI Distinguished Women Scientist Chair

Message

Professor Meghnad Saha established the National Academy of Sciences in 1930. This is oldest of the science academies in India. Our founder set the mandate of the academy as Science and Society. Following his ideas and dreams, NASI is continuously working to promote science and technology for the betterment of the society.

Keeping the mandate of NASI in mind, on the 125th birth anniversary of Professor Saha, it was thought that the younger generation should be sensitized about the life and works of Professor Saha, and its impact on the society. To do so, a 2-day seminar was organized at Prayagraj under the guidance of Professor Ajoy Ghatak and his team. There were many talks, and the seminar was attended by more than 400 students. The response of the students was so good that NASI thought of preparing an edited book based on some of the lectures delivered at the seminar for the benefit of those who could not attend the seminar. The manuscript has now been nicely edited by Professor Ajoy Ghatak and Professor Anirban Pathak.

I hope the inspiring story of Professor Saha depicted in this book will encourage some bright young minds to follow his path and thus to do science for the welfare of the country.

Manju Sharma

(Manju Sharma)

Preface

Professor Meghnad Saha, Founder President of The National Academy of Sciences, India (usually abbreviated as NASI), was born on October 6, 1893. On the occasion of 125th birth anniversary of Professor Meghnad Saha, Dr Anil Kakodkar, then President NASI, decided to have a 2-day seminar at NASI Headquarters in Prayagraj during October 6 and 7, 2018, with an objective to tell the younger generation about the many contributions of Professor Meghnad Saha. The convener of the seminar was Dr Ajoy Ghatak and Dr Manju Sharma was the co-convener of the event.

NASI, which is the oldest science academy in India, organized this event on the eve of 125th birth anniversary of its founder. In fact, in the December 1929 issue of Allahabad University magazine, Professor Meghnad Saha (who was then Professor and Head of Physics Department at the University of Allahabad) published an article entitled 'A Plea for an Academy of Sciences' with the idea of establishing a forum for scientists, which would bring them together to discuss and find scientific solutions to the problems of the country. Subsequently, in 1930, The Academy of Sciences of the United Provinces of Agra and Oudh was founded with the objectives to provide a national forum for the publication of research work carried out by Indian scientists and to provide opportunities for exchange of views among them and Professor Meghnad Saha was elected as the first President of the Academy. Later, the name of the Academy was changed to The National Academy of Sciences, India.

Professor Saha was an outstanding astrophysicist, best known for the Saha ionization equation (1919), for which he was nominated for the Nobel Prize several times. He had also contributed immensely in many other areas. In 1923, he was appointed as the first Professor and Head of Physics Department at the University of Allahabad and contributed immensely to the growth of the Department. At Allahabad he wrote (with Prof. B.N. Srivastava) the

famous book with the title *Treatise on Heat* which, even today, is considered as one of the most authoritative textbooks on the subject.

In 1935, along with Acharya Prafulla Chandra Ray, Professor Saha established **The Indian Science News Association** (**ISNA**) publishing the journal *Science and Culture* every month; Professor Saha was its editor until his death. In 1938, he returned to Calcutta as Palit Professor of Physics. Nuclear fission was discovered in 1939 and Professor Saha immediately started a strong programme on nuclear physics. He was the founder of **Institute of Nuclear Physics** in 1949. The building was formally inaugurated by Dr Irène Joliot-Curie on 11 January 1950. After the death of Professor Saha, it was named as **Saha Institute of Nuclear Physics** (SINP).

In 1946, **Indian Association for the Cultivation of Science** (usually abbreviated as IACS) embarked upon a new development plan under the dynamic leadership of Professor Saha envisaging the creation of an active research school in many different areas. By February 1948, Professor Saha with the help of prominent architects in Calcutta prepared a master plan and eventually created the Jadavpur Campus of IACS. It is now one of the premier research institutes in our country. In addition, Professor Saha played the most important role in establishing **Central Glass and Ceramic Research Institute** (a major R&D Laboratory of CSIR) and also Positional Astronomy Centre both in Kolkata.

Professor Saha was the chief architect of river planning in India and prepared the original plan for the Damodar Valley Project. Further, to actively participate in planning of education, industrialization, health, and river valley development, Professor Saha 'decided to offer himself' as a candidate in the constituency of North-West Calcutta in the 1951 Lok Sabha election .. which he won!!!

It is indeed amazing that one person could contribute so much to the development of our nation and it is very difficult to imagine what more he would have achieved had he not died at the early age of 63.

In the seminar, we had many lectures to make the younger generation aware of the many contributions of Professor Saha in very diverse areas and also to discuss recent R&D activities in the areas which are closely related to the works of Professor Meghnad Saha. Our speakers were Dr Anil Bhardwaj (Director, PRL, Ahmedabad), Dr Anil Kakodkar (then president NASI), Dr Arnab Rai Choudhuri (Professor at IISc, Bangalore), Dr Ashoke Sen (Professor at HRI, Prayagraj), Dr Atri Mukhopadhyay (Formerly Professor at Saha Institute of Nuclear Physics (SINP), Kolkata), Dr Hari Prakash (Formerly Professor of Physics at the University of Allahabad),

Dr M.C. Chattopadhyaya (Formerly Professor of Chemistry at the University of Allahabad), Dr Palash Baran Pal (Formerly Professor at SINP, Kolkata), Dr Ram Gopal (Formerly Professor of Physics at the University of Allahabad), Dr S.C. Dutta Roy (Formerly Professor of Electrical Engineering at IIT Delhi), Dr S.K. Joshi (Formerly DG CSIR), Dr Shyamal Bhadra (Emeritus Scientist, IACS, Kolkata), Dr Somak Ray Chaudhury (Director, IUCAA, Pune) and also the two editors of this book: Dr Ajoy Ghatak and Dr Anirban Pathak. In addition, Dr Sandip Trivedi (Director, TIFR, Mumbai) and Dr Anurag Sharma (Professor and Head of the Department of Physics at IIT Delhi) delivered the 2016 and 2017 Meghnad Saha Memorial Award Lectures. Dr Manju Sharma, co-convener of the event, was also supposed to deliver a talk in this event, but unfortunately she became unwell just before the event because of which she could not attend the seminar. However, she had greatly contributed in planning out the event. Later, she also agreed to write-up the talk that she had planned to deliver at the event. We also had very eminent scientists (like Dr Amit Ghosh, Dr Ashok Misra, Dr Asis Datta, Dr Girjesh Govil, Dr H.S. Mani, Dr K.N. Uttam, Dr Manoj Saxena, Dr Satya Deo, Dr S.L. Srivastava, Dr Suchitra Banerjee, Dr U.C. Srivastava and Dr V.P. Kamboj) who not only chaired the sessions but also interacted with the participants and provided a very stimulating atmosphere. Dr S.C. Dutta Roy and Dr Anirban Pathak coordinated a special session interacting with young students.

Nearly 450 people (comprising of college students, teachers, scientists from research and teaching institutions, and persons associated with NASI) attended the seminar and stayed on till the end.

The present book contains detailed write-ups of a few of the talks delivered by various scientists detailing the many important contributions of Professor Saha. Certainly much more can be written about Professor Saha's contributions. Few speakers could not submit a manuscript because of their other commitments. Our grateful thanks to Dr Manju Sharma, Dr Atri Mukhopadhyay, Dr Shyamal Bhadra, Dr S.C. Dutta Roy and Dr M.C. Chattopadhyaya for spending a lot of time in writing the chapters.

The role of science and technology is probably the most important factor in the growth of a nation. We hope that the present book will give the readers a perspective of the outstanding contributions of Professor Meghnad Saha and help the younger generation to plan out the road map for future.

We are extremely grateful to Dr Manju Sharma for her help in planning out the seminar. We also thank Dr Nasir Alam (at JIIT) and Dr Smita Venkatesh

(at NASI Headquarters) for their help in compiling this book and designing the cover. Finally, our sincere thanks to Dr Neeraj Kumar (Executive Secretary, NASI) and his colleagues at NASI for making excellent arrangements at the seminar, their warm hospitality and their help in compiling this book.

Ajoy Ghatak and Anirban Pathak
Editors

1. Meghnad Saha: A Brief History[1]

Ajoy Ghatak
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Professor Meghnad Saha was born on October 6, 1893. His 125th birthday was celebrated by **The National Academy of Sciences, India** (usually abbreviated as NASI) in Allahabad by organizing a 2-day seminar during October 6-7, 2018; the academy was established in 1929 by Professor Saha and his colleagues and Professor Saha was its founder president. In addition to his outstanding research work which led to what is referred to as the **Saha Ionization Equation** (which many feel should have given him the Nobel Prize) and many other very important research papers, Professor Saha made Allahabad University a world-class university; he created the **Institute of Nuclear Physics** at Kolkata; he moved the Indian Association for the Cultivation of Science (usually abbreviated as IACS) to a beautiful Jadavpur campus and transformed it to a world-class research organization; he created the **Central Glass and Ceramic Research Institute** at Kolkata and was also responsible for the eventual creation of the **Positional Astronomy Centre** at Kolkata. Professor Saha also established (in Allahabad) what is now known as NASI, the first science academy in India. He also played a very important role in the creation of what is now known as INSA (**Indian National Science Academy**). And, in the year 1935, along with Acharya Prafulla Chandra Ray, Professor Meghnad Saha established the **Indian Science News Association** (ISNA) publishing the journal *Science and Culture* every month.

[1] This chapter is a slightly revised version of an article with the same title which has appeared in Ref. [1].

It is indeed amazing that one person could contribute so much to the development of our nation and it is very difficult to imagine what more he would have achieved had he not died at the early age of 63. In this chapter we would describe briefly his main contributions to science and towards the development of our nation.

1. Early Years

Meghnad Saha was born on October 6, 1893 in a small village (Sheoratali) near Dacca. His parents were very poor and belonged to a backward class. Thus, he could not afford to go to a good school. However, he did win merit scholarships and eventually joined Presidency College (which was originally named as Hindu College) for the B.Sc. degree in 1911. His friend and classmate Professor Nikhil Ranjan Sen, wrote in an article entitled 'Reminiscences of the School and College Days with Professor Meghnad Saha' [2]:

> *'Saha passed the Entrance Examination from the K L Jubilee School in Dacca in 1909 and in 1911, he joined The Presidency College, Calcutta, as a student of the BSc. class… I was with Saha all through at the Dacca Collegiate School and joined him again in Presidency College in 1911. Saha studied 4 years in this college and passed out in 1915 with a first class MSc. degree in Applied Mathematics'.*

Hindu College in Calcutta was formally opened on 20th January 1817 with 20 'scholars'. The foundation committee of the college was headed by Raja Ram Mohan Roy who along with 6 others donated their personal wealth to establish the college. Hindu College was the first institution of higher learning in the modern sense in Asia; in 1855, it was renamed as Presidency College (see Fig. 1) and on 23rd July 2010 it became Presidency University. The pioneering discoveries of Jagadish Chandra Bose (in Physics and Plant Physiology) and of Prafulla Chandra Ray (in Industrial Chemistry) were made in the laboratories of Presidency College (see Fig. 2). In 1857, three universities were set up: in Bombay, Calcutta and Madras (see Fig. 3) – similar to the structure of the University of London.

Fig. 1: On January 20, 1817, The Hindu College in Calcutta was formally opened; this was the first institution of higher learning in the modern sense in Asia. The foundation committee of the college was headed by Raja Ram Mohan Roy who along with 6 others donated their personal wealth to establish the college.

(a) (b) (c)

Fig. 2: (a) Acharya Prafulla Chandra Ray was the founder of Bengal Chemicals and Pharmaceuticals, India's first pharmaceutical company. (b) Jagadish Chandra Bose made outstanding contributions to Physics & Plant Physiology. (c) The microwave apparatus of J.C. Bose; adapted from https://en.wikipedia.org/wiki/Jagadish_Chandra_Bose

(a) (b) (c)

Fig. 3: In 1857, three universities were set up: in Madras, Calcutta and Bombay – similar to the University of London. (a) Madras University Senate House and Marina Beach, 1905; adapted from https://en.wikipedia.org/wiki/University_of_Madras#/media/File:MadrasUniversitySenateHouse1905.jpg (b) Calcutta University in the mid 19th century; adapted from http://oldkolkata.blogspot.in/2013/05/oldest-known-university-in-calcutta.html (c) Bombay University in the mid nineteenth century; adapted from https://www.oldindianphotos.in/2010/11/bombay-mumbai-university-hall-19th.html

When Meghnad Saha was studying for his B.Sc. degree (in Mathematics) and later M.Sc. (in Mixed Mathematics), his classmate was Satyendra Nath Bose who stood first in both examinations (and Meghnad Saha stood second). At Presidency College, Prasanta Mahalanobis (who made outstanding contributions in statistics and later created the Indian Statistical Institute at Kolkata) was one year senior to Meghnad Saha and Subhash Chandra Bose (the great freedom fighter) was one year junior to Meghnad Saha. What great people Presidency College created!

In 1916, both Meghnad Saha and Satyendra Nath Bose were appointed as lecturers in the Department of Applied Mathematics in the University College of Science. However, very soon they were transferred to the Physics Department, where (in 1917), C.V. Raman joined as Palit Professor of Physics. All appointments were made by the great visionary Ashutosh Mukherjee, who was then Vice Chancellor of Calcutta University.

Meghnad Saha started his research work almost independently and submitted his thesis in 1918; he was awarded the D.Sc. degree from Calcutta University in 1919.

In 1916, Einstein had published his very famous paper on General Theory of Relativity[2]; Minkowski had also made very important contributions to Relativity. In 1919, only 3 years after the very famous paper by Einstein on General Theory of Relativity, Meghnad Saha and Satyendra Nath Bose translated the papers of Einstein and Minkowski (see Fig. 4). Apparently this was the first English translation of Einstein and Minkowski's works and Saha and Bose both taught Theory of Relativity to their M.Sc. students. Professor Prasanta Mahalanobis wrote a historical introduction to the book (see Fig. 4).

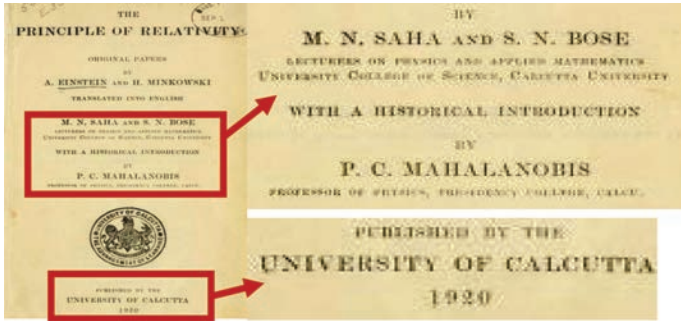


Fig. 4: In 1919, only 3 years after the very famous paper by Einstein on General Theory of Relativity, Meghnad Saha and Satyendra Nath Bose translated the papers of Einstein & Minkowski.

[2]The English translation of his famous 1916 paper on 'The Foundation of the General Theory of Relativity' can be read at http://www.alberteinstein.info/gallery/pdf/CP6Doc30_English_pp146-200.pdf (Translated by Alfred Engel).

2. The 2 Famous Papers

In 1919, the Premchand Roychand Scholarship of Calcutta University was awarded to Meghnad Saha which enabled him to spend about two years in Europe; Fig. 5 shows a group photograph taken in 1920 at the farewell party just before Saha's departure for UK. Seated with him are S.N. Bose and C.V. Raman. Saha first went to London where he spent about five months in the laboratory of Professor A. Fowler at Imperial College, London. From London he moved to Berlin where he worked in the laboratory of Professor Nernst; Professor Walther Nernst formulated what is referred as **Nernst' Heat Theorem** which led to the third law of thermodynamics, for which he won the 1920 Nobel Prize in Chemistry. Figure 6 shows a 1921 photograph of Meghnad Saha when he was in Berlin.

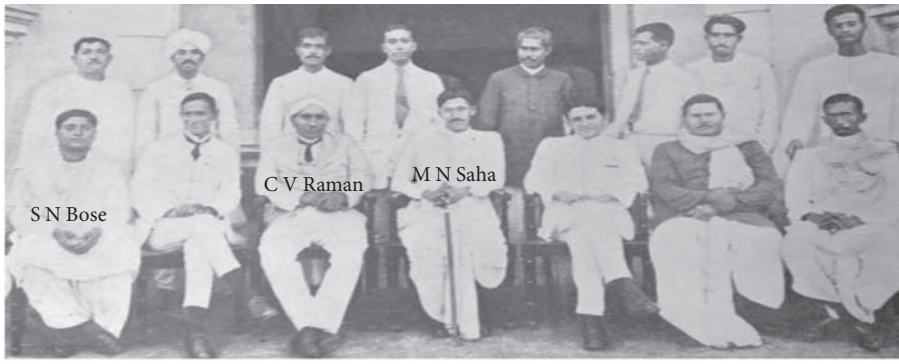


Fig. 5: A group photograph taken at the Farewell Party…just before Saha's departure for UK (1920). Seated left to right: S.N. Bose, P.N. Ghosh, C.V. Raman, M.N. Saha, D.M. Bose, B.N. Chakravarty; standing left to right: H. Mitra, G. Dutt, D.D. Banerjee, S.K. Mitra, S.K. Acharya, A.C. Saha, A.N. Mukherjee, B.B. Ray. Adapted from https://www.insa.nic.in/writereaddata/UpLoadedFiles/IJHS/Vol52_3_2017.
Photo credit: *Science and Culture.*

Fig. 6: Meghnad Saha in Berlin (1921).

During 1919-21, Saha published quite a few important papers, the two important papers on the formulation of the famous ionization equation were [3,4] (see also [5], [6] and [7]):

1. M.N. Saha, 'Ionization in the Solar Chromosphere', *Philosophical Magazine Series*, 6, 40, 472-488 (1920); see http://www.saha.ac.in/web/images/library/digitised%20doc/papers/Page%2038.pdf
2. M.N. Saha, 'On a Physical Theory of Stellar Spectra', *Proceedings of the Royal Society*, A 99, 135 (1921); see http://www.saha.ac.in/web/images/library/digitised%20doc/papers/page%2059.pdf

The first paper was communicated from Calcutta and was received in the office of Philosophical Magazine on March 4, 1920. The second paper was communicated by Professor A. Fowler and was received in the office of the Royal Society on January 18, 1921; a few simple applications of Saha's ionization formula are discussed in Appendix A. In order to understand the applications of Saha's ionization formula, it is necessary to understand the atomic spectra; this we have briefly discussed in Appendix B.

Professor Saha's ionization equation had a tremendous impact on astrophysics. Professor Otto Struve, who was one of the most distinguished and prolific astronomers of the mid-20th century and served as director of Yerkes Observatory, wrote the following in September 1953 [2]:

> *'On behalf of the astronomers of the University of California in Berkeley and also on behalf of the International Astronomical Union, I extend my heartiest congratulations to Professor M N Saha upon the occasion of his 60th birthday. His brilliant work on the ionization of stellar atmospheres more than 30 years ago resulted in a revolution in scientific thought comparable to that which occurred with Fraunhofer and Kirchhoff laid the foundations of the spectroscopic investigations of the celestial bodies. Saha's work has been a source of constant inspiration to virtually every astrophysicist during the present generation. My own earlier studies in stellar spectroscopy received an impetus from his work and I believe that I have never written a scientific article in which I have not in one form or another made use of his theory of ionization'.*

For this work, Professor Saha was (unsuccessfully) nominated for the Nobel Prize several times including a strong nomination by Arthur Compton who had received the 1927 Nobel Prize in Physics for his work on what is

now known as *Compton Effect*. In September 1953, on the occasion of Professor Saha's 60th birthday, Professor Compton wrote [2]:

> *'It is a pleasure to have the opportunity of congratulating you on the occasion of your 60th birthday for your outstanding achievements, especially in the field of thermodynamics. As you may know, I at one time had the honor of nominating you for the Nobel Prize for your work in this area. But it is not only as a scientist that you have held my high regard over the years that we have known each other. I have been continually impressed by your human interests and your concern for the best development of the students who have come under your care'.*

Saha did get elected to the Fellowship of the Royal Society which was also a very significant recognition.

3. Return to India and 15 years in Allahabad

In November 1921, Meghnad Saha returned to India and joined the University of Calcutta as Khaira Professor of Physics; however, he was unable to get financial support for his research work. In 1923, he was appointed as the first Professor and Head of Physics Department at Allahabad University (see Fig. 7). At Allahabad University, he contributed immensely to the growth of the department and initiated many areas of research.

Fig. 7: In 1923 Saha moved to University of Allahabad as the first Head of the Physics Department. Photograph courtesy Dr Manoj Saxena.

Fig. 8: Photograph taken after the felicitation function (in 1927) when Professor Saha was elected as Fellow of the Royal Society. Source: Meghnad Saha Archives.

In 1927, because of his famous ionization equation, he was elected as Fellow of the Royal Society. Figure 8 shows a group photograph taken at the end of a function felicitating Professor Saha for his election as a Fellow of the Royal Society. This recognition by the Royal Society enabled him to get more grants for his department.

In the December 1929 issue of the Allahabad University magazine, Professor Saha (then Professor and Head of Physics Department at Allahabad University) published an article entitled **'A Plea for an Academy of Sciences'** with the idea of establishing a forum for scientists, which would bring them together to discuss and find scientific solutions to the problems of the country. Subsequently, in 1930, The **Academy of Sciences of United Provinces of Agra and Oudh** was founded with the objectives to provide a national forum for the publication of research work carried out by Indian scientists and to provide opportunities for exchange of views among them. The Memorandum of Association was signed by seven distinguished and patriotic scientists including Professor Meghnad Saha, Professor K.N. Bahl, Professor D.R. Bhattacharya, Professor P.C. MacMohan, Professor A.C. Banerji, Professor Wali Mohammad and Professor N.R. Dhar. Professor Saha was elected as the first President of the Academy (see Fig. 9). The rules and regulations of the Academy were based on those of the Royal Society of England and the Asiatic Society of Bengal. These have since been revised and updated to meet the emerging challenges. To quote from the official website of NASI (see http://nasi.org.in/vision.htm):

> *'The 1st World War and the world-wide economic depression caused a setback to scientific research globally - much more so in India whose*

> *scientists found it difficult even to publish their research work since they had to be almost entirely dependent on foreign journals. The post-World War India also saw the rise of the freedom movement which incidentally also drew attention to the numerous problems of the Indian people like poverty, hunger, diseases, recurrent floods, droughts, famines etc. Patriotic scientists felt deeply concerned with these. It was in this background that the idea of establishing a forum for scientists, which would bring them together to discuss and find scientific solutions to the problems of the country, was mooted by Prof. Meghnad Saha, a great scientist, patriot and then Professor of Physics at Allahabad University in 1929'.*

Professor Saha wrote:

> *'An Academy of Science can do a great deal by educating public opinion, undertaking particular problems, and bringing out scientific workers in various fields for discussion and cooperative research. But the main function of the Academy should be towards cultural improvement by contributions to human knowledge'.*

In its Silver Jubilee Session in 1955, Professor Saha, further emphasized the role of the academies in developing human scientific resources.

While at Allahabad, Professor Saha (with Professor B.N. Srivastava as his co-author) wrote the famous book with the title *Treatise on Heat* which was published by Indian Press in 1931 (see Fig. 10 and Ref. [5]).

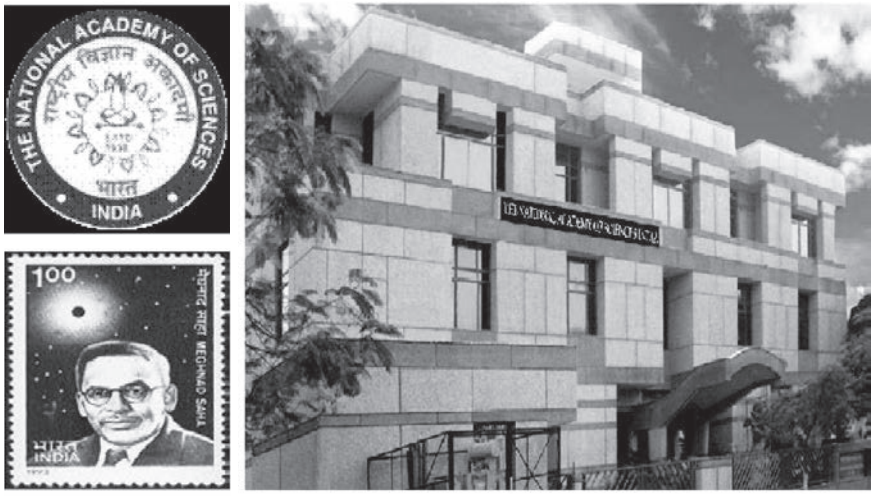
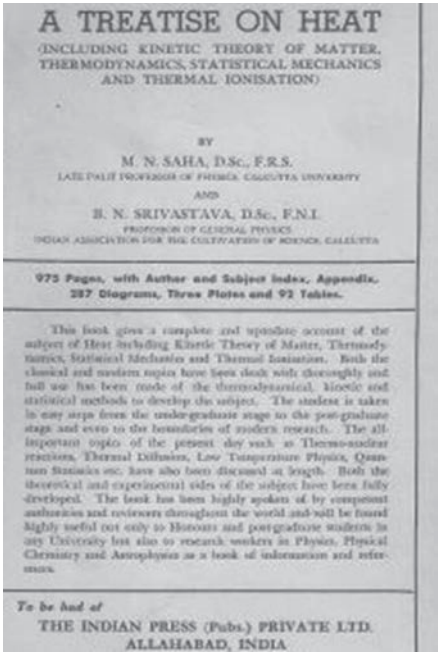


Fig. 9: Building of The National Academy of Sciences, India on Lajpat Rai Road in Allahabad. In 1929, the Academy was established by Professor Saha and his colleagues and Professor Saha was the founder president of the Academy.



A TREATISE ON HEAT

(INCLUDING KINETIC THEORY OF MATTER, THERMODYNAMICS, STATISTICAL MECHANICS AND THERMAL IONISATION)

BY

M. N. SAHA, D.Sc., F.R.S.

LATE PALIT PROFESSOR OF PHYSICS, CALCUTTA UNIVERSITY

AND

B. N. SRIVASTAVA, D.Sc., F.N.I.

PROFESSOR OF GENERAL PHYSICS

INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE, CALCUTTA

975 Pages, with Author and Subject Index, Appendix, 287 Diagrams, Three Plates and 92 Tables.

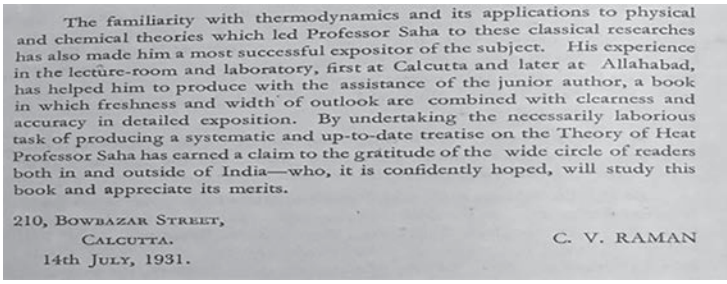
This book gives a complete and up-to-date account of the subject of Heat including Kinetic Theory of Matter, Thermodynamics, Statistical Mechanics and Thermal Ionisation. Both the classical and modern topics have been dealt with thoroughly and full use has been made of the thermodynamical, kinetic and statistical methods to develop the subject. The student is taken in easy steps from the under-graduate stage to the post-graduate stage and even to the boundaries of modern research. The all-important topics of the present day such as Thermo-nuclear reactions, Thermal Diffusion, Low Temperature Physics, Quantum Statistics etc. have also been discussed at length. Both the theoretical and experimental sides of the subject have been fully developed. The book has been highly spoken of by competent authorities and reviewers throughout the world and will be found highly useful not only to Honours and post-graduate students in any University but also to research workers in Physics, Physical Chemistry and Astrophysics as a book of information and reference.

To be had of

THE INDIAN PRESS (Pubs.) PRIVATE LTD.
ALLAHABAD, INDIA

Fig. 10: While at Allahabad, Professor Saha (along with Professor B.N. Srivastava) wrote the famous book with the title *Treatise on Heat* which was published by Indian Press in 1931. Even today, the book is considered as one of the most authoritative text books on the subject.

This book is considered as one of the most authoritative textbooks on the subject; of course we now have a revised edition of the book. We all had used this book when we were students. Even today, if we have to teach concepts related to heat and thermodynamics, we get the fundamentals from the book by Saha and Srivastava. Both the ionization equation and the equation describing Bose statistics are explained very nicely there. The Indian Press at Allahabad was the publisher of the book. It is widely believed that Professor Saha's relationship with Professor C.V. Raman was not very cordial; however, Raman did write a nice Foreword of the book; the last para of the Foreword is given below.



The familiarity with thermodynamics and its applications to physical and chemical theories which led Professor Saha to these classical researches has also made him a most successful expositor of the subject. His experience in the lecture-room and laboratory, first at Calcutta and later at Allahabad, has helped him to produce with the assistance of the junior author, a book in which freshness and width of outlook are combined with clearness and accuracy in detailed exposition. By undertaking the necessarily laborious task of producing a systematic and up-to-date treatise on the Theory of Heat Professor Saha has earned a claim to the gratitude of the wide circle of readers both in and outside of India—who, it is confidently hoped, will study this book and appreciate its merits.

210, Bowbazar Street,
Calcutta.
14th July, 1931.

C. V. RAMAN

In 1935 Professor Saha, while still at Allahabad, published (with Professor N.K. Saha) another book with the title *Modern Physics*. Although the book had many good points, it did not become very popular. Professor N.K. Saha later joined Delhi University where he became Professor of Physics.

In the year 1935, along with Acharya Prafulla Chandra Ray, Professor Meghnad Saha established the Indian Science News Association (ISNA). The main objective of the Association was to promote and disseminate knowledge, laying special stress on scientific studies in India and abroad and to advocate the methodical application of science to problems of national regeneration. With the above objectives in view, the Association has been publishing the journal *Science and Culture* every month with the first issue being published in June 1935 with Meghnad Saha and Bidhu Bhushan Ray as editors; see Ref. [8]. Professor Saha remained its editor until his death in 1956. As mentioned by Professor Suprakash Roy (its current Editor-in-Chief) '*From the very beginning,* ***Science and Culture*** *played an important role, not only in disseminating knowledge, but also in planning for the prosperity of the country*'.

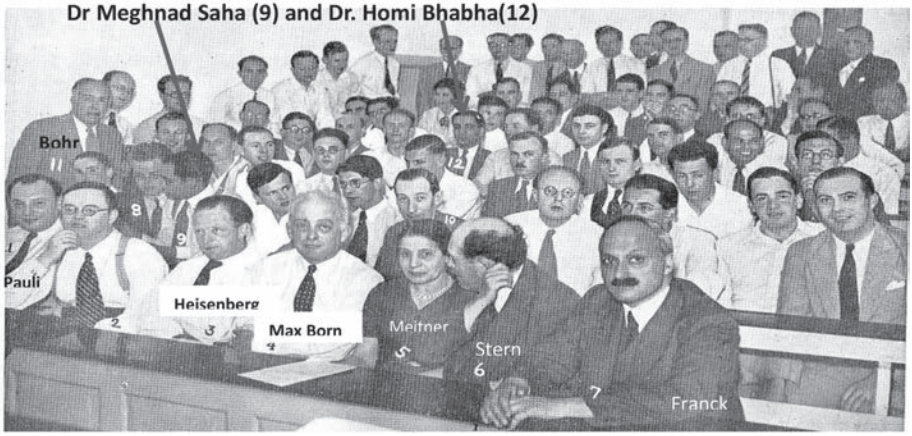
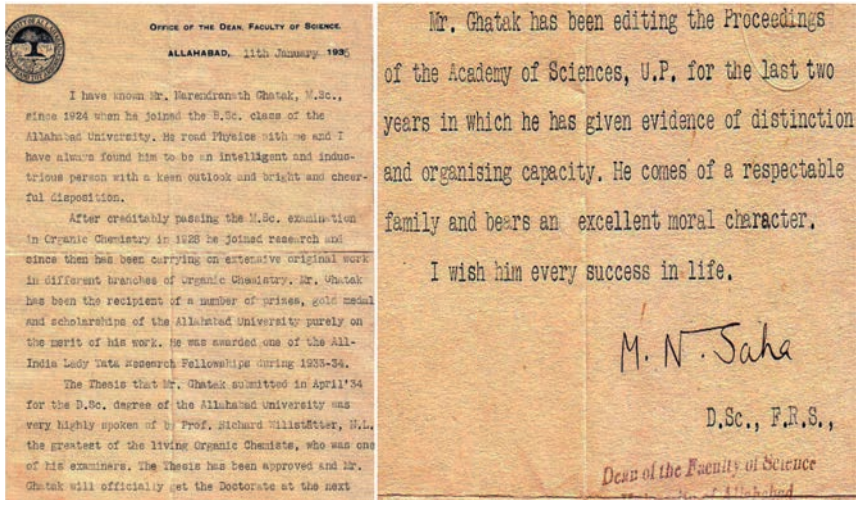


Fig. 11: Dr Meghnad Saha (9) and Dr Homi Bhabha (12) attending a conference in Copenhagen in 1936. Also shown in the photograph are Dr Wolfgang Pauli (1), Dr P. Jordan (2), Dr W. Heisenberg (3), Dr Max Born (4), Dr Lise Meitner (5), Dr Otto Stern (6), Dr J Franck (7), Dr Mark Oliphant (8) and Dr Niels Bohr (11).

Figure 11 shows Dr Meghnad Saha and Dr Homi Bhabha attending a conference in Copenhagen in 1936. Also shown in the photograph are great giants of Physics: Dr Wolfgang Pauli, Dr Jordan, Dr W. Heisenberg, Dr Max Born, Dr Lise Meitner, Dr J. Franck, Dr Mark Oliphant and Dr Niels Bohr.

4. My Father's Association with Professor Saha

My father, Dr Narendranath Ghatak, did his B.Sc. and M.Sc. from Allahabad University in 1926 and 1928, respectively. He had taken classes taught by Professor Saha and would often tell us the affection that Professor and Mrs Saha had for students.



OFFICE OF THE DEAN, FACULTY OF SCIENCE.

ALLAHABAD, 11th January 1935

I have known Mr. Narendranath Ghatak, M.Sc., since 1924 when he joined the B.Sc. class of the Allahabad University. He read Physics with me and I have always found him to be an intelligent and industrious person with a keen outlook and bright and cheerful disposition.

After creditably passing the M.Sc. examination in Organic Chemistry in 1928 he joined research and since then has been carrying on extensive original work in different branches of Organic Chemistry. Mr. Ghatak has been the recipient of a number of prizes, gold medal and scholarships of the Allahabad University purely on the merit of his work. He was awarded one of the All-India Lady Tata Research Fellowships during 1933-34.

The Thesis that Mr. Ghatak submitted in April'34 for the D.Sc. degree of the Allahabad University was very highly spoken of by Prof. Richard Willstätter, N.L. the greatest of the living Organic Chemists, who was one of his examiners. The Thesis has been approved and Mr. Ghatak will officially get the Doctorate at the next

Mr. Ghatak has been editing the Proceedings of the Academy of Sciences, U.P. for the last two years in which he has given evidence of distinction and organising capacity. He comes of a respectable family and bears an excellent moral character.

I wish him every success in life.

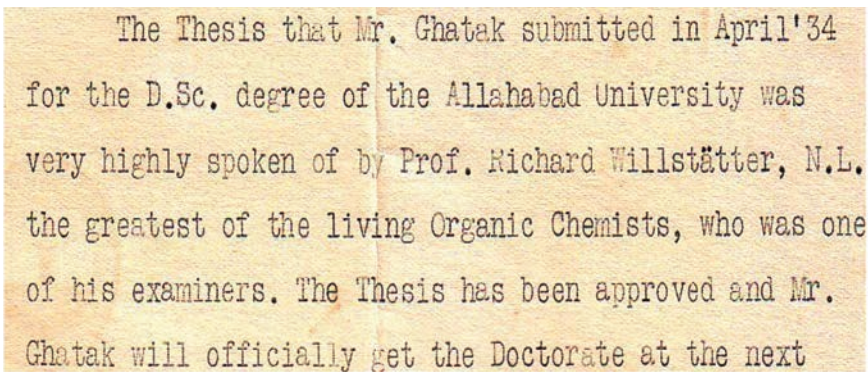
M. N. Saha

D.Sc., F.R.S.,

Dean of the Faculty of Science

Fig. 12: A testimonial (in the name of my father) from Professor Meghnad Saha dated 11 January 1935.

My father did his D.Sc. (in Organic Chemistry) under the guidance of Professor Nil Ratan Dhar. Figure 12 shows a testimonial that Professor Saha (who was then Dean, Faculty of Science at Allahabad University) wrote for my father. A small portion of the testimonial is pasted below.



The Thesis that Mr. Ghatak submitted in April'34 for the D.Sc. degree of the Allahabad University was very highly spoken of by Prof. Richard Willstätter, N.L. the greatest of the living Organic Chemists, who was one of his examiners. The Thesis has been approved and Mr. Ghatak will officially get the Doctorate at the next

As written in the testimonial, my father's D.Sc. thesis (submitted in April 1934) was sent to Professor Richard Willstatter who was a Nobel Laureate and, according to Professor Saha, he was the greatest of the living organic chemists. That a D.Sc. thesis was sent to a Nobel Laureate for examination, shows that (in pre-independent India), Professor Saha and his colleagues tried their best to promote research of the highest international standards. Only very recently Professor S.K. Joshi (who did his M.Sc. and Ph.D. from Allahabad University) told me that his doctoral thesis was sent to Nobel Laureate Professor von Laue for examination; his examiner from India was Professor Satyendra Nath Bose (who many feel should have won the Nobel Prize). Thus, the traditions initiated by people like Meghnad Saha and Nil Ratan Dhar were maintained in later years also. We only hope that other universities also set such high standards for their students and try to promote excellence in teaching and research.

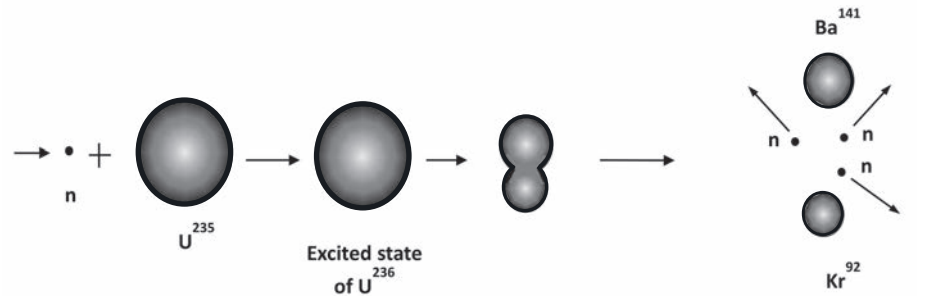
On the second page of the testimonial (see Fig. 12), Professor Saha wrote that my father was editing the Proceedings of the National Academy of Sciences, India which Professor Saha referred to as 'Academy of Sciences, UP' makes me feel very proud. It is in this context that my father got very closely associated with Professor Saha.

5. Return to Calcutta in 1938: Saha Institute of Nuclear Physics (SINP)

After spending nearly 15 years at the University of Allahabad, Professor Saha came back to the University of Calcutta, as Palit Professor of Physics in July 1938. In 1938, Otto Hahn and Lise Meitner discovered nuclear fission (see Fig. 13) and shortly afterwards, it was discovered that the neutrons emitted in a fission process can lead to a chain reaction leading to release of an enormous amount of energy (see Fig. 14). Controlled release of fission energy happens in a nuclear reactor whereas, in an atomic bomb, we have uncontrolled release of fission energy[3]. Professor Saha realized the importance of the discovery and of the need to study nuclear physics in India. He immediately persuaded the University authorities to include nuclear physics in the curriculum. He was the founder of Institute of Nuclear Physics in 1949. The building was formally inaugurated by Madame Irène Joliot-Curie on 11 January 1950 (see Fig. 15). After

[3] The first nuclear reactor was built by Enrico Fermi (and his collaborators) in Chicago and it became self-sustaining on December 2, 1942. Robert Oppenheimer was made the Director of the Manhattan project to build the atomic bomb and the first atomic bomb was exploded in Alamogordo, New Mexico, USA on July 16, 1945.

the death of Professor Saha, it was named as Saha Institute of Nuclear Physics (usually abbreviated as SINP). Figure 16 shows a photograph (taken during 1948-49) of Dr B.D. Nag Chaudhuri (who later became scientific advisor to the Ministry of Defence) and Prof. Meghnad Saha in front of the magnet of the cyclotron at the Institute of Nuclear Physics.



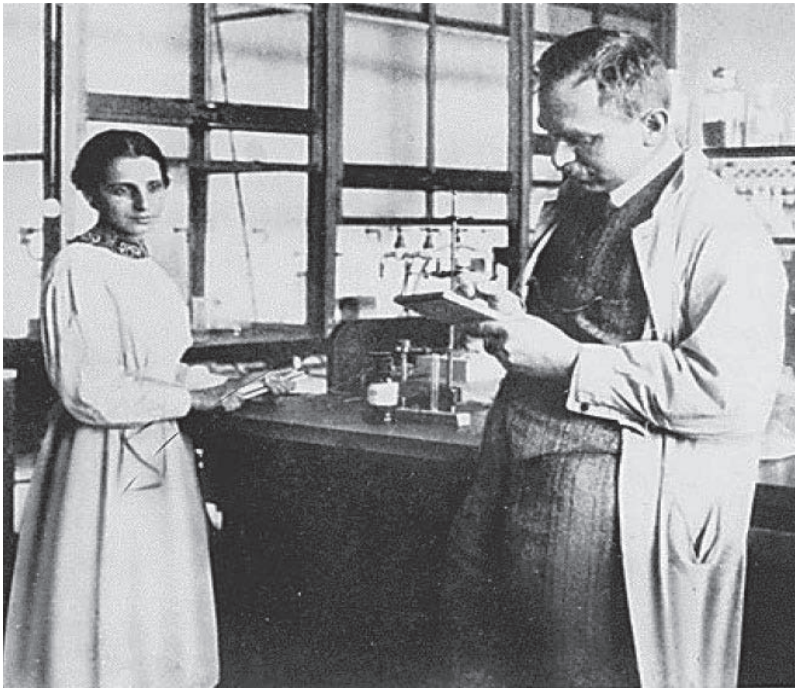


Fig. 13: In 1938, the fission of the uranium nucleus was discovered in Berlin by Lise Meitner and Otto Hahn. The fission fragments (shown as Ba and Kr in the figure) are very tightly bound nuclei and hence large amount of energy is released in the process.

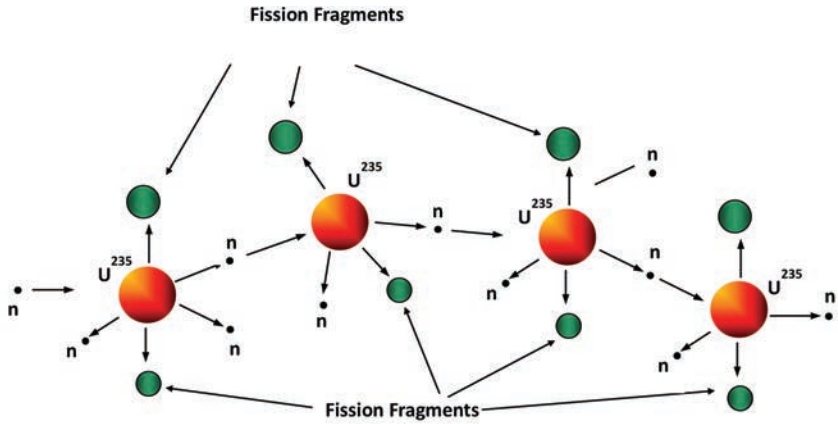


Fig. 14: The neutrons emitted in a fission process can lead to a chain reaction leading to release of an enormous amount of energy; controlled release of fission energy happens in a nuclear reactor whereas, in an atomic bomb, we have uncontrolled release of fission energy.

Fig. 15: The Institute of Nuclear Physics was formally inaugurated by Nobel Laureate Irène Joliot Curie on 11th January 1950. After Professor Saha's death in 1956, the Institute was renamed as Saha Institute of Nuclear Physics.

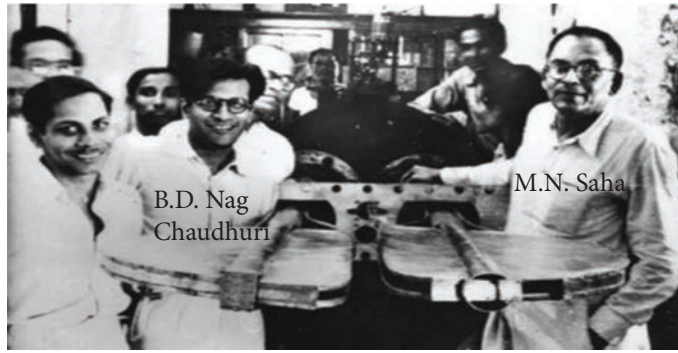


Fig. 16: Dr B.D. Nag Chaudhuri and Prof. Meghnad Saha (both with glasses) in front of the magnet of the cyclotron at the Institute of Nuclear Physics (1948-49). Photograph adapted from https://link.springer.com/content/pdf/bfm%3A978-81-322-2547-8%2F1.pdf

6. Jadavpur Campus of the Indian Association for the Cultivation of Science (IACS)

In 1869, in an article entitled 'On the Desirability of a National Institution for the Cultivation of Science by the Natives of India' the great visionary and philanthropist, Dr Mahendra Lal Sircar wrote:

> *'that the prevailing backwardness of the country was due to backwardness of science and, that the solution was in the vigorous pursuit of the sciences by original research[4]'.*

And, on 29th July 1876, Dr Mahendra Lal Sircar founded the size Indian Association for the Cultivation of Science (usually abbreviated as IACS) at 210 Bow Bazar Street, Calcutta (see Fig. 17) – supported by generous public contributions. It is at this institute that C.V. Raman carried out his Nobel Prize winning work.

In 1946, IACS embarked upon a new development plan under the dynamic leadership of Professor Saha envisaging the creation of an active research school in many different areas. By February 1948, Professor Saha with the help of prominent architects in Calcutta prepared a master plan of the Jadavpur campus of IACS (see Fig. 18). Professor Saha was the honorary secretary of IACS during 1944-45; president of IACS during 1946-51 and was the director of IACS from 1953 until his death in 1956.

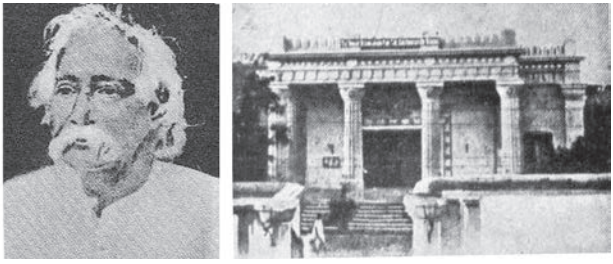


Fig. 17: Dr Mahendra Lal Sircar was the Founder of IACS at 210 Bow Bazar Street, Calcutta where C.V. Raman carried out research which got him the Nobel Prize.

[4] This is true even today: According to reports, today more than 30% of the population live below the poverty line that would imply that more than 360 million people are living in India below the poverty line. That is a staggering number and should be a matter of tremendous concern to all of us. We still have 'safai karamcharis' dying cleaning the sewers in the nation's capital and we also have numerous children bonded in slavery. And as mentioned by Dr Mahendra Lal Sircar, the solution to this problem is through education, science and technology.

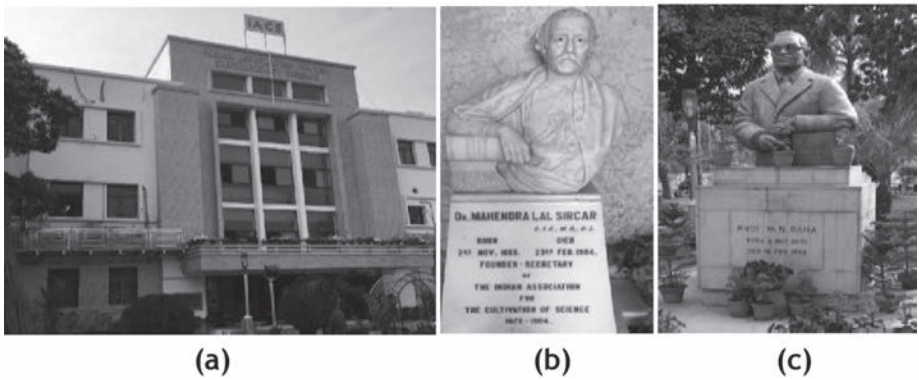


Fig. 18: (a) The new campus of IACS at Jadavpur, Kolkata; on the lawns of the new campus are the statues of (b) Dr Mahendra Lal Sircar (who was the founder of IACS) and of (c) Professor Meghnad Saha (who in 1948 prepared a master plan of the Jadavpur Campus of IACS) and was its Director from 1953 until his death in 1956. Photographs taken by the author in February 2018.

Professor Saha was also closely associated with the planning and establishment of the Central Glass and Ceramics Research Institute (CGCRI) at Calcutta (see Fig. 19); one of the national laboratories under the CSIR. He convinced Dr Shyama Prasad Mookerjee, then industry minister in the central cabinet, for setting up new building of CGCRI and requested him to arrange building grant from the government. New building was inaugurated in 1950. Professor Saha was for many years chairman of its Advisory Committee.

Fig. 19: Dr Bidhan Chandra Roy (First Chief Minister of West Bengal), Dr S.S. Bhatnagar (First Director General, CSIR), Dr Meghnad Saha, and Dr Atma Ram (First Director of CGCRI, Kolkata) with Pandit Jawahar Lal Nehru at CGCRI, Kolkata (a major R & D laboratory of CSIR).

In the year 1952, a Calendar Reform Committee was formed (under the Council of Scientific and Industrial Research of the Government of India) with Professor Meghnad Saha, as its chairman. A need was felt to develop a unified National Calendar on the basis of the most accurate modern astronomical data for the interest of national integrity. This eventually led to the creation of the Positional Astronomy Centre at Kolkata (see Fig. 20).

Fig. 20: Positional Astronomy Centre at Kolkata which was created to develop a unified National Calendar on the basis of the most accurate modern astronomical data.

7. Final Years

Professor Saha was the chief architect of river planning in India and prepared the original plan for the Damodar Valley Project.

And, in his final years, Professor Saha entered into politics and actively participated in planning of education, health, and river valley development. Professor Saha's own observations were (quoted from https://en.wikipedia.org/wiki/Meghnad_Saha):

> *'Scientists are often accused of living in the "Ivory Tower" and not troubling their mind with realities and apart from my association with political movements in my juvenile years, I had lived in ivory tower up to 1930. But science and technology are as important for administration now-a-days as law and order. I have gradually glided into politics because I wanted to be of some use to the country in my own humble way'.*

Professor Saha fought the 1951 Lok Sabha election against the 'powerful' congress candidate Mr Prabhu Dayal Himatsingka and won by more than

16% margin. To quote again from https://en.wikipedia.org/wiki/Meghnad_Saha:

> *'To actively participate in planning of education, industrialization, health, and river valley development Saha "decided to offer himself" as a candidate in the constituency of North-West Calcutta in the 1951 Loksabha … Saha actively participated in the parliament in the areas of Education, Refugee and Rehabilitation, Atomic Energy, Multipurpose River Projects and Flood Control and long term planning. In the book "Meghnad Saha in Parliament" Saha is described as "Never unduly critical, Saha was so forthright, so incisive, so thorough in pointing out lapses that the treasury bench was constantly on the defensive. This is brought out by the way he was accused of leaving his laboratory and straying into a territory not his own. But the reason why he was slowly drifting towards this public role (he was never a politician in the correct sense of the term) was the gradually widening gulf between his dream and the reality—between his vision of an industrialized India and the Government implementation of the plan. Saha was the chief architect of river planning in India and prepared the original plan for the Damodar Valley Project"'.*

Professor Saha had hypertension and on the morning of 16 February 1956, when he was going to the Planning Commission (in New Delhi), he suffered a massive cardiac arrest. He died while being taken to a hospital.

8. Concluding Remarks

In addition to the outstanding work which led to the Saha Ionization Equation (which should have given him the Nobel Prize) and many other very important research papers, he

(a) made Allahabad University a world-class university,

(b) created the Institute of Nuclear Physics at Kolkata (see Fig. 15),

(c) made IACS (Indian Association for the Cultivation of Science) a world-class research organization (see Fig. 18),

(d) created the CGCRI at Kolkata (see Fig. 19)

(e) and was responsible for the eventual creation of the Positional Astronomy Centre at Kolkata (see Fig. 20).

Professor Saha also established the first science academy of India (in Allahabad) and also played a very important role in the creation of what is

now known as INSA (Indian National Science Academy). And, in the year 1935, along with Acharya Prafulla Chandra Ray, Professor Meghnad Saha established The Indian Science News Association (ISNA) publishing the journal *Science and Culture* every month.

It is indeed amazing that one person could contribute so much to the development of our nation and it is very difficult to imagine what more he would have achieved had he not died at the early age of 63.

Many people (of all ages) have often asked me as to why no Indian scientist has been able to win the Nobel Prize after C.V. Raman. I tell them that whereas it will be very good to have an Indian win the Nobel Prize, but such a prize is the recognition of an individual; what we urgently require are people having leadership qualities (like Homi Bhabha, Meghnad Saha, Vikram Sarabhai, S.S. Bhatnagar and others like them) who have created institutions where research of the highest standards can be carried out. In a country of more than 1.2 billion people, what is very urgently required are many such leaders who would create many more institutions and also create an atmosphere of learning and innovation. We also require many more leaders of extraordinary vision who would guide the younger generation to world-class research and development. Then and then only we will be able to have many scientists who will make outstanding contributions in science and technology. We also require people like Ashutosh Mukherjee who have the vision of appointing outstanding scientists in senior positions. Ashutosh Mukherjee had appointed C.V. Raman (who did not have a doctorate degree) as Palit Professor of Physics; Raman did have a Master of Science degree with the highest distinctions from the University of Madras. Today no one will be able to appoint a faculty (no matter how brilliant he maybe) if he did not have a Ph.D. degree!!!

Acknowledgements

I thank Professor Patrick Dasgupta for telling me about the discovery of Helium and Professor Anirban Pathak for going through the manuscript and for his constructive suggestions.

Appendix A

Some Applications of Saha's Ionization Formula

In 1920 Professor Saha wrote a very important paper with the title 'Ionization in the Solar Chromosphere' which was published in the British Journal *Philosophical Magazine*, Series VI, 40, 472 (1920) (see Ref. [3]). What is chromosphere? To quote from https://en.wikipedia.org/wiki/Chromosphere

> *The **chromosphere** (literally, 'sphere of color') is the second of the three main layers in the Sun's atmosphere and is roughly 3,000 to 5,000 kilometers deep. The density of the chromosphere is only 10^{-8} times that of the atmosphere of Earth at sea level.*

Figure 21 shows a photograph of the chromosphere taken during the 1999 total solar eclipse in France.

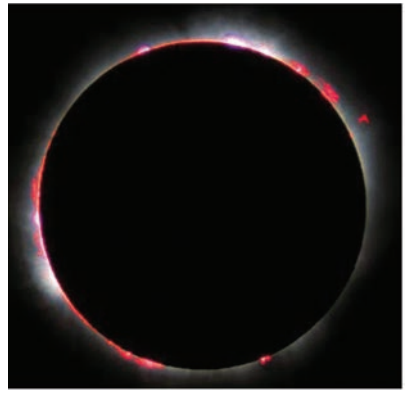


Fig. 21: Photograph of the chromosphere taken by Luc Viatour during the 1999 total solar eclipse in France; the photograph has been adapted from https://en.wikipedia.org/wiki/Chromosphere#/media/File:Solar_eclips_1999_5.jpg

A1. Ionization of Hydrogen Atoms

In the above-mentioned paper, using his ionization equation, Professor Saha derived the following formula for hydrogen:

$$\boxed{\log\frac{x^2}{1-x^2}P = -\frac{3.2.10^5}{4.571T} + \frac{5}{2}\log T - 6.5} \qquad (1)$$

where
P - represents pressure in atmospheres
x - represents fraction dissociated
T - represents absolute temperature

Thus, for example, at $T = 6000°$ K we get

$$\log\left(\frac{x^2}{1-x^2}P\right) = -\frac{3.2\times10^5}{4.571\times6000} + \frac{5}{2}\log(6000) - 6.5 \approx -8.72238$$

$$\Rightarrow \frac{x^2}{1-x^2}P = 1.89503\times10^{-9}$$

For $P = 10^{-11}$ atmospheres, we get

$$\frac{x^2}{1-x^2} = 189.503$$

Adding 1 on both sides, we get

$$\frac{1}{1-x^2} = 190.503 \Rightarrow x \approx 0.99 \qquad (2)$$

showing that the ionization is almost complete. In his 1920 paper, Professor Saha wrote:

> Thus only at the highest points of the chromosphere, where the partial pressure falls to 10^{-11} atmosphere, can the ionization be complete, and the vanishing of the H-lines be expected.

The boxed equation [Eq. (1)] is copied from Professor Saha's original 1920 *Phil. Mag.* paper. Thus, using Professor Saha's ionization equation, one can infer that the disappearance of the H-lines from the spectra obtained from the highest points of the chromosphere is due to the fact that the pressure must have fallen below 10^{-11} atmospheres. Using Saha's ionization formula, it also became possible to explain the absence of the spectral lines of alkali metals from certain regions of the chromosphere.

A2. Ionization of Calcium Atoms

We consider the ionization of calcium atoms in the outer layers of the Sun. Figure 22 shows that as we move away from the photosphere of the Sun, the pressure becomes low and calcium atoms become more and more ionized.

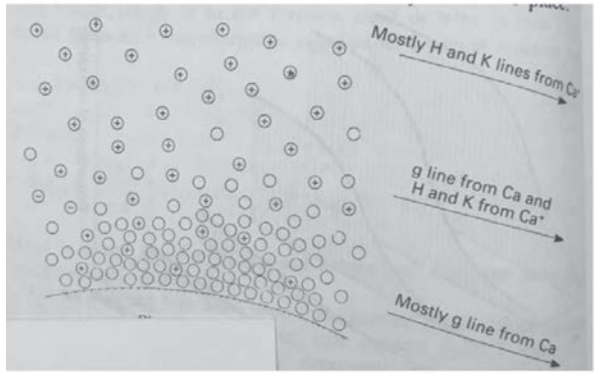


Fig. 22: As we move away from the photosphere of the Sun, the pressure becomes low and Calcium atoms become more and more ionized. Diagram adapted from Ref. [9].

Now, using the Saha ionization equation, Saha and Srivastava (Ref. 5) have obtained the following equation

$$\boxed{\log \frac{x^2}{1-x^2} P = -\frac{U}{2.3RT} + \frac{5}{2} \log T - 6.459,} \tag{3}$$

where
P - represents pressure in atmospheres
x - represents fraction dissociated
T - represents absolute temperature and
U - represents ionization energy

They apply the above formula to calcium and obtain the table given below:

Table 6.—Percentage Ionisation of Calcium.

Temp. \ pressure	1 atmos.	10^{-2} atmos.	10^{-4} atmos.
2000°K.	..	..	$1{\cdot}4 \times 10^{-3}$
3000	..	..	1
4000		2·8	26
5000	2	20	90
6000	8	64	99
7000	23	91	100
8000	46	98·5	,,

Source: Table adapted from the book by Saha and Srivastava (Ref. [5]) giving percentage ionization of calcium at various pressures.

Saha and Srivastava (in Ref. [5]) wrote:

> We may regard the ionization of a calcium atom as taking place according to the following scheme, familiar in physical chemistry,
>
> $$Ca \rightleftharpoons Ca_+ + e - U. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$
>
> Where Ca is the normal atom of calcium (in the state of vapour), Ca_+ is an atom which has lost one electron, U is the

Now for calcium[5], Ionization energy $U \approx 589.8$ kJ/mol. Further, the Gas constant $R = 8.314$ kJ/mol K.

Substituting the above values, we get for calcium

$$\frac{x^2}{1-x^2} P = 6.8425 \times 10^{-6}.$$

For $P = 10^{-4}$ atmospheres (see the last column in the Table), we get

$$\frac{x^2}{1-x^2} = 0.068425 \;\Rightarrow\; x \approx 0.253. \tag{4}$$

Thus, we get 25.3% for percentage ionization (instead of 26% in the Table) because we may have used a slightly different value of the ionization energy than that used by Saha and Srivastava. Similarly, we can calculate other numbers in the above table which has been adapted from Ref. [5]. Thus by using Saha's ionization equation, we can deduce that at temperatures over 6000°K, calcium atoms will be almost fully ionized at pressures less that 10^{-4} atmospheres.

We may mention here that the ionization energy of hydrogen is 13.598 eV which will correspond to 1312 kJ/mol. Thus

$$-\frac{U}{2.3\,RT} = -\frac{1312 \;\; (\text{kJ/mol})}{2.3 \times 8.314 \; (\text{J/mol K}) \times T\,(\text{K})} \approx -\frac{6.86 \times 10^4}{T\,(\text{K})}.$$

The first term on the right hand side of Eq. (1) is

$$-\frac{3.2 \times 10^5}{4.571 \times T\,(\text{K})} \approx -\frac{7.00 \times 10^4}{T\,(\text{K})}.$$

[5] The first ionization energy of the Calcium atom is $6.11316 \text{ eV} \approx 9.79438 \times 10^{-19}$ J; if we now multiply it by the Avogadro number 6.0221416×10^{23} we would get $U \approx 589.8$ kJ/mol; values adapted from https://en.wikipedia.org/wiki/Ionization_energies_of_the_elements_(data_page)

The small difference in the value of the numerator is due to the fact that Saha wrote that *Phil. Mag.* paper about 100 years back and the values of R and U used may have been slightly different!!

As mentioned by Dr Sam Kean (see Ref. [10])

> *'Electrons within atoms absorb light of specific frequencies, creating the dark bands in stellar spectra. And Saha determined that as rising temperatures strip more and more electrons out of atoms, the location and number of the dark bands change. In other words, different temperatures lead to different patterns of bands. So when astronomers were sorting stars into different groups by spectrum, they were really sorting them by temperature. What's more, after Saha provided equations to describe thermal ionization, other astronomers could determine related information, such as the precise temperatures of stars and the abundance of elements in side them. Thanks to Saha, humankind understood what stars were fiery balls of hydrogen for the very first time'.*

Svein Rosseland writes in his 1936 book *Theoretical Astrophysics: Atomic Theory and the Analysis of Stellar Atmoshperes and Envelopes* (see Ref. [11]):

> *'The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas'.*

Appendix B

Understanding of Spectra of Atoms and Ions

The emission (and the absorption) spectrum of each atom is unique and can be considered as its signature and therefore many properties of a star are determined from the analysis of spectra obtained by viewing the star. As such, we will discuss here the emission and absorption spectra of atoms. In Appendix A we have shown that, for example, at very low pressures, the hydrogen atom in the chromosphere of the Sun is almost totally ionized. Thus if we look through the telescope, we will find the absence of the spectra from hydrogen atoms.

B1. Spectra of Hydrogen and Hydrogen like Atoms

The simplest atom is the hydrogen atom which consists of one proton and one electron and in the simplest model of the hydrogen atom (put forward by Niels Bohr in 1913), the electron rotates in discrete circular orbits around the proton as shown in Fig. 23 such that the radii of different orbits are given by

$$r_n = n^2 a_0 \text{ where } n = 1,2,3\ldots \tag{5}$$

and

$$a_0 \approx 0.529\times10^{-10}\ \text{m} \tag{6}$$

is known as the Bohr radius; the radii in the Fig. 23 are also in that ratio. Thus the radii of different orbits are

0.529×10^{-10} m, 2.116×10^{-10} m, 4.761×10^{-10} m, … .

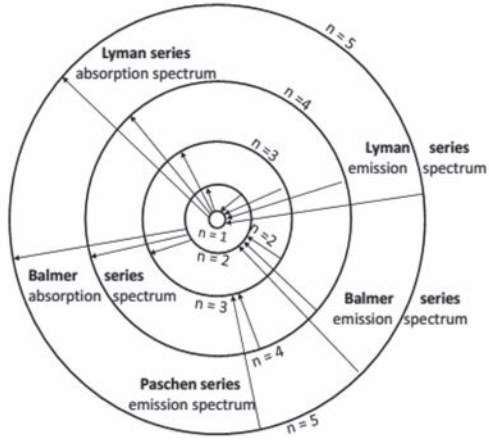


Fig. 23: The discrete orbits of the hydrogen atom as predicted by Bohr's theory.

The total energy of the atom depends on which orbit the electron is rotating. According to Bohr's theory, the total energy (potential energy + kinetic energy) of a one electron atom, when the electron is rotating in the n^{th} orbit, is given by

$$E_n = -|E_n| = -\frac{\mu c^2 Z^2 \alpha^2}{2n^2}; n = 1,2,3,.... \quad (7)$$

where c = 2997924588 m/s represents the speed of light in free space; Zq represents the charge of the nucleus (Z = 1 for hydrogen and deuterium atoms, Z = 2 for He^+ ion, Z = 3 for Li^{++} ion, etc.);

$$\alpha = \frac{q^2}{4\pi\varepsilon_0 \hbar c} \approx \frac{1}{137.036} \quad (8)$$

represents the fine structure constant and further,

$$\mu = \frac{m_e M_N}{m_e + M_N} \quad (9)$$

is the reduced mass with m_e and M_N representing the mass of the electron and that of the nucleus respectively with. For the hydrogen atom

$$m_N = m_p \approx 1.6726 \times 10^{-27} \text{ kg}$$

giving

$$\mu_H \approx 9.1045 \times 10^{-31} \text{ kg}$$

where we have taken $m_e \approx 9.1094 \times 10^{-31}$ kg. On the other hand, for the deuterium atom

$$m_N = m_D \approx 3.3436 \times 10^{-27} \text{ kg}$$

giving $\mu_D \approx 9.1070 \times 10^{-31}$ kg

The energy states of the hydrogen atom, as given by Eq. (3) are shown in Fig. 24.

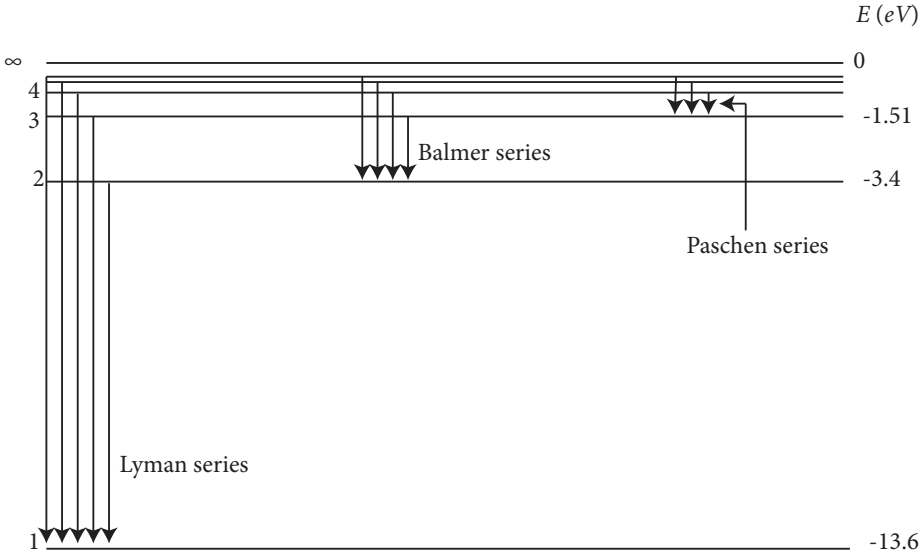


Fig. 24: The discrete energy levels of the hydrogen atom as predicted by Bohr's theory.

When an electron jumps from a higher energy state E_m to a lower energy state E_n, a photon of energy $E_m - E_n$ is emitted; this results in the *emission spectrum of the atom*. Conversely, when a photon of energy $E_m - E_n$ is absorbed by the atom, the electron jumps from a lower energy state E_n to a higher energy state E_m; this results in the *absorption spectrum of the atom*. Now, for the $m \to n$ transition, the wavelength of the emitted radiation is given by

$$\frac{1}{\lambda} = \frac{\nu}{c} = \frac{E_m - E_n}{hc} = Z^2 R\left[\frac{1}{n^2} - \frac{1}{m^2}\right] \tag{10}$$

where

$$R = \frac{2\pi^2 \mu}{ch^3}\left(\frac{q^2}{4\pi\varepsilon_0}\right)^2 = \frac{\mu c \alpha^2}{2h} \tag{11}$$

is known as the Rydberg constant. Values of the Rydberg constant for different (one electron) hydrogen like atoms are given below:

$$R = \begin{cases} 109677.58\ \text{cm}^{-1} & \text{(for the hydrogen atom)} \\ 109707.56\ \text{cm}^{-1} & \text{(for the deuterium atom)} \\ 109722.40\ \text{cm}^{-1} & \text{(for the } He^{+}\text{ - atom)} \\ 109728.90\ \text{cm}^{-1} & \text{(for the } Li^{++}\text{ - atom)} \end{cases} \quad (12)$$

The slight difference in the values of R is because of the difference in the values of the reduced mass μ. The solution of the Schrödinger equation for the Hydrogen-like atoms gives the same expression for the energy levels.

B2. Spectrum of the Hydrogen Atom

We consider the hydrogen atom for which $Z = 1$. For the $m \to 2$ ($m = 3,4,5,\ldots$; $n = 2$) transitions, the wavelength of the emitted radiation will be

0.656 μm (which is in the red region of the spectrum) for the $3 \to 2$ transition

0.486 μm (which is in the blue region of the spectrum) for the $4 \to 2$ transition

0.434 μm (which is in the violet region of the spectrum) for the $5 \to 2$ transition and

0.4103 μm (which is also in the violet region of the spectrum) for the $6 \to 2$ transition.

The $m \to 2$ $(m = 3,4,5,\ldots; n = 2)$ transitions given above are referred to as the Balmer series, the corresponding spectral lines are in the visible region of the spectrum. The $m \to 1$ $(m = 2,3,4,5,\ldots; n = 1)$ transitions give rise to what is known as the Lyman series, the corresponding spectral lines are in the ultraviolet region; for example, the $2 \to 1$ transition give rise to wavelength of 0.1217 μm which is in the ultraviolet region; we may recall that the violet end of the visible spectrum has a wavelength of about 0.35 μm. Similarly, the $m \to 3$ $(m = 4,5,6,\ldots; n = 3)$ transitions give rise to what is known as the Paschen series, the corresponding spectral lines are in the infra-red region. Each wavelength is a characteristic of the Hydrogen atom and is referred to as the 'emission spectrum' which is obtained by having a discharge in a gas of Hydrogen atoms and allowing a collimated beam to fall on a prism (see Fig. 25). The electric discharge gets the hydrogen atom excited to higher energy states and when the atoms (in the higher energy state) make a transition to the lower energy state, we obtain the characteristic lines of the Hydrogen atom. This is known as the emission spectrum which is kind of a signature of the atoms (or molecules) in the gas. The emission spectrum of the Hydrogen atom shown in Fig. 25.

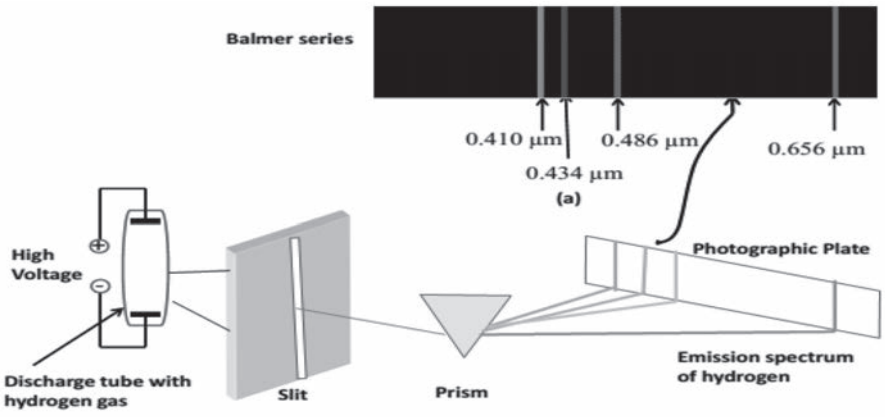


Fig. 25: The emission spectrum of the hydrogen atom.

B3. Comparison of the spectrum of the Hydrogen atom with that of deuterium

For deuterium, the values of the reduced mass (and hence of the Rydberg constant) are slightly different. For the $n = 3 \rightarrow n = 2$ transition, the wavelength of the emitted radiation comes out to be 0.65652 μm for the hydrogen atom and 0.65634 μm for the deuterium atom respectively. The corresponding wavelengths for the $n = 4 \rightarrow n = 2$ transition is 0.48631 μm and 0.48617 μm for the hydrogen atom and the deuterium atom respectively. Such small differences in wavelength (which is due to the difference in the reduced mass μ) was first observed by Urey in 1932 which led to the discovery of deuterium.

One can see the power of spectroscopy: careful measurement of the wavelength of the spectral lines leads to great discoveries.

B4. Spectra of Other Atoms

The spectra of the helium atom or of the lithium atom are quite different from that of hydrogen. Figure 26 shows the emission spectrum of hydrogen, helium, lithium and oxygen. The most important point is

> **The emission (and the absorption) spectrum of each atom is unique and can be considered as its signature. By studying in detail a measured spectrum, one can determine the elements present in the gas. In fact, spectroscopy is one of the most important tools to determine the gases present in the stars.**

In Fig. 26 we see a strong yellow line in the spectrum of helium. Indeed on August 18, 1868, during a total solar eclipse in Guntur (in South India), the French astronomer Jules Janssen saw a yellow line in the spectrum of the chromospheres of the Sun[6]. Initially, it was thought to be that from sodium which gave rise to 2 yellow lines of wavelengths 0.5890 μm and 0.5896 μm (these are the well-known D1 and D2 lines of sodium). However, careful measurements showed that the wavelength of the observed yellow line was 0.5875 μm (see Fig. 26) which was different from that of sodium. Thus it was surmised that the wavelength was due to an element which was not yet detected on earth. The English chemist Edward Frankland named it helium element deriving it from the word '*helios*' – the Greek word for the Sun. Once again we see the power of spectroscopy and this time it is the spectroscopy of the light coming from our Sun.

Although the spectra of the helium atom or of the lithium atom are quite different from that of hydrogen, the spectra of the He^+ ion (i.e., singly ionized helium atom) or of the Li^{++} (doubly ionized Lithium atom) are similar to that of the hydrogen atom because both He^+ ion and Li^{++} ion are single electron ions. However, the corresponding wavelengths are smaller by a factor of about 4 for the He^+ ion and by a factor of about 9 for the Li^{++} ion; this is because of the Z^2 term in the expression of energy levels and also because of the slight difference in the values of the reduced mass. For example, for the $n = 4 \rightarrow n = 3$ transition, the wavelength of the emitted radiation comes out to be 1.8756 μm (which is in the far infra-red region) for the hydrogen atom and 0.4687 μm (which is in the visible region) for the He^+ ion respectively.

If we have a white light source (like an incandescent light bulb), we will have a continuous spectrum on the photographic plate as shown in Fig. 27. All colors between red and blue will be present. If we put a glass container of hydrogen gas between the white light source and the slit (see Fig. 28), then certain frequencies will be absorbed by the hydrogen atom and will result in the atom getting excited to higher energy states; the subsequent emission will, in general, be in different directions. This will result in the black lines – exactly at wavelengths where we had the emission spectrum. This is the absorption spectrum of the element (in this case, hydrogen).

[6] Georges Rayet, C.T. Haig, Norman R. Pogson and John Herschel are also credited with the discovery of helium from the observations made during the total Solar eclipse on August 18, 1868; see https://en.wikipedia.org/wiki/Helium.

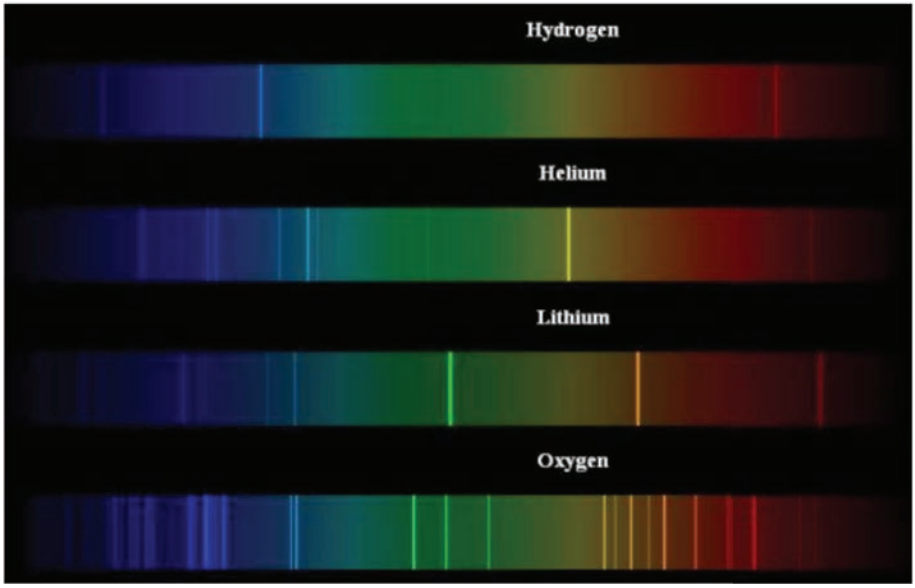


Fig. 26: The emission spectrum of hydrogen, helium, lithium and oxygen. The emission (and the absorption) spectrum of each atom is unique and can be considered as its signature. By studying in detail a measured spectrum, one can determine the elements present in the gas. In fact, spectroscopy is one of the most important tools to determine the gases present in the stars. The above photograph has been adapted from http://www.thunderbolts.info/forum/phpBB3/viewtopic.php?f=3&t=14811

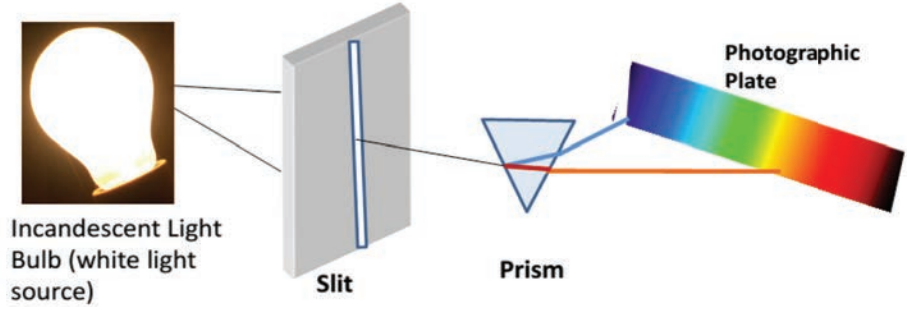


Fig. 27: If we have a white light source (like an incandescent light bulb), we will have a continuous spectrum on the photographic plate. All colours between red and blue will be present.

Figure 29 shows the emission (and the absorption) spectrum of the hydrogen atom. Notice that the dark lines occur exactly at the same wavelength as that of the emission spectrum. In the emission spectrum, a photon of a particular frequency is emitted as the atom makes a transition from an excited state to another state (associated with a smaller energy). On the other hand, in the absorption spectrum, a photon of a particular frequency is absorbed as the atom makes a transition from a lower energy state to an excited state.

Now, instead of the incandescent bulb, if we have sunlight illuminating the slit (see Fig. 30), we will have many dark lines superimposed on the continuous spectrum. These dark lines were first observed by W.H. Wollaston in 1802.

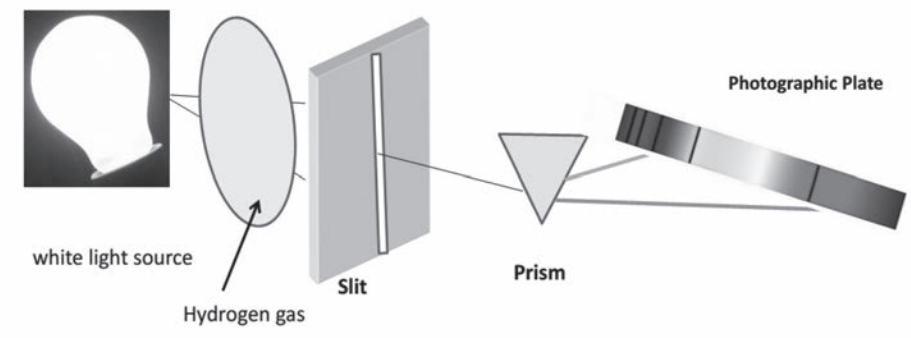


Fig. 28: If we put a glass container of Hydrogen gas between the white light source and the slit, then certain frequencies will be absorbed by the hydrogen atom and will result in the atom getting excited to higher energy states; the subsequent emission will, in general, be in different directions. This will result in the black lines – exactly at wavelengths where we had the emission spectrum. This is the absorption spectrum of the element (in this case, hydrogen).

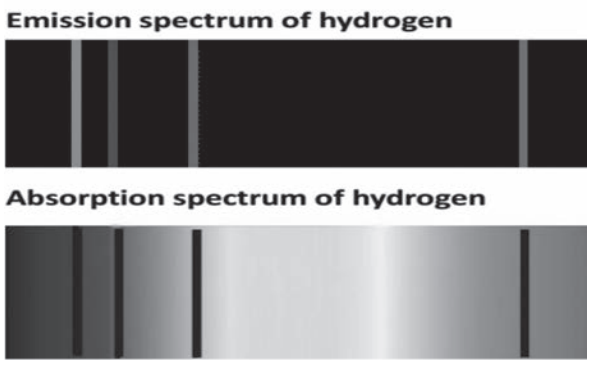


Fig. 29: Emission and absorption spectrum of the hydrogen atom.

In 1814, Fraunhofer independently discovered this and carefully measured the wavelengths corresponding to the various dark lines and therefore the dark lines are usually referred to as Fraunhofer lines. Later, in 1845, Kirchhoff and Bunsen carefully compared the measured wavelengths of the dark lines with the emission spectrum of various atoms and concluded that the dark lines coincide with the emission spectrum of different atoms and therefore they occur because of absorption by different elements present in the atmosphere of the Sun. Thus, the C and F lines shown in the diagram correspond to the wavelengths 0.656 μm and 0.486 μm which are due to absorption by the hydrogen atom [see Fig. 30]. Other lines correspond to the presence of other elements like helium, oxygen, sodium, etc. Therefore, a careful analysis of the Fraunhofer lines has tremendous applications in astrophysics as it allows us to determine the gases present in the atmosphere of various stars.

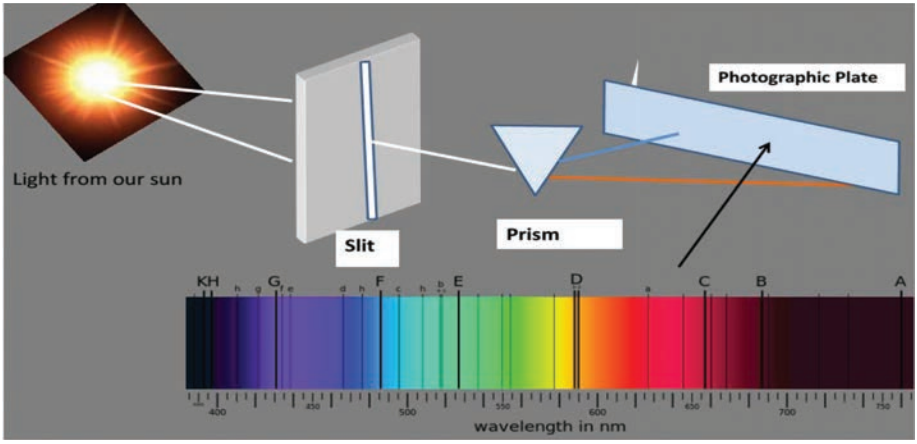


Fig. 30: Fraunhofer lines in the solar spectrum. The C and F lines shown in the diagram correspond to the wavelengths 0.656 μm and 0.486 μm which are due to absorption by the hydrogen atom [see Fig. 12.2(a)]. Other lines correspond to the presence of other elements like helium, oxygen, sodium (D lines of sodium), etc. Therefore, a careful analysis of the Fraunhofer lines has tremendous applications in astrophysics as it allows us to determine the gases present in the atmosphere of various stars. Photograph adapted from http://upload.wikimedia.org/wikipedia/commons/2/2f/Fraunhofer_lines.svg

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2. Meghnad Saha and NASI

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For any academy or any other organization, it is one of the happiest occasions when the founder's birth anniversary is being celebrated. In that sense, this is one of the happiest years for the National Academy of Sciences India (NASI) as it is celebrating 125th birth anniversary of its founder Professor Meghnad Saha, who was a very distinguished scientist, an administrator, planner and above all a great patriot – he had a unique personality and he was always concerned with the scientific and technological progress of the country. He established the Academy of Sciences of the United Provinces of Agra and Oudh in 1930 at Allahabad as the first science academy in India. It was registered on 4th December 1930. The name of the Academy was later changed to the National Academy of Sciences India (NASI) on 5th December 1936. Today, it has more than 3500 scientists, technologists, doctors, engineers and other professionals as fellows and members. It is the oldest of the science academies in India. A unique feature of the Academy is the membership which is given preferably to the younger scientists, also to senior ones, who are unable to compete for the fellowship. There are more than 1730 members today widely spread across the nation. The numbers of fellows are 1759 with 18 Local Chapters located in the following places:

- Bangalore
- Chandigarh
- Chennai
- Delhi
- Hyderabad
- Jammu
- Jharkhand
- Kharagpur
- Kolkata
- Lucknow
- Mumbai
- N.E. (Shillong)
- Patna
- Pune
- Uttaranchal
- Varanasi
- Bundelkhand E R
- Ahmedabad

Professor Meghnad Saha, the founder president gave the most relevant mandate to the Academy – 'Science and Society'. He said:

> *'An Academy of Science can do a great deal by educating public opinion, undertaking particular problems, and bringing out scientific workers in various fields for discussion and cooperative research. But the main function of the Academy should be towards cultural improvement by contributions to human knowledge'.*

Even today NASI follows the views of the founder and some of the main objectives of the Academy are:

- Cultivate and promote Science and Technology in all its branches.
- Promote scientific and technological research concerned with the problems of national welfare.
- Organize meetings and hold discussions on scientific and technological problems.
- Publish such proceedings, journals, memoirs, transactions and other works as may be considered desirable.
- Maintain a science library.
- Undertake, through properly constituted committees and bodies, such scientific work of technological or public importance as it may be called upon to perform.
- Co-operate with other organizations in India and abroad, having similar objectives, and to appoint representatives of the Academy to act on national and international bodies.
- Do and perform all other acts, matters and things that may assist in, conducive to, or be necessary for the fulfillment of the above-mentioned aims and objectives of the Academy.

During last 25 years, there has been a major transformation in the activities of the Academy. It has had the benefit of being guided by many eminent scientists. Noteworthy in the recent times being Professor M.S. Swaminathan, Late Professor M.G.K. Menon, Professor P.N. Tandon, Professor K. Kasturirangan, Professor Akhilesh Tyagi, Late Dr V.P. Sharma, Late Professor A.K. Sharma and Professor Asis Datta. Dr Anil Kakodkar is presently the president and Professor G. Padmanaban, one of the most distinguished biologists of the country is the president elect for 2019. Inspired by the views of its founder Professor Saha, there is a special focus of

the Academy on science and technology interventions for societal benefits, programmes being guided by the council and its fellows and members.

Briefly I would like to describe the important activities of the Academy and their alignment with some of the national missions like Swachh, Swastha and Samarth Bharat. There are very important programmes of skill development and importance of science and technology education.

The major programmes being undertaken under the supervision of distinguished scientists of the country are:

- Science and Technology Communication, Popularization of Science, S & T Awareness and Sensitization.
- Awareness and training, Safe drinking water and pollution abatement especially for the rural areas and municipal workers – contributing towards '**Swachha Bharat Mission**'.
- Special focus on women scientists
- School children
- Rural chaupals
- Sensitization and awareness building for science and technology interventions for defence personnel – the first of its kind.
- Science paper writing workshops – so far more than 10 have been held in different academic institutions, educating the young scientists on writing scientific papers (see Appendix 1 and Fig. A-2).
- Writing of science proposals, etc.

Fig. 1: Baoli-before and after rejuvenation at Bundelkhand. This was the programme conceptualized and implemented under the supervision of Late Dr V.P. Sharma.

(See Appendix 1 to obtain a glimpse of the various programmes being undertaken by the Academy across the country.)

In addition, the Academy organizes hundreds of science communication/ education programmes to stimulate the school and college students for cultivation of the scientific temper and to opt for science as a career. A few of those programmes are:

- Children science meet, summer and winter schools, vocational training programmes, scientific writing contests, vigyan, jal and health chaupals, seminars, teacher's training and celebration of national technology day, national science day and world environment day, etc.

The Academy also recognizes individual scientists and teachers by giving various lecture awards and NASI-Science Teacher's Awards. They also organize workshops on 'scientific paper writing' and programmes on 'women's sensitization'. Specially, following activities/steps have been taken up as the follow-up of the Academy's women's sensitization initiatives (also see Appendix 1 and Fig. A-1).

- NASI-Science Teacher's Awards.
- A series of workshops on scientific paper writing.
- NASI and ICAR held a joint meeting of stakeholders to discuss the need for farm implements to reduce the drudgery of farming community, especially the women; and NASI–ICAR award has been instituted to be given every year to a researcher for developing farm implements.
- A joint meeting/workshop was also held at the National Institute of Nutrition, Hyderabad, to discuss the problems and hazards of malnutrition in India; the programmes are being developed for implementing the recommendations of this workshop in collaboration with the NIN and other bodies.

There is an Inter Academy panel for women which has produced a vision document highlighting the achievements of various schemes and giving several recommendations for the future progress.

We have already mentioned that NASI recognizes the contributions of individual scientists and confer various fellowships and awards (see Fig. 2). Some of them are:

- NASI Lecture Awards – given to about 15 scientists every year, for promoting research vigorously.
- NASI-Reliance Industries Platinum Jubilee Awards for the Application Oriented Innovations covering both Physical and Biological Sciences.
- NASI-Young Scientist Platinum Jubilee Awards in the fields of Biological/Physical/Chemical Sciences, to boost the zeal of enterprising young scientists.
- NASI – Swarna Jayanti Puruskars for Best Paper Presentation in the Annual Session by the budding scientists.
- NASI Scopus Awards given to the budding scientists.

Fig. 2: (Year 2015) – Hon'ble Minister for Science and Technology, Govt. of India, Dr Harsh Vardhan, presenting the Professor M.G.K. Menon Lecture Award to Professor Govind Swarup at New Delhi.

Under the leadership of Professor M.S. Swaminathan, Late Professor M.G.K. Menon and the then President, I developed the concept of establishing galleries for important rivers of the country. These depict scientific, cultural, religious and educational aspects of the river for the education of general public particularly the students. So far it has been possible with the full support of the presidents of the Academy to establish galleries at Allahabad for river Ganges (see Fig. 3): at Guwahati for river Brahmaputra (see Fig. 4); and at Mysore for

river Cauvery. All these have been widely appreciated by the general public and scientific community. They also attract tourists in large numbers. These galleries also depict the views of our founder Professor M.N. Saha who also initiated scientific studies of river physics and river planning in India.

Fig. 3: Ganga Gallery at NASI, Allahabad.

Fig. 4: Brahmaputra Gallery at Guwahati.

A very important aspect of the Academy is its publication: A few important publications are listed below:

- **Proceedings of NASI, Sec. A & B, each in IV parts & Science Letters in VI parts**. These journals are published in collaboration with Springer India and important research papers are published in these journals;
- Several important publications on **'Socio-scientific'** issues;
- **9 volumes** of the **'History of Science in India'**, which were distributed to the concerned government and non-government agencies;
- **Vision Document** on women in science;
- **'Festschrift'**, dedicated to the legendary scientist **Professor M.G.K. Menon**, released by Hon'ble Minister for Science & Technology, Govt. of India; a copy of which was also presented to Hon'ble Prime Minister of India (see Fig. 5).

Fig. 5: (Year 2016) 'Festschrift', dedicated to the legendary scientist Professor M.G.K. Menon, being presented to Hon'ble Prime Minister Shri Narendra D Modi, by Professor Akhilesh K. Tyagi and Professor Manju Sharma, Past Presidents, NASI.

Among the publications, the proceedings of the 'Symposium on Basic Research – It's Role in National Development' has been published, it has been edited by Professor P.N. Tandon and myself. This is dedicated to Late Professor M.G.K. Menon, the architect of the New Initiatives of the Academy.

As it's already mentioned, the Academy continuously works on women empowerment. On 8th March 2018, on the International Women's Day, a mega event was organized at Vigyan Bhawan to commemorate the day and to discuss the Technological Empowerment of Women. Many national and

international experts participated. The proceedings have been printed. More than 1000 women scientists were present. The event was inaugurated by the Minister for Science and Technology, Environment and Earth Sciences, Dr Harsh Vardhan. Large number of women scientists and the IIT Directors were so appreciative of this programme that they all wanted many more to be organized (see Fig. 6 and Fig. 7).

Fig. 6: (a) and (b) Inauguration of the National Conference on the Technological Empowerment of Women, (c) and (d) Conferment of Foreign Fellowship to Professor Karen Nelson, USA by the Hon'ble Minister, S&T, Earth Sciences & Environment, Dr Harsh Vardhan, (e) and (f) Felicitation of Guests, 8th March 2018, Vigyan Bhawan, New Delhi.

Fig. 7: Glimpses of mega event on 8th-9th March 2018.

As Academy has always been interested in taking up new and relevant activities for the welfare of the society, the Council had designated late Professor M.G.K. Menon as the chairman for the New Initiatives – as a result the Science Popularization Activities really got a big boost. After him I took over as the chairperson of the New Initiatives and have started many activities as mentioned above with a focus on the society.

The Department of Science and Technology entrusted the Academy to do some programmes for the scheduled tribes. I as the chairperson of the Expert Committee constituted by the Council, contacted various institutes/ organizations/local chapters of NASI to come forward with specific programmes for which I developed a format and an illustrative list of areas in which proposal could have been submitted. Very good response was received. In total more than 20 proposals were received, examined and approved by the Academy for implementation. Some of the institutions and Local Chapters involved were:

- NASI-NER Chapter, Shillong
- NASI-Jharkhand Chapter
- NASI-BER Chapter, MP
- NASI-Jammu Chapter
- Biotech Park, Lucknow
- CSIR-CIMAP, Lucknow
- M.S. Swaminathan Research Foundation
- Sri Padmavati Mahila Visva Vidyalayam (Women's University), Tirupati
- ICMR-NITM, Belagavi, Karnataka

- Indira Gandhi National Tribal University, Amarkantak (MP)
- ICMR-National Institute of Traditional Medicine, Belagavi
- Institute of Life Sciences, Bhubaneswar, Odisha

The programme is being reviewed six monthly at one of the Centres where the implementing institutions give detailed presentation. Mid-term corrections are made on the basis of the reviews. List of workshops organized for this programme are given in Appendix 2 (also see Figs. B 1-B 10).

Two special events have been organized this year by NASI. On 2nd October 2018 at a village near Allahabad – Sankargarh, to commemorate birth anniversary of Ba and Bapu, a programme was launched; several students and villagers from nearby areas attended (see Fig. 8). Message of both Ba and Bapu was communicated and were greatly appreciated by the participants. NASI has written to all its Local Chapters to organize at least one lecture during the year, some of the Chapters (including Delhi Chapter) have already organized it.

Fig. 8: Photographs taken on October 2, 2018 at Sankargarh, to commemorate birth anniversary of Ba and Bapu.

Another event was held on 6th -7th Oct. at NASI, Allahabad to celebrate the 125th anniversary of Professor Meghnad Saha (see Fig. 9); very eminent scientists of the country participated in the programme leading to its grand success. This book actually originates from the lectures given in that event. Local Chapters have also been requested to organize events in this regard.

Fig. 9: Photographs taken on October 6 and 7, 2018 at Allahabad during the two-day seminar organized to celebrate the 125th birth anniversary of Professor Meghnad Saha.

Conclusions

Professor Meghnad Saha said:

> *'Scientists are often accused of living in the "Ivory Tower" and not troubling their mind with realities and apart from my association with political movements in my juvenile years, I had lived in ivory tower up to 1930. But science and technology are as important for administration now-a-days as law and order. I have gradually glided into politics because I wanted to be of some use to the country in my own humble way'.*

World over his vision and keen interest in promoting science and technology was recognized. Albert Einstein wrote about him as:

> '*Professor M.N. Saha to whom Physics, particularly, Astrophysics, is indebted for many valuable contributions, has reported to me about the Academy of Sciences, which has been called into existence at Allahabad with a high object'.*

I have tried to summarize the impact of Professor Meghnad Saha's vision on NASI's activities; the mandate given by the founder was always used as the roadmap for future endeavours of the Academy. I may not have covered everything that NASI does, but in this humble effort it has been brought out clearly that NASI, through its fellows and members, has been doing more and more programmes for the welfare of the society through S & T interventions towards the socio-economic progress of the nation.

The scientific community still believes firmly and works towards what Sir C.V. Raman said in 1948:

'There is only one solution for India's economic problem and that is science and more science and still more science'.

Acknowledgements

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Appendix 1

Programmes undertaken by the Academy

Women Sensitization Events

S. No.	Date	Location/Host Institution (Places/ States covered)
1.	Brainstorming Session on 'Women's Participation in Science' **September 15, 2012**	NASI, Allahabad **UP**
2.	Workshop on 'Defining the Role of Women Scientists and Teachers for Promotion and Application of Science and Technology' **October 5-6, 2012**	NASI, Allahabad **UP**
3.	Workshop on 'Women in Science & Technology: The Path to an Empowered India' **March 8-9, 2013**	The Institute of Life Sciences, Ahmedabad University **Organized by NASI-Ahmedabad Chapter**
4.	Workshop on 'Defining the Role of Women Scientists and Teachers for Promotion and Application of Science and Technology' **March 23, 2013**	M.S. Swaminathan Research Foundation (MSSRF), Chennai, **Tamil Nadu**
5.	Workshop on 'Defining the Role of Women Scientists and Teachers for Promotion and Application of Science and Technology: North-east India Perspectives' **May 8-9, 2013**	Lady Keane College, Shillong, **Meghalaya**
6.	Workshop on 'Empowerment of Women using Sustainable Technologies' Jointly organized by Allahabad Chapter of the National Academy of Sciences, India and Institute of Rural Health Research & Development, Allahabad (IRHRD) **June 5-6, 2013**	NASI, Allahabad, **UP**

S. No.	Date	Location/Host Institution (Places/ States covered)
7.	Stakeholders Meeting on 'Women related Farm Mechanization Issues' Jointly Organized by CIAE Bhopal (ICAR) and NASI **June 25, 2013**	**Delhi**
8.	Workshop on 'The Resistant Problem of Malnutrition in India: Issues and the Way Forward' **July 4, 2013**	National Institute of Nutrition (NIN), Hyderabad, **Telangana State**
9.	Awareness workshop on 'Rajat Jayanti Vigyan Sancharak Fellowship for North India' **September 30, 2013**	NASI, Allahabad, **UP**
10.	Sensitization workshop on 'Societal Research Fellowship (SoRF) for Women Scientists & Technologists under the programme Disha' **March 7, 2014**	Miranda House, Delhi University, **Delhi**
11.	Sensitization workshop on 'Administrative Responsibilities for the Implementation of Societal Research Fellowship (SoRF)-DST/ NASI' **March 21, 2014**	NASI, Allahabad, **UP**
12.	Workshop on 'Technological Empowerment of Women through the SoRF Scheme of DST' in collaboration with NASI **May 14, 2014**	Visva-Bharti University, Santiniketan, **WB**
13.	Sensitization workshop for 'Technological Empowerment of Women' **June 18, 2014**	Graphic Era University, Dehradun, **Uttarakhand**
14.	'Technological Empowerment of Women through the SoRF Scheme of DST' in collaboration with NASI' **June 30, 2014**	NEHU, Shillong, **Meghalaya**

S. No.	Date	Location/Host Institution (Places/ States covered)
15.	Sensitization workshop on 'Sensitizing Women for Development & Empowerment' **September 24 -25, 2014**	CSIR-National Metallurgical Laboratory Jamshedpur**, Jharkhand** Organized by NASI-Jharkhand Chapter
16.	Workshop on 'Technological Empowerment of Women through the SoRF Scheme of DST' in collaboration with NASI **February 04, 2015**	Punjab State Council for Science & Technology, Chandigarh, **Punjab**
17.	Orientation Programme for SoRF Interns **February 13, 2015**	NASI, Allahabad, **UP**
18.	NASI Workshop for Sensitization of Women regarding S & T Fellowships and Internships **May 22, 2015**	Jiwaji University, Gwalior, **MP**
19.	Sensitization and Technological Empowerment of Women teachers/ researchers/scientists for their S & T endeavours **September 25, 2015**	Savitribai Phule Pune University, Pune, **Maharashtra**
20.	Sensitization Workshop for Technological Empowerment of Women **March 14-15, 2016**	Banasthali Vidyapeeth **Rajasthan**
21.	Workshop on 'Technological Empowerment of Women' **February 15-16, 2017**	Sri Padmavati Mahila Visvavidyalayam – A Women's University, Tirupati, **AP**
22.	S & T Sensitization Programme for Uttarakhand **June 9-10, 2017**	Kumaun University, Nainital, **Uttarakhand**

S. No.	Date	Location/Host Institution (Places/ States covered)
23.	S & T Sensitization Programme for Women Leading Towards Entrepreneurship **October 5-6, 2017**	NML, Jamshedpur, **Jharkhand**
24.	S & T Sensitization Programme for Women **October 27-28, 2017**	NBRI, Lucknow, **UP**
25.	Sensitization Workshop on Technological Empowerment of Women **Nov 03-04, 2017**	IIT, Guwahati, **Assam**
26.	NASI Mega Event – National Conference on Technological Empowerment of Women **March 8-9, 2018**	Vigyan Bhawan **New Delhi**
27.	S & T Sensitization Programme for Women **May 27-29, 2018**	AIIMS **Rishikesh**

Total no: 27 (including Mega Event)

Glimpses of Women Sensitization Workshops

(a) (b)

Fig. A-1 L-R: (a) Professor (Mrs) Manju Sharma chairing the panel during a women sensitization workshop joined by Professor Paramjit Khurana, Dr Shashi Bala Singh and Dr Suchitra Banerjee; (b) Women researchers attending the Orientation Programme at NASI HQ.

Workshops on Scientific Paper Writing

S. No.	Date	Location/Host Institution (Places/States covered)
1.	**June 10-11, 2011**	Banaras Hindu University, Varanasi, **UP**
2.	**Oct. 22-24, 2011**	NASI, Allahabad, **UP**
3.	**Jan. 06-08, 2012**	SGPGI, Lucknow, **UP**
4.	**June 8-10, 2012**	CIFE, Mumbai, **Maharashtra**
5.	**Nov. 8-10, 2012**	NASI, Allahabad, **UP**
6.	**Apr. 5-7, 2013**	M L S University, Udaipur, **Rajasthan**
7.	**June 17, 2014**	Graphic Era University, Dehradun, **Uttarakhand**
8.	**Dec. 16-17, 2014**	Pune University, Pune, **Maharashtra**
9.	**March 4-5, 2016**	Amaravati University, Amaravati, **Maharashtra**
10.	**April 18-19, 2017**	Chaudhary Charan Singh Haryana Agricultural University, Hisar, **Haryana**
11.	**June 10, 2017**	Kumaun University, Nainital, **Uttarakhand**
12.	**Oct. 5-6, 2017**	NML, Jamshedpur, **Jharkhand**
13.	**Oct. 27-28, 2017**	NBRI, Lucknow, **UP**
14.	**May 25-26, 2018**	AIIMS, Rishikesh, **Uttarakhand**

Total no: 14

Glimpse of Scientific Paper Writing Workshops

Fig. A-2: The session on ***Scientific Paper Writing*** at Kumaun University.

S & T Awareness Programmes for Defence Personnel

S. No.	Date	Location/ Host Institution (Places/ States covered)
1.	**March 27, 2014**	ITBP Camp, **New Delhi**
2.	**July 15, 2014**	ITBP SHQ, **Bareilly, UP**
3.	**June, 2015**	Dehradun, **Uttarakhand**
4.	**June 25, 2016**	40th Bn ITBP, Ranchi, **Jharkhand**
5.	**May 15, 2017**	ITBP SHQ, Bhubaneshwar, **Odisha**
6.	**July 28, 2018**	33rd Bn ITBP, **Guwahati**

Glimpses of S & T Awareness Programmes for Defence Personnel

Fig. A-3: (a) Professor M.G.K. Menon delivering the inaugural addresses; (b) Professor P.N. Tandon delivering the special address on 27th March 2014 at ITBP Camp, New Delhi.

Fig. A-4: Dr Shashi Bala Singh, Director, DIPAS delivering a talk to Defence Personnel on July 15, 2014 at ITBP SHQ, Bareilly.

Appendix 2

Workshops Organized by the NASI under the Programme for the Scheduled Tribes

- **Two-day Awareness Building and Sensitization Programme on Health, Nutrition and Environment of Nicobari Tribals**

Venue: ICAR-Central Island Agricultural Research Institute, Port Blair – 744 105, Date: April 20-21, 2018

Following lectures were delivered; followed by interaction/discussion with the participants:

- **Promotive Health Care for Healthy Living** by Professor U.C. Srivastava, Allahabad
- **Major Health Issues Among the Tribals** by Dr Anamitra Barik, Kolkata
- **Science & Technology for Skill Development Towards Employment Generation** by Professor Paramjit Khurana, New Delhi
- **Ancestries of Tribal Populations can Inform Health-Management** by Dr Partha Majumdar, Kolkata
- **Fisheries Development and Activities in Island** by Dr R. Kiruba Sankar, Port Blair

Fig. B-1: Dr Manju Sharma addressing the participants of programme for the scheduled tribes at Port Blair, A & N Islands.

Fig. B-2: Group photograph of participants of the programme for the scheduled tribes organized at Port Blair with the experts.

- **Two Days Workshop on Awareness Building and Sensitization of Science & Technology for the Tribal Population of Uttarakhand**

Date: June 27-28, 2018 **Place: Chakrata, Uttarakhand**

The National Academy of Sciences India (NASI) organized a 2-day workshop on Awareness Building and Sensitization of Science & Technology for the tribal population of Uttarakhand in joint collaboration with Uttarakhand State Council for Science and Technology (UCOST), Dehradun at Chakrata, Uttarakhand on June 27-28, 2018.

Fig. B-3: Glimpses of the workshop organized for the tribal population of Uttarakhand at Chakrata.

Recommendations & Suggestions of the Workshop:

- Establishment of a Technology Park in the region which can be accessed by people from nearby regions as per their requirements.
- The need for advancement in the field of agriculture, animal husbandry or horticulture and training to be imparted in such profession. Scientific approach must be used for the betterment of the people of tribal areas.
- The participants raised a problem that the absence of government officials in their respective departments is a major concern.
- The various groups of people may form a 'Locals Samiti' to provide them better skill sets and trainings related to it.
- Establishment of dairy and animal husbandry to be focussed.
- It was requested by Dr A Pattanayak, Director, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora to provide support for training on above-mentioned areas at Chakrata. Dr Pattanayak assured for support as well as given consent to install an electric operated maize sheller in their area.

Fig. B-4: Expert members interacting with the villagers during the event organized at Chakrata.

Glimpses of some ongoing programmes in the village surrounding

Fig. B-5: Health & Hygiene Awareness Programme in the tribal areas of Lakhimpur-Kheeri district of Uttar Pradesh (L) and Awareness/Sensitization/Training Programmes in tribal areas of Northeast India (R).

Fig. B-6: Bioresources used by tribes inhabiting Ladakh – Survey and sensitization programme by Jammu Chapter.

Fig. B-7: Darchik (Aryan Village) 9190 ft. Fruits of ***Physalis alkekengi***, solanaceae.

Fig. B-8: Enhancing productivity and profitability of small and marginal tribal farmers of Tigiria block of Odisha implemented by Institute of Life Sciences, Bhubaneswar.

Fig. B-9: Training programme on vermicomposting for schedule tribes – An initiative towards enhancing bioeconomy.

Fig. B-10: Health, Hygiene and Nutrition Solutions for Schedule Tribes of Jharkhand.

Dr Manju Sharma is currently NASI Distinguished Women Scientist Chair. She is a distinguished biologist, nationally and internationally recognized for her monumental contributions in promotion of science and technology, in particular the emerging field of biotechnology. With her vision, dedication and sustained efforts she is largely responsible for the rapid progress of biotechnology research, application and commercialization in India. She has played a pivotal role in taking up the cause of women in science and application of science and technology for the benefit of women, disadvantaged people and rural areas. She has been conferred with the Padma Bhushan and has received numerous awards. She was also the President of NASI during 1995-96.

3. The Early Science of Meghnad Saha

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By the early science of Meghnad Saha I refer mainly to the problems that engaged his mind in the first three decades of his life. It is an era marked by the extreme indifference of the colonial rulers towards helping India acquire a scientific temperament. There was no institution in the country as in Cambridge, Berlin, Göttingen and Munich in Europe offering any scope of rigorous scientific training. The best of the libraries in Kolkata had hardly enough journals to keep them abreast of the scientific advances made elsewhere.

And yet, we find, Meghnad Saha's first research paper appeared in 1918 when he was just appointed as a lecturer in the newly founded University College of Science, Kolkata. And, in three years, he rose to be one by whose theory, in Eddington's words,

> *'all the details of stellar spectra became quantitatively connected with the temperature and pressure in the reversing layers' [1], and the theory 'dominated all recent progress in the observation and interpretation of stellar spectra' [1].*

Saha reached the zenith of his career at 28. In this chapter, I deal with the things he was doing around this time, adding, at the end, a few words on his later work.

Saha was born into an indigent family of a village some thirty miles north of Dhaka in the then East Bengal of undivided India where education hardly ever received priority. Saha proved an exception. Against all odds, societal and pecuniary, he made his way into Calcutta University first as a student and then as a teacher, shortly becoming a world-renowned scientist, all on his own. In his student days, he supported himself and his younger brother by

giving tuitions from one end of the city to the other, first in Dhaka and then in Kolkata where he did his B.Sc. and M.Sc. in mixed mathematics [2].

Saha and his friends got to know of the scientific advances made in Europe and elsewhere in the West mostly through stray news, not from any research supervisor; he did not have any. This, casting an ill effect on his later science, initially produced a happy result. The inquisitive mind looked at the existing problems with a freshman's eyes and made the most of the basic intelligence. And that makes an interesting as also instructive study.

Consider, for example, his work on the interferometric determination of mass of a radiating atom or a molecule [3]. This was important in connection with the disputed origin of the secondary spectra of hydrogen, that is, those which did not fit into the Balmer series. The experiment deployed a coherent source, from which a ray strikes almost normally on the outer surface of a separated pair of parallel glass-plates (the Fabry-Perot etalon). On entering the clearance the ray suffers multiple internal reflections and refractions. The rays partially emerging from the other side of the pair, being all phase-correlated, produce an interference pattern when brought to a focus on a screen. Ideally, the pattern should persist even when the clearance is slowly increased. In actuality, however, it disappears as soon as the separation of the plates attains a critical value (interference limit). Lord Rayleigh [4] had worked out the theory of it in 1889 by taking into account the fact that the waves reaching the screen suffer a Doppler-Fizeau spread in wavelengths due to the randomly moving radiating sources at a given temperature. He also related the critical separation (interference limit) to the mass of the radiating centre to within a factor typical of the set-up. In this, he, however, considered only two interfering rays, resulting in a dubious estimate of the mass. Saha, always having an eye for the details, pointed out that a better estimate of the mass can be obtained by considering all the interfering rays which lend a geometric series for the intensity. It is to be noted here that in the published version of Saha's paper [3], a factor exp $[-(1/\beta)(n\,\delta/c)^2]$ multiplying the cosine term was missing from the expression for the intensity of the interference line. The factor owes its origin to the Maxwellian distribution of velocity – components of the sources along the line of sight. Here δ, related to the clearance, is the phase difference between two consecutive rays reaching the screen, and n an integer. Mass m of the radiating source enters through $\beta = m/2kT$, k being the Boltzmann constant and T the absolute temperature]. The resultant intensity I, periodic as δ increases from 0, differs from the one with stationary sources mainly by this attenuation factor. The critical separation is then obtained by requiring that the visibility factor, which is

the ratio of $(I_{max} - I_{min})/(I_{max} + I_{min})$, attains a value of 0.025. On calculation, it turns out to be an instrumental constant times $\lambda\sqrt{(m/T)}$, λ being the wavelength at source. Later, Saha (1920) dispensed with the constant by taking the ratio of the masses obtained separately with the H_α line (due to normal hydrogen) and the secondary line of hydrogen as the source in the same set-up. He concluded thereby that the secondary spectrum of hydrogen is due to molecular hydrogen or its ion. He hastened to underscore the importance of the method in identifying the unknown source of light in solar corona or nebula. This marked the beginning of the many ventures into astrophysics he would make soon.

Consider, again, the case of photon momentum. Before Einstein made the formal announcement in 1916 that photons possessed not only energy, but also momentum despite their zero rest mass. Saha had a preconceived notion about the photon momentum from his reading and translating Einstein's papers on special theory of relativity. In 1918-19, he made use of Einstein's mass-energy equivalence relation (1905), and assuming that it holds also for photons, deduced [5] the photonic mass, multiplied that by the photonic velocity (c), and got the photon momentum. He then argued that handing over of this momentum to an object of any size a photon strikes would result in a radiation pressure on it. He went as far as to devise an experiment to prove his point [6].

Shortly afterwards, Saha made use of this idea of momentum transfer, in combination of Bohr's theory of hydrogenic atoms, to assert that an atom while receiving the energy necessary to effect a resonance transition from a lower to higher level, will, because of the momentum transfer, get a kick in the forward direction. Thus, he sought to explain why in the upper layers of the Sun and stars we get signatures of the heavier elements like calcium which should otherwise lie buried in the inner layers [7].

The signatures, of course, are the spectral lines found in the light of the Sun and stars. Next he concludes from Bohr theory that at the pressure and high temperatures prevalent in the Sun and stars, the thermal energy providing the requisite ionization potential, the elemental atoms are mostly ionized. Once ionized, he added, an atom would emit spectral lines that are higher in frequency than those for the corresponding neutral atoms. Thus, an age-old oddity that the solar spectrum does not have the lines of the elements known on the earth is finally resolved. Saha showed, they are there, albeit displaced to the high frequency side. Using statistical thermodynamics and Nernst's reaction isobar after Eggert, he then arrived at an equation saying what percentage of an atom with its characteristic ionization potential get ionized at a given temperature and pressure. It turned out that the higher the

temperature and the lower the pressure and ionization potential, the greater is the degree of ionization. This is the essence of what we now know as Saha Ionization Equation [8]. From an examination of the spectral lines, Saha then found out the elemental composition of the Sun [9] and stars. It is easily said than done. The result bears on knowledge of the ionization potential of the elements, the ambient pressure and the temperature. At Saha's time, the ionization potentials of only a few atoms were experimentally known, the rest as also the order of pressure were Saha's guesswork [8,10]. That is one characteristic of Saha; combining an incomplete set of data with a strong intuition, he could meaningfully relate diverse things and glean the truth, almost always.

Saha carried forward his theory to resolve [11] the age-old mystery of the Harvard classification of stars. According to this, 99 per cent of the stars fall in the so-called Harvard sequence, namely O B A F G K M R N S, with the colour changing from blue to red along the sequence. The spectra has also this continuity that as we move from right to left in this sequence, a line first appears, becomes more and more intense and then starts fading away to zero visibility when a new line appears, and the story goes on. Saha resolved this mystery by showing that this is nothing but the effect of the temperature rising from one type of stars to another as we move from S to O.

Saha submitted in 1920 all the four papers [8-11] written in a row, before he left for London in September 1920, hoping to experimentally verify his ionization theory. While working as a visitor in Alfred Fowler's laboratory, he called back his fourth paper for a revision on the basis of the rich reserve of spectral data and Fowler's critical comments. The writing vastly improved, but the contents remained the same. Fowler himself forwarded the revised manuscript to the Proceedings of Royal Society where it got published soon [11]. Saha's admission to the Royal Society as a Fellow in 1927 owed much to this paper.

Saha's later work, mainly conducted at Allahabad (1923-38) dealt with spectroscopy of complex atoms and propagation of electromagnetic waves in the ionosphere, to both of which he was naturally led by his ionization theory. In the first case, he showed that in addition to the Appleton conditions there should be another condition for reflection of the vertically incident electromagnetic waves. In spectroscopy, he derived a few results which, but for Hund (who beat him by a few months), would have been pioneering. Incidentally, this highlights the shortcoming of having to work in isolation at a place far removed from the then meccas of science.

Saha began taking an interest in the virgin field of nuclear physics as soon as the nuclear particle neutron was discovered by Chadwick in 1932. As

the news of the neutron discovery spread, he frantically tried to buy a small amount of neutron-emitting radium to invade a nucleus with, as he thought neutron, being chargeless, would easily penetrate a nucleus. But the princely price of the material was beyond Saha. In 1934, Fermi made it happen. It is not widely known that, the first paper in nuclear physics from India was published by Saha and his illustrious student D.S. Kothari in 1933, offering an explanation of the beta decay [12]. While it fell through as Pauli proposed the correct theory, it shows how Saha kept abreast of the contemporary physics and participated in it.

In 1936 summer, Saha was invited to Copenhagen to take part in a nuclear physics conference at Niels Bohr's institute. Following this, he also visited the States, particularly the laboratory of Ernest Orlando Lawrence, the discoverer of the atom-smashing machine, cyclotron. This visit inspired him to assemble in later years a prototype of the machine in Kolkata.

Two years after his coming back to India, Saha returned to his *Alma Mater* in the Palit Chair of Physics, and introduced Nuclear Physics in the M.Sc. curriculum in Physics and engaged some of his students in small-scale experiments in Nuclear Physics in the Palit Laboratory, like measurements of half-lives of the radioactive nuclei [2]. Alongside, his own work proceeded in two parallel streams, ionosphere (in continuation of the work initiated at Allahabad) and cosmic rays. He did not continue long in either field, for S.K. Mitra in the Department had already taken up ionospheric work, and H.J. Bhabha in Mumbai, the cosmic ray research. Very soon, Saha undertook a project of assembling a baby cyclotron to facilitate exploration of the atomic nucleus. In this, he was helped by his old student from Allahabad, B.D. Nag Chaudhuri, then doing a Ph.D. under Ernest Lawrence in Berkeley. He shipped, in installments, the essential components of the machine from the USA to Kolkata. A dedicated team of Saha's pupils at home drawing on theoretical knowledge as also technical know-how was working hard on assembling the parts. Initially, sponsored by the Tatas, the flow of funds stopped as soon as Homi Bhabha envisaged the Tata Institute of Fundamental Research in Bombay (Estd. 1945). Fighting various odds, firstly the Second World War and then, an acute fund crunch, the cyclotron project has a long and interesting history. Soon after Saha died in 1956, the machine, first of its kind in Asia, produced a steady proton-beam affording quite a few spectroscopic studies of nuclei around mass number 100.

Long before the cyclotron came alive, the volume of work in nuclear physics had outgrown the confines of the Palit research laboratory, and Saha envisaged,

within the fold of the University, an Institute for nuclear studies. This was perhaps prompted by the American tradition. And as a result, the Institute of Nuclear Physics was born in 1947. Initially, housed within the Department of Physics, it was shifted to a separate building erected at the cyclotron site in the University Science College Campus in Rajabazar area of Kolkata, inaugurated by Madame Irène Joliot-Curie on 11th January 1950. Since then this date is celebrated as the Foundation Day of the Institute. Soon after Saha's demise in 1956, the Institute was renamed as Saha Institute of Nuclear Physics.

The cyclotron project spawned in the Institute a first rate workshop, and activities in many branches of physics related to the cyclotron ensued soon. Work in biophysics was already initiated in the Palit Laboratory and an electron microscope, of transmission type, successfully assembled. It was taken to the new building. In the following 6 to 7 years, units dealing with instrumentation, plasma physics, mass spectroscopy, nuclear chemistry and nuclear magnetic resonance spectroscopy came up one by one. A very strong group in Theoretical Physics was a forte of the Institute from its early days. The Institute soon matured into a national and an all-embracing centre for cultivating various aspects of nuclear science. A training programme was introduced in 1953 to rear the requisite manpower. Students from far and wide in the country poured in the Institute to work. Grants from the Atomic Energy Commission, initially scanty and irregular, became a steady flow in 5-year blocks from 1955, a year after the Department of Atomic Energy, Govt. of India was instituted (August 3, 1954). The Institute presently is a fully DAE-aided autonomous institution independent of the mother University, an unfortunate development to which Professor Saha would not have taken kindly, if alive. He had always wished that the Institute remained a part and parcel of the University [2].

The Institute, since its foundation, has been following the footsteps of its founder. One notable trend set by Professor Saha is that like the cyclotron machine, most of the instruments called for in research during the first five decades were either fabricated or assembled *in situ* by the scholars, the nuclear magnetic resonance spectrometer (continuous wave type), the beta-ray spectrometer being two prime examples. Basically, there was not enough money to buy these costly instruments, and most importantly, as Professor Saha would insist, the researchers would thereby gain a fair knowledge of the working of the machine and have a control over it. This was an important legacy hailing from Saha's Allahabad days where he had to build up his laboratory from scratch. Unfortunately, that tradition is fast eroding in the Institute today.

Saha remained wide awake to the contemporary developments in physics even in 1936. He derived [13] Dirac's charge quantization rule just by setting

the intrinsic angular momentum associated with a dyon (a separated charge e and a monopole of strength g with the unit vector $\mathbf{n}$ pointing g to e), which is $\frac{eg\mathbf{n}}{c}$, equal to $\frac{h}{4\pi}$. That a spinless two-body system carries half a quantum of angular momentum, however strange, is presently required in the context of the dynamical supersymmetry theory [14]. A prophetic vision, indeed!

In the end, let me qualify the remark made in the beginning on the limitations of being self-taught. True, apart from the above piece, the bulk of Saha's later work did not match the brilliance of his early contributions. His theory of solar corona and that of beta activity were embarrassingly wrong. These kept Henry Norris Russell, whom Saha owed much for his recognition in the West, wondering, 'why Saha's activity in the theoretical field fell off after his return to India' in 1921 [15].

Here, it pays to recall that Robert Oppenheimer, after graduation from Harvard under Percy Bridgman and a brief stint in Cambridge, was recommended to Max Born at Göttingen to acquire the competence that must underlie brilliance. Even after that Paul Ehrenfest found Oppenheimer's thinking as original but loose, and sent him for tightening to Europe's sharpest mind and tongue, Wolfgang Pauli at Zurich [16]. On the other hand, Saha did not have anybody of the like at home to give such training as would help him transcend his natural limitations. And, while in Europe, he chose not to enroll as a student of Alfred Fowler or Walther Nernst because of his strong nationalistic feeling. It did take its toll on his later work, typifying what it means in science to be entirely self-trained, however brilliant.

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Atri Mukhopadhyay (born 1946), a Ph.D. in physics from the University of Calcutta had held visiting positions in UK, Denmark, Sweden and Poland. His research relates to electron structure theory of atoms and molecules resulting in about 40 research papers published in international journals. Deeply interested in history of science, Mukhopadhyay is responsible for restructuring and enriching the Meghnad Saha Archives of the Saha Institute of Nuclear Physics. His book entitled *Abinash Meghnad Saha* (Meghnad Saha the Invincible) in Bengali is an in-depth analysis of life and work of Saha *vis-à-vis* the contemporary scientists in colonial India. He was the general secretary of the Indian Physical Society and editor of its quarterly organ *Physics Teacher* for several years.

4. Meghnad Saha: His Contributions to Science & Society

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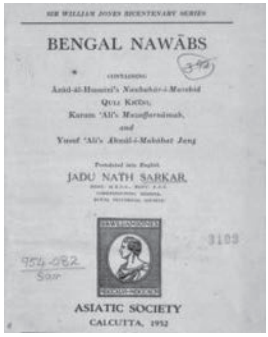
The period during the years of 1850 to 1950, about 100 years, is considered to be the most fertile period of fundamental science and also critical period for the evolution of social consciousness all over the globe though it had witnessed two World Wars. During this period, excluding the last three years, India was under colonial rule. Therefore, whatever achievement made by any individual during this time was against non-cooperation from the erstwhile administrative authority and severe economic hardship. Now, if we want to see the journey of a man like Meghnad Saha, a great educationist, an exceptionally brilliant scientist with committed social mission, we must look back at the socio-economic condition of undivided Bengal during that period. Calcutta University and later Dacca University were established mostly to educate and train local people so that they could serve and assist the colonial ruler. At the beginning of 20th century, a bunch of dedicated youth came to these universities with committed mission to serve the country with their zeal and conviction. One of them was Professor Meghnad Saha who had witnessed the poverty-stricken village of Bengal and sufferings of people during natural calamities like floods and deadly diseases. It is really astonishing to see how he could manage his successive ascending steps of education to become a world renowned scientist.

From his childhood, apart from his scientific pursuit, his interest in history was noticed by his teachers and close associates. In school days he

Fig. 1: Sir Jadunath Sarkar (From Internet archive)



studied thoroughly the book on Annals and Antiques of Rajasthan by James Todd. In later years, his interest in history was evident from his closeness with Sir Jadunath Sarkar, a great historian. More so when Meghnad Saha succeeded Dr. Shyama Prasad Mookerjee as president of the Royal Asiatic Society, Kolkata in 1945: The society had planned to commemorate the 200th birth year of Sir William Jones in 1946; accordingly Sir Jadunath Sarkar prepared a scheme in 1945 for publication of a series on Bengal Nawabs as *Sir William Jones Bicentenary Series*. Professor Meghnad Saha as president of the Royal Asiatic Society encouraged and endorsed his proposal as society's tribute to its great founder. During this time it was his interest and initiative that also led to the publication of the famous book, *Ionosphere* by Sisir Kumar Mitra, by Asiatic Society. He was also associated with the trustee of the Victoria Memorial of Calcutta, Indo-Soviet Friends' Society and Sino-Indian Cultural Association.

Best example related to the condition of Bengal villages during first half of the 20th century has been portrayed in the cinema *Pather Panchali* directed by Satyajit Ray based on a story written by Bibhutibhusan Bandyopadhyay. It is really a great surprise how Professor Saha had overcome the barriers of poverty and social constraints prevailing at that time, and became a great celebrity. He took science subject during intermediate education at Dacca College where in addition to science subjects he studied German language as fourth subject. He entered Presidency College with scholarship in the year 1911 and in his B.Sc. honours class, his classmates were Satyenendra Nath Bose, Jnan Chandra Ghosh, Jnanendra Nath Mukherjee, Nikhil Ranjan Sen and others. Prasanta Chandra Mahalanobis was one year senior and Nil Ratan Dhar was two years senior to them, and their teachers were Acharya Prafulla Chandra Ray (Chemistry), Sir Jagadish Chandra Bose (Physics) and Professors D.N. Mallik and C.E. Cullis (Mathematics). Two elder brothers of Subhas Chandra Bose were also his classmates. Therefore, it is evident that his academic journey started in association with a galaxy of great minds and visionaries. Acharya Ray wrote in his book *Life and Experiences of a Bengali Chemist*-Vol-I about his first-hand impression of the students of the Presidency College

Fig. 2: Photographed in 1916 at Krishnanagar. Sitting at the centre Acharya P.C. Ray. Standing at the back from left: M.N. Saha, Unknown person, J.C. Ghosh (Meghnad Saha Archive).

> *'…..returned from England in 1912 as a delegate to the congress of universities of the Empire. I went on as usual with my work at Presidency College. J.C. Ghosh, J.N. Mukherjee and Meghnad Saha were now making'. In the beginning of the next chapter of the book, he wrote 'I joined the College of Science in 1916 after the October (Puja) holidays. The discriminatory eyes of Asutosh Mukherjee was not slow to recognize that J.C. Ghosh, J.N. Mukherjee, M.N. Saha and S.N. Bose would each and all make a name for himself, if suitable opportunities were offered them. They were therefore insisted to join the new Institution (University College of Science)'.*

During the period (1916-1920) M.N. Saha published four important papers in the journal *Philosophical Magazine*, UK and based on these papers he was awarded the D.Sc. degree of Calcutta University. Amongst others, one of his external examiners was Nobel Laureate Professor O.W. Richardson, who was Wheatstone Professor of Physics at King's College in the University of London. After a year long academic visit to Europe, Professor Saha joined Calcutta University as Khaira Professor in November 1921. Later at Calcutta University, he found it difficult to set up his own laboratory to pursue his research work. In 1923, Professor Saha joined Department of Physics, Allahabad University and he delivered his first lecture on 17th November 1923 in a large lecture theatre on 'Earthquakes' with Prof. N.R. Dhar, Dean of the Faculty of Science in Chair. He devoted most of his time in teaching graduate and postgraduate students. The

lectures were carefully prepared and he mostly used blackboard in inimitable style of clear handwriting and often resorted to demonstrating experiments. As mentioned 'Within few years the Department of Physics began to throb with new life. Research gradually picked up and for many years…..Physicists of Allahabad School dominated the national scene'. It attracted talented pool of students and some notable scientists from abroad visited the department during that period. Sir Arthur Eddington delivered lectures in February 1927, on i) Light Waves and Light Projectile, ii) The architecture of Atoms and iii) X-rays' while visiting Allahabad for a short sojourn.

Professor Saha visited Kolkata in January 1938 in connection with the 25th session of the Indian Science Congress which was held in Calcutta. Lord Rutherford was supposed to be the general president of this silver jubilee session, but he died prematurely. Sir James Jeans presided over the general session of the Science Congress. Professor Jeans along with Sir U.N. Brahmachari and Professor Meghnad Saha are seen in the photo during the programme (see Fig. 3). Perhaps during this time Professor Saha had contemplated to come back to Kolkata. Acharya J.C. Bose passed away in November 1937 and Professor D.M. Bose joined Bose Institute as director vacating the Palit Professor post in physics at Calcutta University. At that

Fig. 3: From right Sir James Jeans, Sir U.N. Brahmachari and Prof. M.N. Saha, Calcutta, January, 1938 (M.N. Saha Archive).

time Dr Shyama Prasad Mookherjee was the Vice-Chancellor of Calcutta University and he made the offer to Professor Saha to join the University as Palit Professor. At the same time Professor Saha got an offer as Principal of the Royal Institute of Science, Bombay, but he decided to come back to Kolkata and to join Calcutta University as Palit Professor and Head of the Department of Physics in July 1938. In Kolkata, he started planning to initiate activities in nuclear physics and the cyclotron project. In fact the spectrum of intellectual community at Calcutta was large and by then some of his classmates were elevated to head or chair professor of different departments of the University. Most importantly, Acharya P.C. Ray was still around the Science College Campus of the University with his ill-health. The period from 1938 to 1956 is important due to Second World War, intense freedom struggle, Bengal famine and post-independence reconstruction of India. Professor Saha had played a significant role in national and international arena during this period.

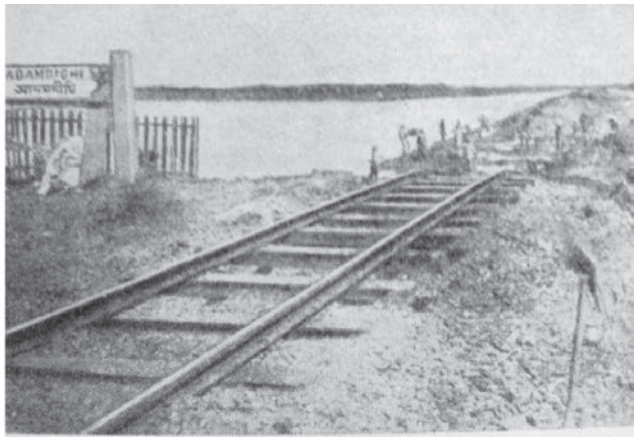


Fig. 4: Railway lines were damaged by devastating flood in North Bengal in 1922. Adapted from *Collected works of Meghnad Saha*, Edited by Santimay Chatterjee, Orient Longman Ltd., 1983.

Amongst all his students Acharya Ray had a deep affection for Meghnad Saha since both of them came from rural Bengal. During the devastating flood in North Bengal in 1922, Acharya Ray took the leadership role for relief work and the whole Science College was the centre of activities involving all his colleagues and students. During the relief operation Meghnad Saha was his lieutenant.

I came to know from the family members of Professor Saha that Acharya Ray did stay in their Kolkata residence when he frequently fell ill perhaps

during the period 1940-44. Acharya Ray died in 1944. Acharya Ray used to read the journal *Science and Culture* with special attention to the articles written by Professor Saha – mostly on colonial rules, administration and academic issues. This journal was initiated by Professor Saha in the year 1935. Once Acharya Ray commented –

> *'…you are sending battery shocks from Allahabad.'*

Science and Culture is the mouth-piece of the Indian Science News Association (INSA) which is also the brainchild of Meghnad Saha and Acharya Ray was its first President. Though they had differences on industrialization policy and political issues, their relationship was like father and son. While commenting on Professor Saha's academic pursuit Samarendranath Sen, who was then the registrar of the Indian Association for the Cultivation of Science (IACS), wrote in the book titled *Professor Meghnad Saha: His Life, Work and Philosophy* published by the Meghnad Saha Sixtieth Birthday Committee in 1954 –

> *'In course of his private studies, Saha acquainted himself with the elements of the quantum theory of radiation, and the special theory of relativity, and picked up some knowledge of the generalized theory. His knowledge of German stood him in good stead as all literature on relativity was in German and there was practically no information on the subject in English'.*

When Sir Arthur Eddington had proved the general theory of relativity on May 29, 1919 during a total solar eclipse, Professor Saha wrote an article in the *Statesman* immediately after the news of proof of Einstein's theory reaches Kolkata. This made him known in large sections of people in India when his age was only 26 years'. Later a book titled *The Principle of Relativity*: original papers by A. Einstein and H. Minkowski, translated into English by M.N. Saha and S.N. Bose with a historical introduction by P.C. Mahalanobis was published by Calcutta University in 1920. The content of the book was as follows:

- Historical Introduction
  [By Mr P.C. Mahalanobis]
- On the Electrodynamics of Moving Bodies
  [Einstein's first paper on the restricted (Special) Theory of Relativity, originally published in the *Annalen der Physik* in 1905. Translated from the original German by Dr Meghnad Saha]
- Albrecht Einstein
  [A short biographical note by Dr Meghnad Saha]

- Principle of Relativity
  [H. Minkowski's original paper on the restricted Principle of Relativity first published in 1909. Translated from the original German by Dr Meghnad Saha]
- Appendix to the above by H. Minkowski
  [Translated by Dr Meghnad Saha]
- The Foundation of the Generalized Theory of Relativity
  [A. Einstein's second paper on the Generalized principle first published in 1916. Translated from the original German by Mr Satyendra Nath Bose]
- Notes

In his class lectures, Professor Saha used to discuss the latest development in science particularly on thermodynamics and astrophysics with the students. He started publishing papers and established the theory of thermal ionization and stellar spectral radiation from stars. Subsequently, he obtained D.Sc. degree from Calcutta University and later became Fellow of the Royal Society (FRS) at the age of 34. He was never satisfied with the theoretical work and wanted to do experiments with his own hands to prove the theories.

Professor Saha was deeply concerned with the post-colonial period of India and what should be our preparedness after getting the independence. He was involved in creating the National Planning Committee in order to solve the problems of industrialization and national reconstruction and he insisted Subhas Chandra Bose to pursue the matter. A meeting was convened by Bose in Delhi to discuss the issue in October 1938 when he was the president of the Indian National Congress. Professor Saha persuaded Pt. Jawaharlal Nehru to be the chairman of the Planning Committee. Nehru mentioned all the details of acts and deeds of the National Planning Committee in his book *Discovery of India*.

Fig. 5: Goodwill Mission to UK, USA and Canada in 1944. Indian Scientists at the front row (left to right): Najir Ahmed, J.C. Ghosh, M.N. Saha, S.S. Bhatnagar and J.N. Mukherjee (Meghnad Saha Archive).

On recommendation of Professor A. Hill, Nobel Laureate and Secretary of the Royal Society of London, a team consisting of distinguished scientists from India visited UK, USA and Canada in 1944 to assess the scientific and industrial development. During this visit, Professor Saha delivered lectures on various issues. A lecture

delivered before a joint meeting of the British Institute of International Affairs, and the British Science Association (earlier known as British Association for the Advancement of Science), on November 10, 1944 was entitled 'Science in Social and International Planning, With Special Reference to India'. Later it was published in *Nature* (Volume 155, pp. 221–224, 1945). Subsequently, the whole report of their visit was prepared by Professor Saha and submitted to the erstwhile Govt. in 1946. Therefore, it is evident from the facts that before independence a preparation for establishing scientific institutions and planning for advancement for scientific education and emerging technology had been initiated and conceptualized by a group of dedicated scientists from India. Available documents and evidences show that in all these endeavours, Professor Saha took the pivotal role. His contributions to science no doubt will be remembered forever, but his devotion and conviction for building a modern India should be acknowledged with equal importance.

Professor Saha was also involved in various institutional activities with an objective to build modern India. However, that was not an easy task since he had to fight every step with the authority in order to fulfil his desired goal. A man, who was always behind Meghnad Saha, was Professor Jnan Chandra Ghosh. Professor Ghosh was the Vice-Chancellor of Calcutta University during the period 1952-57. Differences with the views of Nehru had started nucleating after independence and he decided to go to Parliament to raise his voice for greater cause of the country.

Fig. 6: Professor Jnan Chandra Ghosh, CU-Archive.

> *'He was now a full-time director of the Indian Association for the Cultivation of Science, honorary director of the Institute of Nuclear Physics and also a Member of Parliament. His normal routine was to get up at 5 o'clock in the morning, attend to his studies, do physical exercises daily and reach IACS by 9 a.m. He would remain there till 12.30-1.00 p.m. before reaching the Institute of Nuclear Physics. He used to do his public work only after 5 p.m'.*

Santimay Chatterjee once wrote about his entering into politics –

> *'Some hard thinking and unfortunate encounters with the politicians led Meghnad Saha to make up his mind to come to Parliament – a decision for which he had to face some criticism, even ridicule. But taking into account Saha's deep social commitment, his long years of preparation of a blueprint – it was the most natural culmination of his career'.*

Fig. 7: Professor Meghnad Saha delivering a public lecture before the first Parliament Election in 1952, he was elected as an independent candidate to the Parliament (Photo-courtesy Dr Sumantra Das, Grandson of Meghnad Saha).

Professor Saha's entry into the politics received mixed reactions across the globe and some of the foreign scientists welcomed his active political participation in federal democratic system. Most emphatic one was from J.B.S. Haldane –

> *'May I…. congratulate him on his successful re-entry into Politics? India (and Britain too) need men who will bring some understanding of science to the government of the country. Even those who do not share all his political views may rejoice that he can make his voice heard in the councils of people'.*

Fig. 8: Professor Meghnad Saha delivering a lecture on state reorganization in a meeting (Photo courtesy Dr Sumantra Das, grandson of Meghnad Saha).

Immediately after independence, there was a need to recognize the states of the country in order to fix the boundaries of each state. There was a proposal of merger of some districts of Bengal and Bihar. This issue particularly perturbed the mind of Professor Saha and always he felt that the basis of demarcation should be on logical terms justifying the demand of the local people. As mentioned – 'During his term as a Member of Parliament, he never lost the opportunity of reminding the Congress Party of its pledge to recognize the states on linguistic basis. Through his speeches in parliament and articles published in the mass media, he pointed out the significant areas that the Congress had overlooked. He was particularly agitated when parts of Bihar including the city of Jamshedpur were not included in the State of West Bengal'. In another occasion, in a foreword of the book, *Pramatha Nath Bose: A Biography* written by Jogesh Chandra Badal, published by P.N. Bose Centenary committee, 1955, Professor Saha mentioned that P.N. Bose had convinced Jamshedji Tata to set up the Steel Plant near Sakchi (Jamshedpur). Professor Saha had the knowledge of iron ore reserve in Mayurbhanj State, which was identified as highest content of iron in the ore. He was aware of the work of P.N. Bose a great geologist at that time. Later, due to speedy industrialization, Bengalis became majority in the Jamshedpur area. When the question of a possible merger between Bengal and Bihar came up in the Parliament, he was up in arms. He exhorted that the use of mother tongue was the fundamental right of every citizen and to deny that right was going against the basis of democratic principles.

Professor Saha was also greatly involved in research related to huge reserve of ores/minerals in the geological landscape of the country particularly in rock studies. In the Palit Laboratory he started these activities and published a paper titled – 'Measurement of Geological Time in India: The Age of Rocks and Minerals' by M.N. Saha and B.D. Nag Chaudhuri (*Trans. Nat, Inst. Sc. Ind*., Vol-2, 273, 1947). It would be interesting to see the content of the abstract of the paper – '*In this paper, the various physical methods for finding out the age of rocks are reviewed and methods in use in the Palit Laboratory of Physics are described. Plea is made for setting up a Committee on the age of rocks by the Council of Scientific and Industrial Research*'.

Fig. 9: National Geophysical Research Institute (NGRI- Archive).

Perhaps based on his recommendation, the CSIR- National Geophysical Research Institute was established in 1961 at Hyderabad. It may be mentioned that the activities of the Calendar Reform Committee had certain mandate and the structure was – 'The Unit which was functioning as the office of the Calendar Reform Committee at the then Institute of Nuclear Physics of the University of Calcutta where Saha was functioning as its director, was attached to the Regional Meteorological Centre of the Government of India, Calcutta as one of its sections and named **Nautical Almanac Unit**. This was finally transformed into Positional Astronomy Centre (PAC) at Salt Lake, Kolkata, in 1980'. Therefore, it may be concluded by saying that apart from the core scientific activities Professor Saha was also involved in various constructive activities in nation building in the post-colonial period.

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5. Meghnad Saha: A Physicist's Approach to Social Problems

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1. Introduction

This chapter is my homage to Heliophilus on his 125th birthday. You must be wondering about who is that? It's nom-de-plume taken by Professor M.N. Saha when he submitted his article entitled, 'Origin of Lines in Stellar Spectra" for the Griffith Memorial Prize [1]. He received the award and the article was published in the proceedings of the Royal Society in 1920. The rest is history. However, we don't want to stress on Saha's contribution to astrophysics [2]. Many scientists have immensely contributed in their respective fields, so Saha's scientific contributions cannot isolate him from the other scientists in a unique manner. However, his contribution to society characterizes him uniquely [3, 4, 5]. In what follows, we will stress on that.

Scientists don't put much effort to solve social problems because social problems are very complex and they have many degrees of freedom. Usually it's difficult to solve a social problem with the available scientific tools. So normally, scientists spent most of their time in academic or industrial research and teaching. This fact was precisely stated by Nobel Laureate Richard Feynman in [6], where he said,

> '*From time to time people suggest to me that scientists ought to give more consideration to social problems - especially that they should be more responsible in considering the impact of science on society. It seems to be generally believed that if the scientists would only look at these very difficult social problems and not spend so much time fooling with less vital scientific ones, great success would come of*

> *it. It seems to me that we do think about these problems from time to time, but we don't put a full-time effort into them - the reasons being that we know we don't have any magic formula for solving social problems, that social problems are very much harder than scientific ones, and that we usually don't get anywhere when we do think about them. I believe that a scientist looking at nonscientific problems is just as dumb as the next guy - and when he talks about a nonscientific matter, he sounds as naive as anyone untrained in the matter'.*

Most scientists agree with this opinion and they normally spent their life in academic research. So was the case with Saha until 1930, but it changed after that and in that context, he himself said,

> *'Scientists are often accused of living in an Ivory Tower and not troubling their mind about realities; apart from my association with the political movement of juvenile years, I lived in the Ivory Tower till 1930'.*

This chapter is about that part of Saha's life, where he is more concerned about social issues, policy development and applying science to solve national problems. In all such things, he adopted a scientific approach. Here we would briefly touch couple of those aspects of Saha's works.

It will be out of scope to discuss all aspects of Saha's contribution to social issues, so we will restrict ourselves to discuss his approach to the following problems of socio-economic relevance and of national importance.

1. Calendar reform
2. Flood and river projects
3. Superstitions and scientific temperament

Here, it will be apt to note that we will not discuss a few other important aspects of Saha's works on social issues. Specifically, we will not describe Saha as a politician/parliamentarian and as a crusader for the establishment of planning commission with an active collaboration and support from Netaji and Tagore. These aspects of Saha's work are discussed in other chapters of this book.

Rest of the chapter is organized as follows. In Section 2, we will discuss his works on calendar reform. In Section 3, his works on river physics is discussed and finally this chapter is concluded in Section 4 with a brief discussion on the articles of Saha that reflected his views against superstitions.

2. Calendar Reform

Before we understand the need of the calendar reform, we need to understand a set of terms which are associated with the calendars. Such terms are briefly defined below:

Winter solstice or midwinter: This refers to an astronomical phenomenon which leads to a day with the shortest period of daylight and the longest night of the year. This happens twice in a year when the path of the Sun in the sky is farthest south in the Northern Hemisphere (December 21 or 22) and farthest north in the Southern Hemisphere (June 20 or 21). In the Northern Hemisphere, the date of this astronomical event is closely connected with the date of Christmas.

Vernal equinox: The word vernal means spring and equinox refers to the time when the Sun crosses the equator, and the duration of day and night become equal. In the Northern Hemisphere, this happens on 21st March in a normal year and on 20th March in a leap year. Similarly, the equinox is observed on September 22 or 23, in the Southern Hemisphere. In what follows, we will restrict our discussion to the Northern Hemisphere.

2.1 Calendar Reform Efforts before Saha

It would be interesting to note that Saha's initiative of calendar reform was not the first of its kind. Julian year was of 365.25 days, which is slightly greater than the duration of a tropical year (365.2422 days). The difference is $365.25 - 365.2422 = 0.0078$ days only. Now, in 323 AD, winter solstice (at Northern Hemisphere) happened on 21st December. After 1259 years, in 1582 AD, it was shifted by $0.0078 \times 1259 = 9.8202$ days (i.e., about 10 days). Consequently, the Christmas day lost its connection to midwinter or winter solstice. Recognizing this discrepancy, the council of Trent authorized the Pope to take a corrective measure. In 1582, Gregory XIII (who was the Pope at that time) ordered that Friday, October 5 of 1582 was to be considered as Friday, October 15 of 1582. Further, he announced that centurial years will not be considered as leap year, unless they are divisible by 400 [4]. This reform was successful. We specifically, mention about it to stress on the point that historically, at least one successful calendar reform has happened.

It's easy to observe that there are several shortcomings of the Gregorian calendar. For example, a month can have 24-27 working days (considering Sunday as the holiday), a quarter can have 90-92 days, and a month can have 28-31 days. This non-uniform distribution of days has direct influence on the business, economics and planning. Specially in the analysis of statistics and

accounts [4]. Further, the day of the week on which a year or a month starts is not fixed. Keeping these in mind, in 1834 an Italian padre, Abbe Mastrofini proposed an uniform calendar, but there was no taker for it and it went in to oblivion (for more details on this world calendar see Page 136 of Ref. [7]).

2.2 Calendar Reform Effort of Saha

Since long Saha was concerned about the ambiguities and discrepancies present in the Indian calendars which were in use at that time (see [8, 9, 10] and references therein), but first of his serious proposals on the need of calendar reform was published in an article of 1939, which was published in *Science and Culture* and was entitled, 'Need for Calendar Reform'. After independence, he strongly advocated the need for the calendar reform and as a result the then Prime Minister of India, Jawaharlal Nehru gave his consent for it in 1952, and Council of Scientific and Industrial Research (CSIR) constituted a Calendar Reform Committee under the chairmanship of Saha; L.L. Lahiri was secretary. Other members of the committee were A.C. Banerjee (Allahabad), K.L. Daftari (Nagpur), J.S. Karandikar (Pune), Gorakh Prasad (Allahabad) and R.V. Vaidya (Ujjain).

Pandit Nehru was very clear about the need of calendar reform; the clarity of his thoughts are nicely reflected in the following message to the committee [7]:

> *'I am glad that the Calendar Reform Committee has started its labours. The Government of India has entrusted to it, the work of examining the different calendars followed in this country and to submit proposals to the Government for an accurate and uniform calendar, based on a scientific study for the whole of India. I am told that we have at present thirty different calendars, differing from each other in various ways, including the methods of time reckoning. These calendars are the natural results of our past political and cultural history and partly represent past political divisions in the country. Now we have attended independence; it is obviously desirable, that there should be a certain uniformity in the calendar for our civic, social and other purposes and that this should be based on a scientific approach to this problem.*
>
> *'It is true that for governmental and many other public purposes, we follow the Gregorian calendar, which is used in the greater part of the world. The mere fact that it is largely used, makes it important. It has many virtues, but even this has certain defects, which make it undesirable for universal use.*
>
> *'It is always difficult to change a calendar to which people are used, because it affects social practices. But the attempt has to be made,*

> *even though it may not be as complete as desired. In any event, the present confusion in our own calendars in India, ought to be removed.*
>
> *'I hope that our Scientists will give a lead in this matter'.*

The committee submitted a report in 1955, and the Government accepted it, and recommended it for use with effect from 21st March 1956, i.e., 1 Chaitra 1878 Saka. Major recommendations of the committee were [11]

1. The Saka era should be used in the unified national calendar.
2. The year should start from the day following the vernal equinox day. As 1956 was a leap year, vernal equinox day was on 20th March. So the corresponding Saka year started from 21st March.
3. A normal (leap) year would have 365 (366) days. To find out whether a year is leap year or not, 78 is to be added to Saka era and subsequently, it will be checked whether the corresponding year in the English calendar is leap year or not. If yes, then the corresponding Saka year will be a leap year.
4. Chaitra should be the first month of the year and it should have 30 days in a normal year and 31 days in a leap year. Length of the other months would be fixed in a manner which is easy to remember – next five months, i.e., Vaisakha to Bhadra would be of 31 days each, and the remaining 6 months would be of 30 days each.

These recommendations were expected to fix the seasons of India and to ensure that the rituals connected to agriculture and other things to happen in the right time.

Further pursuing the cause, Saha insisted Indian Government to take up the issue of Calendar reform to the Economic and Social Council of the UNO. It was discussed in the 18th session of the Economic and Social Council of the UNO which was held at Geneva. Saha himself attended the meeting and presented the Indian proposal for a reformed world calendar. However, it was not accepted because of strong objections from certain groups, specifically due to the objections of Jewish groups. This happened due to the fact that an effort was made to make the World Calendar as uniform as possible. For example, it was made in such a way that every year should start with Sunday and finish with Saturday. In that case, in a year there would be $52 \times 7 = 364$ days. What would happen to the extra 1 day in a normal year and extra 2 days in a leap year? It was proposed that the last date of the year would be called World Day or December 31, this would be a year-end World Holiday.

Similarly, in a leap-year, there will be a Leap-year Day which will be another World Holiday and to be added at the end of the second quarter as a Leap-year Day or June 31. These two World Holidays will not be part of any week. In other words, these two days will not be referred to as Monday, Tuesday, etc., here, comes the objection of Jewish group. They felt that it would interfere with their religious life that evolve with the unbroken seven-day week, as the proposed World Day and Leap-year Day had no weekday denomination.

The World Calendar was very symmetric. As it proposed to have 91 days or 3 months or 13 weeks in each quarter, and exactly 26 weekdays, plus Sundays, in every month. However, it was never adopted. Even the reformed calendar adopted in India was not very successful as Government never persuaded its offices to follow it and it never became popular among common people. So, Saha's efforts eventually added one more calendar in the list of 30 different calendars which were in use in India at that time.

3. Flood and River Projects

Rivers are physical entity and they do follow the laws of physics. It can be understood easily, if we note that in the upper motion of the rivers, potential energy gets converted into the kinetic energy as it flows downwards, the speed increases and consequently the rivers are fast and narrow. In the middle motion of the rivers, the rivers approach the plane where there is not much change of altitude; so as such no conversion of potential energy to kinetic energy takes place, but there is a loss of energy due to friction, and consequently, following Bernoulli's principle (more precisely, due to equation of continuity) the rivers become wide. They continue losing energy, and in the lower motion problems become worse with the increasing responsibility of carrying the silt with it. Consequently, it needs to reduce the cross-section of the river bed and thus to increase the velocity. If it breaks in two equal parts, velocity will be doubled according to the equation of continuity. To understand that assume that the track of the river is semi-circular with radius 2r, then its area is $\frac{\pi (2r)^2}{2} = 2\pi r^2$. Now, if it breaks into two streams of the same shape, but each with radius *r*, then the area of each stream would be $\frac{\pi (r)^2}{2} = 0.5\pi r^2$ and the total area would be πr^2. Thus, the total area becomes half of the original area, now to ensure that the input flow and the output flow of these two streams are the same, velocity of river water must be doubled. This is why rivers are broken in lower motion and deltas are formed. This

example lucidly establishes that rivers follow physical laws and there is a need for systematic study of river physics and the establishment of laboratories for the closely related field of hydraulic research. Saha persuaded a lot for both of these causes. To further stress on his point and to lucidly express the need, he noted that a big river like the Dhaleshwari keeps on depositing silt along its banks. There are populous villages along the banks, as the deposition of silts raises level of the river side, after some time, the level of the villages becomes lower than that of the fields and stagnant pools are formed within the villages [4]. Then the stagnant water of those pool leads to sudden break out of malaria. To circumvent such situation, one would require to teach the villagers how to clean their ponds, and how to scientifically deal with these rivers. Just note that a physicist concerned about the society finds physics even in the cause of malaria. This clarity and social concerns were characteristics of Saha. And these characteristics define his unique position in the Indian Science.

3.1 Early Experience of Flood

Saha had experience of flood from his childhood, and probably the devastation observed by him influenced his interest in river physics. Specifically, he was born in a village located in the Brahmaputra delta, where flood was a regular phenomenon and it was often said that children learn to swim before they learn to walk [11]. In 1913 and 1923 there were devastating floods in the Damodar Valley. In 1913 flood, Saha (then a student of M.Sc.) worked as a member of a volunteer group who were working to provide relief to the flood affected people. In 1923, also he played a crucial role in the relief work. The direct experience of observing the effect of flood had long-run influence on him and probably that led to his works in the related field of river physics.

3.2 Scientific Studies and Articles that Influenced Policy Decisions

By 1922 Saha had been already interested in the scientific solution of flood and in 1922 he wrote an article in *Modern Physics* (cf. *Modern Physics*, 32 (1922) 805) describing the physical reasons behind flood and how science can be used to reduce the devastating effects of flood. In 1932, he wrote another article entitled, 'Need for a Hydraulic Research Laboratory in Bengal'. He wanted such a laboratory to be built in association with a university and not with an engineering college. In 1938, the Presidential address given by Saha in the annual symposium of the Indian National Sciences Academy, India (then National Institute of Sciences, India) was focussed on the 'Problems of

Indian Rivers'[1]. His articles and talks largely influenced the decision of the Government to establish Bengal River Research Institute in 1943.

In the same year (i.e., in 1943), another flood happened in the Damodar river. This time Saha wrote many articles which eventually compelled the Government of Bengal to form a Damodar Flood Inquiry Committee, and Saha was one of the members of the committee. This time the magazine *Science and Culture* established by Saha played a crucial role as it provided the platform to express scientific opinions that can influence policy decisions of the Government of that time and also of the Government of independent India. For example, in 1944, in collaboration with Kamlesh Ray he wrote an article entitled 'Planning for the Damodar Valley' (*Science and Culture* 10 (1944) 20). To understand the problem of Damodar and other Indian rivers, Saha rigorously studied the successful and unsuccessful flood control projects outside India with specific attention to Tennessee Valley System, USA.

These studies and field works led to the conclusion that scientific river management is needed. This is articulated nicely in his 1944 article with Ray, where they wrote –

> '*The solution of the problem lies in the scientific storage and adequate management and distribution of the water resources of the basin, combined with the land reclamation measures*'.

In fact, Saha and Ray proposed a set of locations of dams that can be built in the Damodar valley. Saha even met B.R. Ambedkar (then member-in-charge of power and works in the Viceroy's Cabinet) to discuss the need of river control project in Damodar valley. His constant persuasion finally led the establishment of Damodar Valley Corporation (DVC) almost immediately after our independence. It became functional in March 1948.

4. Scientific Temperament of Saha and His Views on Superstitions and Cultural Practices

In this section, I'll mostly refer to Saha's talks and writings in Bengali. Saha often criticized the illogical religious and non-religious customs followed in India. His views were not well taken by some people and they opposed Saha's views. In some cases, Saha responded to the points of his critiques. Here, we briefly mention about those debates, specifically because most of his opinions and concerns of Saha are still valid in India.

[1] Interestingly, works presented during the symposium was published in Vol. 4 of *Proc. Nat. Inst. Sc.* India and a report on those works and Saha's talk was published on the May 13, 1939 issue of *Nature*.

Saha himself was a victim of Indian caste system, and he was naturally against it. He could never accept it and asked fundamental questions, like

> '*Why will the social respect of an uneducated priest who recites chants in Sanskrit without knowing their meaning be more than that of a cobbler or a weaver? …*'

4.1 Debate 1: M.N. Saha vs. Anil Baran Rai

One of the most interesting debates, started with a lecture of Saha delivered at Santiniketan on 13th November 1938 in honour of Rabindranath Tagore. This lecture was later published in Bengali magazine *Bharatbarsha* 26 (1939) 937. In this talk, Saha mentioned about religious intolerance, which is still an issue in India, but he primarily argued that in a country, social status of people involved in different professions depends on which god is considered to be the Creator in the religion followed in that country. As an example, he mentioned that in China the Creator is imaged as a mechanic who created the world by cutting mountains using a hammer and an axe. Consequently, China has produced many outstanding technologists and engineers and the social respect of artisans are extremely high in the Chinese civilization. In China, social hierarchy was in the following descending sequence mandarins, farmers and artisans, business men, soldiers. Thus, the farmers and artisans were relatively more respected in comparison to other civilizations. In contrast, in the Indian scenario, the Creator is a kind of philosopher who created this universe including all the living and non-living objects while he was in meditation. Consequently, in India, especially in Hindu society, all those who are involved in lazy and non-productive philosophical debates and create mysteries or those who only do mental jobs, are respected more compared to the technicians – cobblers, carpenters, blacksmith, etc. Naturally, hand and mind got separated in India and we failed to produce new technologies, and/or products. Saha felt that this was one of the main reasons, why others equipped with contemporary technologies were able to conquer India again and again. His observations are even correct today. Despite much development, our students prefer software jobs in an air-conditioned office over a more challenging technical job in a plant.

Saha's views were criticized by Anil Baran Rai and the criticism was also published in *Bharatbarsha*. He felt that Saha's views are not of his own and are much influenced by Western philosophers. Rai claimed that there is a consciousness (which is not yet understood by science) that has created and rules the universe. Saha is just blindly following some western thinkers and ignoring the great knowledge present in the Vedas. He argued that the Mother

had a spiritual realization through Yoga that there exists a supreme power which has created and controls the universe. Further, Rai also mentioned that Europe is not much benefitted by the advent of modern science. Rai also felt that the root of Hindu philosophy and religion is present in Vedas which contains everything about Hinduism. Interestingly, Saha replied to the criticism in a great detail. To begin with Saha mentioned about the fact that the existence of pre-Aryan civilization has been found in Mohenjo-daro and Harappa, but no such proof of Vedic civilization has yet been found. Further, many rituals and religious practices followed now have originated from the pre-Aryan era, so the opinion that everything has originated from Veda is not correct. Saha added that Rai's argument in support of the prevailing caste system is wrong, and the lines that Rai quoted from Veda in support of caste system have been added to Veda at a later stage. Just like in 1st or 2nd century AD, in the name of Manu Maharaj, it was told that – if a Shudra reads Veda his mouth is to be closed by pouring hot led. Saha was very specific to the point that this type of practices not only led to untouchability and other social problems, it also led to our inefficiency in engineering and experimental science. Unfortunately, it's still true. Just to stress on Saha's view, here I quote a few lines that are translated from Saha's response to Rai in Bengali:

> '*I have looked into the issue from a different perspective. In my opinion, the caste system has completely destroyed the link between our brain and hand, and that's what put us much behind Europe and USA in the development of the materialistic modern civilization. From the middle-age, Indian intellectuals were busy in discussing their bookish knowledge and surprising others by the depth of their abstract knowledge. They were hardly connected to the real life. They never thought of doing something for the development of industry and business. Probably, doing so would have thrown them out of their community (caste). Similarly, the warriors were busy in showcasing their power using the available weapons, they never tried to learn or adopt the new technologies and techniques evolved in other countries. India has not invented any useful technique or procedure since long as here the works done only with the brain have been given a very high position compared to the works done with hands. That's what has cut the connection between brain and hand. Today, an American student or a professor is not reluctant to do the work of a carpenter or another technician, but an Indian student is. Unless our intellectuals themselves work with the machines, and the technicians come in close contact with the intellectuals, new machines and technologies will not be developed, as it happened in Europe and America.*'

Here it would be apt to note that at this context he was even critical about Gandhi's Charkha movement and village-based development plan. He mentioned that after the Vedic era of Charkha, at least 800 new discoveries had led to the textile industries of that time. Saha was always a supporter of heavy industry, but he could not completely support Nehru's plan after independence. They had difference in views regarding foreign investment, and other issues, but primarily Saha felt that machines will increase productivity, reduce unemployment, and boost economy, but to be in the race and to keep the independence, the gap between hand and brain is to be reduced and our own technologies are to be developed. Saha's strong views on this issue expressed through his talks (including lecture in the parliament), articles published in *Science and Culture* and other places have directly or indirectly considerably influenced the post-independent India. One can even see a shadow of his thoughts in recent 'Make-in-India' initiative.

The response of Saha was long, and here it will not be possible to summarize the entire response. We will just mention two critical points. As Rai was a propagator or a believer of a view that everything was present in the Vedas and known to our ancestors, he claimed that (i) Galileo's discovery is not new and it was known at the time of Vedas, (ii) The theory of incarnation present in Hindu philosophy is equivalent to the theory of evolution introduced later by Darwin. Saha strongly criticized these views from the perspective of modern science and stressed on the point that while someone tries to glorify or criticize a civilization, he or she must keep in mind what time that civilization had used the technique/knowledge/method under discussion, and at that particular time what was the know-how of the other contemporary civilizations. To stress on this point he particularly mentioned that from 1400 BC to 80 AD, in Indian astronomy, a year was considered to be of 366 days, but by 5th century BC, Egyptians and Babylonians (little later Greeks and Romans) started computing a year as of 365.25 days. Until 1st century AD, Indians used to make an error of 3.75 days in every 5 years, whereas in 400 BC, Babylonians used to make an error of 2.16 hour in every 19 years. Naturally, after 80 AD, Indians started following Greek-Roman and Chaldean Astronomy, and that led to the development of Indian astronomy.

Saha's views were very clear and logical and probably influenced much by his own unfortunate experiences of caste systems and differences that existed between the rich and poor of the same caste. Specifically, his in-laws were rich and the grandmother of his wife was against the marriage of Meghnad Saha with Radharani Saha, as Meghnad's father was a shopkeeper. Radaharani's grandmother kept herself absent from the marriage to show her protest.

Later, she visited Saha at Allahabad and by then Saha had his own car and Saha took her to different pilgrimage in his car. The old lady was very happy. Saha jokingly asked her, 'Are you now convinced that by marrying me, your granddaughter has not fallen in deep waters?' The grandmother promptly replied, 'you have no credit for it, all good fortune attained by you is due to the good luck of our daughter' [12].

Before we proceed, we must note that his comments in support of Darwin, stress on developing indigenous technology, more stress on experiment and product development, etc., are still relevant for the society as unfortunately, many people are still present in the society who are anti-Darwin in particular and against the scientific (rational) views in general.

4.2 Debate 2: M.N. Saha vs. Mohini Mohan Dutta

Saha strongly expressed his views through two more articles published in Bengali magazine *Bharatbarsha*. The first one was entitled 'Modern World and Hindus: The Campaign of Nonsense in the Name of Science' (*Bharatbarsha* 27 (1939) 90) and the second one was entitled 'Modern Science and Hindu Religion: There is Everything in the Vedas' (*Bharatbarsha* 27 (1940) 407). Saha mostly reiterated his views on the relation between science and religion, the need of modern science and the limitations of the views which led to a belief that everything discovered in modern science was present in Vedas. As Saha's views were in the line of thoughts described in the previous section, we are not repeating it here. However, to establish the need of science, he stressed on the point that per capita income of the countries that accepted science is much more than India and the modern science has almost doubled the average life expectancy. Further, he showed a simple calculation to establish that with the advent of modern machines, slaves will become redundant as a simple machine can do much more work than 10 slaves and costs less than the amount required for food, clothes, etc., of the slaves. Thus, science can also be used to establish human right. This led to a new debate. In an article, (*Bharatbarsha* 27 (1940) 521) Mohini Mohan Dutta questioned Saha's knowledge of Vedas and quoted a few scientists to establish that Saha's views are not supported by many scientists. For example, he quoted James Jeans as,

> '*...It is my own view that the final direction of change will probably be away from the Materialism and strict Determinism which characterized 19th century physics*'.

Dutta was also of the opinion that Saha (for his criticism of orthodox Hinduism) and the editor of *Bharatbarsha* for publishing Saha's opinion will

go to Hell after their death. In response (*Bharatbarsha* 27 (1940) 525) along with the other arguments, Saha told an interesting small story which tells us a lot. Here we would briefly translate the story and conclude the article with the message delivered directly by the story without any analysis or comments from our side.

There were two friends, one was orthodox and the other one was modern. The orthodox friend used to read and follow Vedas, Upanishads, Purans, and perform all the rituals suggested there and in *Panjika* (the Hindu astronomical almanac), he used to do regular fasts, take bath in Ganges, follow caste and lizards and never ate any food which is not recommended in Shastra (religion). In contrast, the modern friend was a non-believer, materialistic and used to eat everything. Naturally, after death, the orthodox friend went to the Heaven of Hindus and the modern friend went to the Hell of the scientists. On the repeated request of the modern friend, one day the orthodox friend bought a return ticket and went to visit the Hell, but he did not return for long time. A concerned friend of the orthodox guy sent him a letter from the Heaven. In response the orthodox friend wrote a letter, part of which is given below:

> '*...reaching the border of the scientist's Hell, I felt thirsty and the temperature was very high. For a while, I thought that I have made a mistake by accepting his invitation. As I entered the Hell, I had to change the train at a junction which was so nice that I have no words to describe it. I left the train of Heaven and boarded a train of the Hell. The new train was amazing – there was no heat, and light cold air was flowing – initially, I was surprised. Later, I heard that all the vehicles are air-conditioned here. After reaching my friend's residence, I was moved to see the system of the Hell. At Heaven, we don't need to work, we just need to be present at the court of Indra and see the routine dance of Apsara, and listen the news of the Earth in the broken voice of Narada muni, in name of drinks we had to drink Bhang and country liquor. In brief, whatever I had carefully rejected during my life at Earth, I had to do those at the Heaven. In contrast, everything is different at the Hell of scientists. This place was originally hot, but the scientists have used machines to convert heat into work and thus to make all houses air-conditioned. Here, we have excellent ice-creams and juices, fresh fruits and vegetables and newly invented processed foods. Traveling at heaven was a pain – horses were old. Here, we have air-conditioned cars powered by steam engines, it's much fun to be here. Switching on the radio, we can hear the news of external world, listen the songs of famous singers, speeches of leaders of other field. I feel mentally well by seeing dances, listening songs and occasionally visiting museums and planetariums*

> *and listening the talks delivered there. The life at the Heaven was boring and monotonous. Personally, I found the comfort and life style of the scientist's Hell much more attractive. So I have cancelled my residency of the Heaven and have decided to live here permanently.'*

Saha concluded by thankfully accepting the offer of his critics to send him to Hell.

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6. Meghnad Saha: As a Human Being

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'Meghnad' literally means one who can roar ('nad') like a cloud ('megh'). This Professor Saha did; all his life, he spoke frankly and bluntly to all, about what he thought was right and what was wrong. The other mythological name of Meghnad was 'Indrajit', meaning one who won fights with Devaraj (the king of Gods) Indra. This Saha did not, on all occasions, but ultimately, the other side agreed to what was spoken. This happened mainly because Saha always decoupled his personal interests from the noble causes which he stood for.

In speaking bluntly, Professor Saha did not spare anybody – be the person a student, a colleague, his Head of the Department Professor C.V. Raman, or even the Prime Minister of India Pandit Jawaharlal Nehru. Because of this character of Saha, he earned many enemies, with the exception of his students, who considered him as God. More about these will be presented later in this chapter.

Professor Saha was a man of many talents – an outstanding scientist, a great institution builder, a staunch patriot, and over and above everything, a great human being. His scientific contributions and their importance have been discussed, in details, by other authors in this book. It is the humanitarian aspect that I shall focus on, in this chapter.

I have already said about his relationship with his students. In the words of Professor Daulat Singh Kothari, an eminent scientist and a favourite student of Saha at Allahabad University,

> *'He was extremely simple, almost austere in his habits and personal needs. Outwardly, he sometimes gave the impression of being remote, matter of fact, and even harsh, but once the outer shell was broken, one invariably found in him a person of extreme warmth, deep humanity, sympathy and understanding, and though almost altogether unmindful of his own personal comforts, he was extremely solicitous in the case of others. It was not in his nature to placate others. He was a man of undaunted spirit, resolute determination, untiring energy and dedication'.*

Meghnad Saha was born in a remote village of the Dacca district (now in Bangladesh) in a poor family, his father being a petty shopkeeper. He struggled with poverty all his student life to rise to a first grade, world famous scientist. As a result, he knew the sorrow of the underprivileged, and went out of his way to help them.

Saha's patriotism cost him dearly. He was rusticated and his scholarship was cancelled while he was a student of the government school at Dacca, because he was accused of participation in a demonstration against the then British Governor when the latter came to visit his school. Somehow, with great hardship, he passed the Matriculation Examination, and the ISC Examination from Dacca. He then transferred to Kolkata to study for the bachelor's degree. While at the Presidency College, Kolkata, Saha and Satyendranath Bose of Bose-Einstein fame were classmates. Prashanta Chandra Mahalanobis, the founder of the Indian Statistical Institute, Kolkata, was his one year senior. Amongst his teachers were Acharya Prafulla Chandra Ray of Chemistry and Sir Jagadish Chandra Bose of Physics. Saha passed his B.Sc. with honours in mathematics and M.Sc. in mixed mathematics (later renamed as Applied Mathematics). He stood second in both the examinations, with Satyendranath occupying the first position. On invitation from the then Vice-Chancellor of Calcutta University Sir Ashutosh Mukherjee, both Saha and Bose joined the newly established University College of Science as lecturers (initially at the Department of Mixed Mathematics). They were both later transferred to the Physics Department, which had Professor Chandrasekhar Venkataraman as the Head. Although Saha had studied physics only at the B.Sc. level, he learned and taught hydrostatics, spectroscopy and thermodynamics in postgraduate classes. It was a great challenge indeed!

Saha also started research, with virtually no facilities, except for the well-equipped library of the Presidency College. He had virtually no guide, except that in his first few papers, he acknowledged the support received from Professor D.N. Mallik (who communicated Saha's first paper), he also acknowledged Professor Raman, for taking interest in his work. He had to

depend, entirely, on his private studies only. It is worth mentioning that at that time, *Einstein's Theory of Relativity* was published, in German, and Saha and Bose together translated a few papers of Albert Einstein and Hermann Minkowski into English, and published them as monographs, entitled *The Principle of Relativity*. This monograph was published by Calcutta University. These were the first recorded evidence of English translation of these papers, particularly Einstein's important work on relativity.

By the end of 1917, Saha wrote a long paper on 'Selective Radiation Pressure' and sent it to the *Astrophysics Journal*, at his personal cost. The editor agreed to publish the paper, provided Saha, paid part of the publication cost, which ran into three figures in dollars. Saha did not have the required money, and wrote to the editor about his inability. Unfortunately, the paper was neither published nor returned to the author. Later, Saha got it published in the *Journal of the Department of Science of the Calcutta University*, which did not have any circulation worth the name. He can therefore be credited as the originator of the theory. Later, E.A. Milne published a note in *Nature* in 1921, which mentioned Saha's work, but as a footnote only, though nobody appears to have noticed.

Initially, Saha worked on diverse topics like Maxwell stress, Fabry-Perot interferometer, properties of the electron, radiation pressure, quantum theory and several other topics, and got them published in the *Philosophical Magazine*, the *Physical Review* and the *Astrophysics Journal.* For these works, he was awarded the D.Sc. degree of Calcutta University.

Gradually in his research career, he gravitated towards astrophysics and his works got published in a series of papers in the *Philosophical Magazine* and the *Astrophysics Journal.* It was in 1920 that he formulated the famous Theory of Thermal Ionization. More about his work have been discussed by other authors in this book.

Saha later transferred to Allahabad University on invitation of the Vice-Chancellor, as the professor and head of the Department of Physics. The main reason was that, following the British pattern, there used to be only one professor in each department (addressed as 'the Professor'), who also headed the Department. Since there was no scope for a professorship at Calcutta University, in near future, Saha welcomed this invitation. Of course, there was much higher salary than what he was getting as a lecturer at Calcutta University. The University of Calcutta refused to pay higher salary. Contrary to popular belief, Raman had nothing to do with either of these, but it is quite well known that Raman and Saha did not get along with each other.

The Physics Department of Allahabad University was full of faculty who did nothing besides routine teaching. In a short time, Saha infused new

energy and enthusiasm for doing quality teaching and research. To illustrate quality teaching, he taught different subjects of physics. Here, he, jointly with B N Srivastava, wrote the renowned textbook, *A Text Book on Heat,* which was later renamed as *Treatise on Heat.* Curiously, Raman wrote the foreword of the book! I studied it as a textbook in my B.Sc. (Hons.) days. Most of the treatment was original, and besides classical topics, many new topics were introduced. It was the first time that I learnt about the Virial theorem of Clausius, and its applications in simply deriving some well-known equations.

At Allahabad, Saha mentored talented students like D.S. Kothari (Former Chairman of the UGC), P.K. Kitchlu (Former Director of the National Physical Laboratory), R.C. Majumdar (formerly at Delhi University), Atmaram (Former Director General of the Council of Scientific and Industrial Research), K.B. Nath and Basanti Dulal Nag Chaudhuri (Former Director of the Institute of Nuclear Physics and Scientific Advisor of the Ministry for Defence, Government of India), and several others, who made names in teaching, research and technical administration, in their future career.

At Allahabad, Saha established the first science academy of India, naming it as the United Provinces Academy of Science, which was later renamed as the National Academy of Sciences, India. I am a proud fellow of this Academy, as many other authors of this volume are. It was at Allahabad that Saha was elected as a fellow of the Royal Society, for which the then Governor of the United Provinces, Sir William Morris, granted a princely sum of Rs. 5000/- a year to Saha's research activities.

At Allahabad, besides continuing his research work on astrophysical problems, Saha initiated research in some other branches of physics, like statistical mechanics, atomic and molecular spectroscopy, active motion of nitrogen, high temperature dissociation of molecules, propagation of radio waves in the ionosphere, and physics of the upper atmosphere.

Saha ultimately returned to Calcutta University as the Palit Professor of Physics, and of course, the Head of the Department, succeeding Debendra Mohan Bose, who became the Head after Raman left for the Indian Institute of Science, Bangalore, as its director. Here, Saha continued his research, and started working on nuclear physics, and created a special paper on nuclear physics in the final year of the M.Sc. programme. Eventually, his activities on the domain of nuclear physics led to the establishment of a full-fledged institute, named the Institute of Nuclear Physics, at the University. This was later renamed as the Saha Institute of Nuclear Physics. Here, he built the first cyclotron of India, from the meagre resources of the University of Calcutta and a somewhat generous funding by the Atomic Energy Commission of India. Giants in nuclear physics in India are all products of mentorship by this great professor.

Besides the Institute of Nuclear Physics, Saha was a strong supporter of Professor Sisir Kumar Mitra in establishing a Department of Radio Physics and Electronics, which was later renamed as the Institute of Radio Physics and Electronics. I studied at this Institute for my master's and doctorate degrees. Still later, the Institute was renamed as the Sisir Kumar Mitra Institute of Radio Physics and Electronics. Saha was also instrumental in creating the Department of Applied Physics, with Professor P.C. Mahanti as the professor and head.

Feeling the need for a quality science journal of India, Saha established the Indian Science News Association, which published the journal *Science and Culture.* He and Bose also started *Jnan Bignan,* a Bengali science journal, and to both of these journals, he contributed many research papers as well as popular science articles.

Saha was nominated, as many as six times, for the Nobel Prize, as given below:

(i) In 1930 by Debendra Mohan Bose and Sisir Kumar Mitra

(ii) In 1937 and 1940 by A.H. Compton

(iiii) In 1939, 1951 and 1955 by Sisir Kumar Mitra

The first time, the Nobel Prize Committee for Physics opined that Saha's Thermal Ionization Formula was a very important one, but it did not qualify as a 'discovery'; hence it is not worth of a Nobel Prize. During successive nominations later, the committee stuck to its original decision. Thus, Saha missed the Nobel Prize, as Jagadish Chandra Bose, Satyendranath Bose, and several others, did.

Saha founded the Indian Physical Society at Calcutta, which published the famous *Indian Journal of Physics,* founded and edited earlier by Raman. With his initiative, the National Institute of Sciences of India was established at Calcutta. The formation of the All Indian Academy of Sciences was first proposed by Saha in the Presidential address of the Indian Science Congress at Bombay. It was initially called the National Institute of Sciences of India, which was later renamed as the Indian National Science Academy (INSA), and its headquarters were shifted from Calcutta to New Delhi. Saha was also closely associated with the planning and establishment of the Central Glass and Ceramic Research Institute at Jadavpur, as a constituent laboratory of the Council for Scientific and Industrial Research.

Growing up in East Bengal, Saha was familiar with what disaster floods can cause, particularly those caused by the mighty Padma and the Brahmaputra, and were deeply concerned about the recent floods in the Indian rivers. Saha

wrote extensively on floods and its damages, and, as a result, the Damodar Valley Corporation Committee was formed. He was also instrumental in establishing the River Research Institute at Beleghata, near Calcutta, with the hydraulic expert, Dr N.K. Bose, recognized worldwide, as an authority. This institute was later transferred to Haringhata, near Kanchrapar Railway Station. I worked at the River Research Institute as the research officer (Electronics) immediately after my master's, for two years, before I shifted to teaching.

Saha's contribution in reforming the Indian calendar was very significant. He was the chairman of the Calendar Reform Committee constituted by the Government of India, under the aegis of the Council of Scientific and Industrial Research. This topic has been discussed by another author in this book, in fairly good details (see Section 2 of Chapter 5).

Saha's interest in politics matured after he became famous as an Institute builder. He was elected as a Member of the Indian Parliament, as an independent candidate from the North West Calcutta Constituency. In parliament, he debated boldly and frankly, for the improvement of the conditions of millions of poor and the downtrodden. He was selected as a member of the Planning Commission, where he contributed immensely towards projects, particularly aimed at improving the conditions of the poor and the underprovided masses.

It was on 16th February, 1956, the Saraswati Puja Day, that this illustrious and the gifted son of Goddess Saraswati left this mortal world for the Heaven. I was then a student, and I observed that the festivities suddenly stopped and the whole city of Kolkata was immersed in grief.

I close this chapter with my personal interaction with Professor Saha. When I graduated with a bachelor's degree, and was debating what I should study in masters – pure physics, radio physics and electronics or applied physics – I, along with a friend went to the Institute of Nuclear Physics. We were not allowed to enter the premises of the Institute, and the security person told us that Professor Saha's permission is required to visit the Institute. On our insistence, he connected us to Professor Saha on the telephone. It was not his personal assistant, but Professor Saha himself, who answered the telephone, He told us, very softly, 'Boys, if you study Pure Physics, then at the specialization stage, come to the Institute and I shall personally tell you what the prospects of Nuclear Physics are, in India'.

I had the good fortune of touching his feet and asking for his blessings, when he came to interact with students at the Ramakrishna Mission Students' Home at Calcutta (later transferred to Narendrapur, near Garia). Swami Lokeswaranandaji Maharaj, the secretary, popularly known as Kanai Maharaj, introduced selected few of us, who stood first or second in their respective

courses. Maharaj told us to stand in a line, and do pranam to this great son of India, one by one. I was lucky to be one of them. Professor Saha talked to us, individually, and then addressed the gathering. He told us, in a soft voice, about how he struggled in life to rise to what he had become, and gave us the courage and confidence, to face all the difficulties in life bravely and boldly, always speaking the truth, irrespective of the consequences.

In this narrative, I hope I have been able to convey the human aspects of Professor Saha. I hope that the student readers will take a lesson from Professor Saha's life and struggles and be enthused enough to do the best in any walk of life they wish to pursue, and bring laurels to the country.

Acknowledgements

In writing this chapter, I have drawn upon many sources, including several websites on the Internet, and the authored sources which are mentioned below. I thank all authors on this occasion. I owe special thanks to Dr Rajinder Singh, an eminent historian of science and scientists, with emphasis on Indian science and scientists, at the University of Oldenburg, Germany, for promptly sending me a large number of articles, written by him including some which had relevance to Professor Saha, and for a critical review of this manuscript, raising some important points, all of which have been rectified in this revised document. I also thank the editors of this volume, Professor Ajoy Ghatak, formerly at the Department of Physics, Indian Institute of Technology Delhi and Professor Anirban Pathak, of Jaypee Institute of Information Technology, Noida.

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Suhash Chandra Dutta Roy (born 1937) is an Indian electrical engineer and a former professor and head of the department of electrical engineering at the Indian Institute of Technology, Delhi. He is known for his studies on analog and digital signal processing and is an elected fellow of all the three major Indian science academies viz. Indian Academy of Sciences, Indian National Science Academy and National Academy of Sciences, India as well as the Institute of Electrical and Electronics Engineers, Institution of Electronics and Telecommunication Engineers, Systems Society of India and Acoustical Society of India, The Council of Scientific and Industrial Research, the apex agency of the Government of India for scientific research, awarded him the Shanti Swarup Bhatnagar Prize for Science and Technology, one of the highest Indian science awards for his contributions to engineering sciences in 1981.

7. Meghnad Saha: A Visionary at Allahabad

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1. Early Life

Meghnad Saha was born on 6th October 1893 in a poor family in village Sheoratali, near Dhaka. He was a brilliant student. Though his parents could not afford to bear the expenses towards his education due to poverty, he nevertheless carried on school education by earning merit scholarships. However, he could feel the pain and suffering of poverty of poor people, which created a deep impression on his mind and later on, shaped him to find out solutions for social and economic problems.

At Presidency College in Calcutta (now Kolkata), he came in contact with the visionary Acharya Prafulla Chandra Ray, who taught him chemistry in B.Sc. Following the footsteps of Acharya Ray, he not only took keen interest in science, but also gave enough thought towards balanced development of industries and agriculture in India. He passed his B.Sc. examination in 1913, and M.Sc. (Mixed Mathematics) examination in 1915 from Calcutta University. He joined the Department of Mathematics in newly established University College of Science, Calcutta University in 1916 as lecturer. Later on, he was shifted to the Department of Physics in 1917. On the basis of his original research papers, published in *Philosophical Magazine* and *Physical Review*, he was awarded the D.Sc. degree of Calcutta University in 1918. In 1919, Saha was awarded the Premchand Roychand Scholarship which enabled him to spend two years in Europe. Meanwhile, for studying radiation and pressure of the solar atmosphere; Saha developed the famous ionization equation [1] which allowed one to calculate the degree of ionization of an

atom as a function of temperature and pressure (see Appendix A of chapter 1 of this book.)

During his visit to A. Fowler's laboratory at Imperial College, London; Saha worked out the application of his formulation with an aim to explain the ordered gradation in the spectra of stars [2]. He concluded that temperature is the dominant factor in determining the stellar spectra of stars. This work paved the way for astrophysicists to find a new direction of research.

In 1921, Sir Ashutosh Mukherjee, Vice-Chancellor of Calcutta University called Saha back to Calcutta to join as Khaira Professor. Saha came back, but he was not able to get sufficient financial support for his research. In 1922, his guru Acharya Prafulla Chandra Ray summed up the bearing of Dr. Saha's researches on the problem of cosmic radiation in an article published in *Modern Review* [3].

2. Saha at Allahabad

The University of Allahabad became a residential teaching university by AU Act of 1921. Various teaching departments came into existence as scholars from different parts of India joined these departments as faculty.

3. Appointment of Saha at Allahabad University

The post of University Professor of Physics was created. Professor N.R. Dhar and Professor A.C. Banerjee, members of Executive Council of the University, came to know about Saha's Theory of Thermal Ionization and were keen to offer Saha professorship of physics at Allahabad University. There were some oppositions in the council regarding the notion and some objected, stating that Saha had a degree in mathematics and not in physics. However, the opinions of Einstein and Eddington paved the way for Saha's appointment as a professor in the Department of Physics. The Executive Council in its meeting on September 5, 1923 appointed Saha as professor of physics with a pay scale of Rs. 800-50-1,200 per month [4]. Apart from this offer, Saha received offers from Aligarh Muslim University and Banaras Hindu University; but he preferred Allahabad University. After joining, Saha delivered a lecture on earthquake on 17th November 1923 at the large lecture theatre of the Physics Department of Allahabad University. Professor N.R. Dhar, Dean, Faculty of Science presided over the lecture.

4. Early Hiccups

After joining the Department, Saha found to his utter dismay that the Department has to cater 120 undergraduate and 20 postgraduate students with only one reader, one lecturer and two demonstrators. The teaching load was so heavy that it was impossible to undertake research work during academic session. Saha along with some dedicated students and colleagues in spite the summer heat worked tirelessly in summer vacations to pursue research. He found that though the undergraduate laboratories were equipped, postgraduate laboratories lacked equipment. He also noticed that the condition of workshop and library was very poor. Saha tried to overcome these difficulties, but found that people who wielded power were in total disregard to the academic needs; started obstructing the new initiations. Once, when Saha ordered several new books for the library, as the old ones were outdated; the Treasurer came to the library, and enquired from Saha whether he had read all the available books in the library. To this Saha replied he did not, and it is not possible of anybody to read all the books in the library. Treasurer then asked Saha in a condescending fashion to first read all these books in the library before asking for funds for new books.

Saha also had hard time buying equipment for undergraduate and post-graduate laboratories. For electricity-based experiments, Saha ordered a dozen of post office boxes. The bureaucracy immediately inquired why one building requires twelve post office boxes, isn't one sufficient? Unfortunately, bureaucracy was not aware that post office boxes are equipment and is not same as mail boxes.

5. Saha as Teacher

Saha was a dedicated teacher. To make the lectures more interesting and effective, he made copious uses of lantern slides and was fond of demonstration of experiments in classrooms. Saha would never miss his class and even if, he had to go elsewhere, he ensured that his colleague engaged the class in his absence.

Saha build a beautiful house at 7, Beli Road and called it 'Science Villa'. Many prominent scientists on their visits to Allahabad stayed at Saha's residence. Professor D.M. Bose wrote in the foreword of the book *Collected Papers of Meghnad Saha* [5] that in this very house, Saha entertained personalities like Sommerfeld and Eddington. His house was open for the students and many stayed there in their hour of need. Saha found it pleasant to interact with

some of his students outside class hours where he tried to bring the potential of each student. He had a sharp eye to judge the qualities of his students.

His student Sardindu Basu was selected for Provincial Civil Service, but Saha advised him to opt for meteorology, Basu later became the Director General of Meteorology. Saha once came to the hostel room of his student D.S. Kothari and took him for an evening walk. When Saha found that Kothari is not interested in government services, he offered him the position of demonstrator in Physics Department as the position was about to be vacated soon. Kothari was overjoyed. Similarly, when Saha came to know that B.D. Nag Chaudhuri was arrested for his suspected role in the freedom struggle, he called Nag Chaudhuri and advised him that devotion to work can also bring glory to the country. Both Kothari and Nag Chaudhuri marvelled not only in academics, but also played a vital role in science planning and management of free India. Gyan Chandra Mukherji stood first in his M.Sc. batch, but Saha noticed that he was inclined towards arts, culture, history, politics and sociology. Saha persuaded him to join the magazine *Science and Culture* as assistant editor and later helped him to enter the world of cinema. On Saha's advice, his student Atmacharan appeared for Civil Services Examination and excelled. Atmacharan later became the judge in the Mahatma Gandhi assassination case.

Saha loved his students and subordinates very much and tried to provide them as much as he could; but at the same time, he was conscious of the merits of every student.

6. Research Activities

Saha during his tenure at Allahabad faced many financial problems pertaining to research work. Still Saha along with his colleagues rigorously persuaded research activities. Within three years, Saha published nine papers (some with N.K. Sur) in different journals. With the help of S. Bhargava, Saha designed the apparatus for experimental test of thermal ionization of elements.

In 1927, Saha was elected as Fellow of the Royal Society. This honour to Saha was well received by the University authorities. Saha was felicitated by the University. However, Saha's problem remained the same; no research grant was provided by the University. When Saha received a congratulatory letter from Sir William Morris, the Governor of the United Province; Saha thanked the Governor and apprised him with his difficulties in pursuing research activity in absence of any grant. The Governor was once a class fellow of Lord Rutherford; who promptly sanctioned an annual research grant of Rs. 5,000.

The annual grant from Sir Morris was a welcome change, but it was not sufficient. Saha approached the Central Government through Sir Tej Bahadur Sapru for more funds. The Central Government turned down the request. In the meantime, the Royal Society sanctioned a grant of Rs. 15,000 which helped Saha to start his experiments. He also received donations from public for his research works. Soon, Saha had a flourishing research school and the output of the department dominated the national scientific scene. This emergence of a formidable school of physics soon gained international reputation. It attracted talents from both within and outside the country. Nobel Laureates such as Sir A. Eddington, Arthur H. Compton, Arnold Sommerfeld and Dr. Karel Hujar were some of the notable visitors to the department during Saha's time. Compton delivered following three lectures in 1927 –

1. Light Waves and Light Projectile
2. The Architecture of Atoms
3. X-Rays

Compton even proposed Saha's name for the Nobel Prize.

7. Initiatives by Saha for the Physics Department

In order to fabricate various instruments, Saha started a workshop. He appointed Nawab Ali as the incharge of the workshop. In 1933, Saha requested the Executive Council to grant Nawab Ali an increment of Rs. 6 from his personal research grant. It was accepted.

During the birth centenary of Meghnad Saha, I met Nawab Ali; he was 95 years old then. He showed me a testimonial which Saha gave him. He also showed me a copy of farewell citation and the editorial published in an Urdu daily along with an obituary of Saha after his death.

Saha during his time at Allahabad University wanted to develop wireless telegraphy for which he requested for a sum of Rs. 6,000. However, the University granted only Rs. 2,000. Saha then requested Rai Amarnath – a well-known citizen of Darbanga locality of Allahabad to lend his 100W transmitter with its components to the Physics Department for a year. Thereafter, he sent his research student Ramlal Gupta to Bangalore to acquire knowledge about wireless telegraphy from Professor Chaterson Smith.

Saha wanted to start photography classes in the Department and accordingly he forwarded a note to the Executive Council with a well-drafted scheme. The proposal was duly accepted by the council. As a result, the

photography class started at Allahabad University. It was the first such class being conducted by an Indian university.

As an exercise of outreach programme, Saha took the following steps:

1. The X-ray laboratory of the University, for a nominal price use to take X-ray pictures of parts of the body.
2. He went out of his way to help the Municipal Board, Allahabad in connection with its electric works.
3. During golden jubilee celebrations of the University in 1937, Saha arranged interesting and instructive experiments for the public.

8. Saha's Role in University Bodies

In the University, Saha served as a member in various bodies like Academic Council, Executive Council and University Court. He was very active in these bodies. He used to attend the meetings well prepared according to the agenda of every meeting. His speeches were recorded in the minutes of the meetings. He was forceful in his arguments and always ensured to push for the development of the University. Saha was fearless and frank and at the same time was full with a sense of earnestness and sincerity.

9. Saha's Interest in History and Indology

In the Department of Sanskrit and Oriental Languages, University of Allahabad, Pt. Kshetresachandra Chattopadhyaya joined as lecturer in 1924. Professor Saha and Pt. Chattopadhyaya, besides being alumni of Presidency College, Calcutta, shared common interest in ancient history and used to discuss the problems related to ancient Indian history and archaeology. Professor Saha took him and Dr Dharmananda Koshambi of Aligarh Muslim University to the Kaushambi city in his car. This led to the foundation of their desire to start archaeological excavations at Kaushambi and subsequently, they approached the Archaeological Survey of India (ASI) to undertake the excavation work. ASI deputed N.G. Majumdar for this work.

Detouring a bit from the above-mentioned episodes, it is important to mention that eminent physicist Professor S.N. Bose, who was a classmate of Saha, had a very good knowledge of ancient historical studies. Professor Bose was a good friend of Pt. Chattopadhyaya. During his visit to Allahabad University, Professor Bose came to know about the artefacts excavated from

Kaushambi by G.R. Sharma, a student of Pt. Chattopadhyaya; so Professor Bose along with Pt. Chattopadhyaya visited the archaeological museum of the University. Professor Bose carefully studied the inscription and surprised everyone by explaining the date of one of the inscriptions with convincing logic.

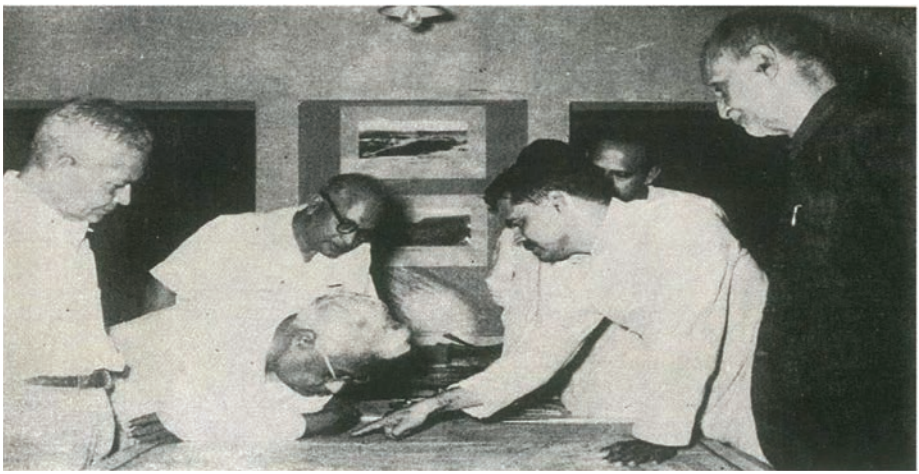

Fig. 1: Professor S.N. Bose inspecting inscriptions excavated from Kaushambi. Also, seen in the picture, Pt. Kshetresa Chattopadhyaya and his student G.R. Sharma.

Professor Saha's love for Indian history and culture inspired him, not only to study different aspects of indology, but to go beyond and to discover facts which were not known at that time. He was interested in the decipherment of Harappan script and read a lot in this connection. Professor Saha's interest in history included religions of the world. He had studied the subject very well.

In a meeting of Executive Council, during a prolonged discussion on the syllabus of ancient Indian history, Saha made a few suggestions. The Vice-Chancellor, unaware of the fact that Saha had great knowledge and interest in history apart from physics, asked Saha to keep his views to himself. Later, Pt. Chattopadhyaya told the Vice-Chancellor about Saha's knowledge of history. Thereafter, the Vice-Chancellor graciously apologized to Saha. Knowing Professor Saha's interest in indology, Max Planck expressed his desire to study Indian philosophy. Professor Saha made available a book on Indian philosophy authored by Professor A.C. Mukherjee of Allahabad University.

10. Saha's Vision for Creation of Organizations

In 1924, Professor Saha wrote an article titled 'Plea for a Museum at Allahabad' in Allahabad University magazine, which reflects his vision as well as his vast knowledge of surroundings of Allahabad [6]. He wrote:

> *'The ideal museum is not a mere collection of "curios" or "specimens". It should cover the whole range of human activity, in the past or at the present time and should teach the truths of all the sciences. The "collections" must be arranged in such a manner that it should provide amusement and instructions to all sorts of people. Of course, such a program cannot be fulfilled by a single institution. We have, therefore, new sub-divisions such as Art Museum, Science Museum, Industrial Museum, Anthropological Museum and so forth'.*

Later on, in the same chapter, Professor Saha described how the museum could be built. He wrote and I paraphrase – The first duty of science section will be to organize a 'Geological Museum' where specimens of rocks and minerals will be collected and classified from all parts of India, specially places near home, namely Bundelkhand, the Central Provinces, the Central Indian States and Shivalik Hills. He further adds –

> *'The art section of the museum may specialize in archaeology works of art and sculptures for which many cities in the United Provinces are still famous. It may attach, to itself a section where Hindi and Urdu manuscripts may be collected and preserved'.*

He goes on – 'Regarding the archaeological section, it is superfluous to add that, Allahabad has great possibilities. The country, round about Allahabad is full of relics of the old days, Hindu and Muhammaden. The archaeological finds at Jhusi (old Pratisthanpur), Kosam (old Kausambi) – capital of King Udayan (celebrated in Buddhist lore), Singraun (old Singverpur – capital of Guhak Chandel, friend of Ramchandra and an old centre of sun worship), Karamanikpur (seats of early Muhammaden rulers), Deora (old Vitabhayapattan) which are all within the Allahabad district and within 30 miles from the city of Allahabad, can find no better name than The Museum of Allahabad. Not merely this, the establishment of a museum at Allahabad, will act as powerful incentive to the public, particularly to the students, hailing from the interior of the province, who collect these finds and deposit them in the central home at Allahabad (which refers to museum at Allahabad).

Professor Nil Ratan Dhar, the founder head of Chemistry Department of Allahabad University was elected as president of chemistry section of the Indian Science Congress Association in 1923. Professor Saha and several

eminent chemists requested Professor Dhar to initiate steps for the formation of the Indian Chemical Society [7]. In May 1924, the society came into existence with Acharya Prafulla Chandra Ray as the founder president of the society. Professor Saha contributed his paper entitled 'Experimental Test of Thermal Ionization' co-authored with N.K. Sur in the very first issue of the *Journal of Indian Chemical Society* [8]. He also published another paper in this journal titled 'The Phase Rule and its Application to Problems of Luminescence and Ionization of Gases' in 1925 [9].

It is often said that Saha and his colleagues discovered the origin of the complex spectra, but they narrowly missed the credit by a few months. Before their results could be published, Hund had already published his results. This delay in publishing was due to the fact that papers sent abroad in those days used to take at least one year to get published. Saha realized this difficulty and felt the need for a science academy in India. He began his efforts very earnestly in this direction. He did two things: Firstly, at the annual meeting of the University Court held in 1928, Saha moved the resolution for establishing a Central Academy of Sciences at Allahabad and secondly, persuaded Dr D.R. Bhattacharya, the then dean, Faculty of Sciences to move a resolution for holding the Indian Science Congress at Allahabad. The sixteenth annual meeting of the congress was held in January of the year 1930.

In the meantime, the December 1929 issue of Allahabad University magazine carried an article titled 'A Plea for an Academy of Sciences' [10]. In this article, Saha narrated about the Royal Society, the French Académie des Sciences and the Russian Academy of Sciences. He felt the need for scientists to seek a common meeting ground for exchange of ideas and strive to apply science and technology for solving various economic problems in the country.

During an Indian Science Congress meeting of scientists in the United Provinces of Agra and Oudh, a committee was formed for the formation of the academy. As a member of the committee, Saha played a leading role in drafting the objectives, rules and regulations. The United Province Academy of Science came into existence in 1930. Thus, Saha's plea became a reality. He was a natural choice for the post of president of the Academy. The Academy was formally inaugurated on March 1, 1932 with Saha as the founder president. In 1934, the United Province Academy was renamed as the National Academy of Sciences, India.

As the president of the Indian Science Congress Association in 1934, Professor Saha made serious efforts for starting an All India Academy of Sciences, which resulted in the formation of National Institute of Sciences; now known as the Indian National Science Academy. His vision to develop a

strong base of research and scientific manpower in India can be understood when he conceived the idea of an institute of nuclear physics as early as 1936 while he was in Allahabad. I would like to mention about Professor Saha's effort in establishment of some more scientific bodies. After Saha went back to Calcutta in 1938 he built the Institute of Nuclear Physics which was later renamed as Saha Institute of Nuclear Physics.

In 1935, Professor Saha established another scientific body, Indian Science News Association (ISNA) with his teacher Acharya Prafulla Chandra Ray as president. The nature of the association was such that it incorporated the cultural activities along with scientific activities which reflected in the journal *Science and Culture* published by the association. Professor Saha was the editor of the journal and appointed his student Gyan Chandra Mukherji as assistant editor.

11. Indian Press and Saha

After leaving his job at Pioneer Press, Chintamani Ghosh started The Indian Press, which was registered on 4th June 1884. In a short period of time, the press established itself as a leading publication house. The first textbook it published was *Physical Geography* by E.G. Hill, Principal of Muir Central College, Allahabad. In 1922, when Allahabad University became a residential teaching university, Muir College became the nucleus of the University. Later on, the press building was acquired by the University to develop the area as arts, commerce and law faculties. The Muir Central College became the science faculty.

The Indian Press started operating from a new building located at Park Road. The Indian Press soon became an important publishing house and its reputation spread all over the country. The Indian Press published more than 80 books of Rabindranath Tagore.

Saha while teaching thermodynamics, kinetic theory of gases and statistical mechanics to the students felt the need for good quality textbooks. This desire prompted him to write a book titled *Text Book of Heat* with his student B.N. Srivastava which was published by Indian Press in 1931. In the foreword of the first edition of the book, C.V. Raman wrote –

> *'The familiarity with the thermodynamics and its application to physical and chemical theories which led Professor Saha to these classical researches has also made him the most successful expositor of the subject'.*

Later on, a second enlarged edition of the book with the title *Treaties on Heat* was brought out. This book was referred by Nobel Laureate Sommerfeld in his book on thermodynamics. Later a concise version of the book was also published by Indian Press. It became so popular amongst the students, that by 1967 its 17th edition had been published. In 1935, Saha wrote another book titled *Modern Physics* with N.K. Saha and it was also published by Indian Press.

When Saha decided to bring out *Science and Culture* in 1935, Indian Press took upon itself the responsibility of printing the magazine and continued to do so till Saha was at Allahabad.

Once Indian Press, decided to print an encyclopaedia 'Shishu Bharati' for children in Bengali. They approached Saha to contribute articles for the encyclopaedia's various volumes. Saha readily agreed and contributed the following articles:

Volume 1: পৃথিবীর আকার ও অবস্থান (Shape and Position of Earth)

Volume 2: উচ্চতা মাপকযন্ত্র (High Temperature Measuring Instrument)

Volume 3: a) পশ্চিম ইউরোপের জাতিদের পৃথিবী পরিক্রমণের চেষ্টা (Efforts of Western European People in Voyage of Earth)

b) পৃথিবী পরিক্রমণে পর্তুগীজ জাতির উদ্দ্যম (Endeavour of Portugese People in Voyage of Earth)

Volume 5: a) ম্যাগেলানের প্রথম পৃথিবী পরিক্রমণ (First Voyage of Myagelaner Around the Globe)

b) জন্ হকিন্স্ ও ডেকের আদি সমুদ্র যাত্রা (Early Sea Voyage of John Hawkins and Dek)

Volume 7: রঞ্জন আলো (Roentgen Rays)

12. Science and Culture

In Calcutta, Professor Saha continued his keen interest in the publication of *Science and Culture*. Besides writing editorial notes, he used to contribute his own articles in the same. Through these articles, he conveyed his ideas on various subjects, ranging from constituents of matter, spectra of comets, solar control of the atmosphere, physics in the aid of medicine to planning for the Damodar Valley. He also made editorial notes on 'National Scheme of Education' and on 'Archaeological Excavations in India'. He even persuaded scholars of other disciplines, including Pt. Chattopadhyaya to contribute

articles in *Science and Culture*. In the first volume, Pt. Chattopadhyaya contributed the article, titled 'A French Account of Ancient India'. During Professor Saha's time, the journal *Science and Culture* devoted to its true fundamental objectives – the interpretation of science and its popularization and advocacy of application of science to bring about a technological revolution.

Following is a list of articles of Saha published in *Science and Culture* from Allahabad:

1. 'Ultimate Constituents of Matter', Vol.1, No.1, pp. 12-19, 1935.
2. 'The March towards Absolute Zero', Vol.1, No.3, pp. 118-121, 1935
3. 'The Existence of Free Magnetic Poles', Vol.1, No. 3, p. 156, 1935.
4. 'Spectra of Comets', Vol.1, No. 8, p. 476, 1936.
5. 'The Intelligent Man's Guide to the Production and Economics of Electrical Power', Vol.3, No. 10, p. 506, 1938.
6. 'The Intelligent Man's Guide to the Production and Economics of Electrical Power', Vol.3, No. 11, p. 574, 1938.

13. Towards Social Goals

Professor Saha was ahead of his time, particularly when it came to correlating social needs with the growth of science. When Netaji Subhash Chandra Bose, the then president of the Indian National Congress addressed the Indian Science News Association in 1938; Professor Saha taking this opportunity, was able to convince him to setup the National Planning Committee (NPC). The proceedings of the NPC bear deep imprint of Professor Saha's concern towards a full-fledged technological revolution in India.

The Presidential address delivered by Professor Saha at the 3rd Annual General Meeting of the Indian Physical Society in January 1937; reflects his concern for problems of India's economic and social development and with the role of scientists in discovery, planning and reform.

One also saw Saha in a new role, that of a people's representative in the Lok Sabha of 1952 parliamentary election. Saha actively participated in the parliament in the areas of education, refugee and rehabilitation, atomic energy, multipurpose river projects, flood control and longtime planning. He was the chief architect of river planning in India and prepared the original plan for the Damodar Valley Project. His speeches in the parliament reveal his deep commitment towards uplifting the masses.

Professor Saha played an important role in fostering a scientific temper and culture in the society. Professor Saha, strongly advocated social and economic planning in India particularly, in science, industry and technology. He was a member of the Planning Commission, chairman of Power and Fuel Committee and member of sub-committee on River Taming and Irrigation. He was also a chairman of the Calendar Reform Committee. To achieve his mission, he even entered in politics. Like his teacher Acharya Prafulla Ray, Professor Saha was a visionary in true sense.

14. Conclusion

Recollecting life and works of Professor Saha, Santimay Chatterjee wrote [11]

> *'It was at Allahabad that Saha became FRS, President and General President of Indian Science Congress Association, President of The National Institute of Science. From here he became a Carnegie Fellow. It was in Allahabad; he mastered his knowledge of ancient Indian history, archaeology, ancient astronomy, pleaded for hydraulic research laboratory and predicted the mass of magnetic monopole-which is the only prediction that has yet to be confirmed. It was from Allahabad that Meghnad Saha, emerged as a strong force in the national arena'.*

Saha returned to Calcutta as Palit Professor of Physics in 1938. Allahabad will always remember his fruitful stay and him as a true visionary.

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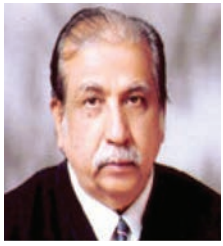

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(1) Dr Anil Bhardwaj delivering his talk. (2) Dr V.P. Kamboj felicitating Dr Atri Mukhopadhyay. (3) Dr Ajoy Ghatak felicitating Dr Hari Prakash. (4) Participants enjoying lunch. (5) Dr Ravindra Dhar giving the Vote of Thanks. (6) Dr Ajoy Ghatak felicitating Dr Arnab Rai Choudhuri. (7) The packed auditorium. (8) Dr Anurag Sharma delivering the 2017 Meghnad Saha Award Lecture. (9) Dr Somak Raychaudhury delivering his talk. (10) Dr Sandip Trivedi delivering the 2016 Meghnad Saha Award Lecture. (11) Dr Ashok Misra felicitating Dr S.C. Dutta Roy. (12) Dr Manoj Saxena felicitating Dr Shyamal Bhadra, (13) Dr S.L. Srivastava felicitating Dr Anirban Pathak.

Professor Meghnad Saha (then Professor & Head of Physics at Allahabad University) was one of the Founders of The National Academy of Sciences, India (usually known as NASI); it is the oldest science academy in India, of which he was the Founder President. His research work provided solution to many mysteries of the universe and he played extremely important roles in establishing many institutes. To tell the younger generation of the many outstanding contributions of Professor Meghnad Saha, on his 125th birth anniversary, NASI organized a 2-day seminar at Prayagraj which was attended by over 400 students, teachers and researchers. This edited book represents some of the lectures that were delivered in the seminar.

Ajoy Ghatak did his M.Sc. from Delhi University and Ph.D. from Cornell University. He is currently Professor Meghnad Saha Fellow of NASI. His research interests are in Fiber Optics and Quantum Mechanics. He has authored several books including his undergraduate text on ***OPTICS*** which has been translated to Chinese and Persian. He is recipient of quite a few awards including the CSIR 1979 S.S. Bhatnagar Award for *'outstanding contributions in physical sciences'* and also the 2008 SPIE Educator Award in recognition of *'his unparalleled global contributions to the field of fiber optics research, and his tireless dedication to optics education worldwide..'.*

Anirban Pathak is a theoretical physicist and is currently Professor of Physics at JIIT, Noida. He did his Ph.D. from Visva Bharati, Santiniketan, West Bengal, India. He was a postdoctoral Fellow at Freie University, Berlin. He is actively involved in teaching and research related to several aspects of quantum optics and quantum information. He is a member of the National Academy of Sciences, India (NASI) and several other professional bodies. He is a visiting scientist at Palacký University, Czech Republic. He has written a few books including an introductory textbook on Quantum Communication and Computation. He is the recipient of the 2017 Shri O.P. Bhasin Award in the field of *Electronics and Information Technology.*

(1) Dr Anirban Pathak, Dr Satya Deo, Dr Anil Kakodkar, Dr Ashoke Sen, Dr Ajoy Ghatak and Dr U.C. Srivastava releasing the Proceedings of the seminar that was organized during October 6-7, 2018. (2) Dr Shyamal Bhadra, Dr Satya Deo, Dr Anil Kakodkar, Dr Ashoke Sen and Dr Ajoy Ghatak releasing the book ***DARWIN OF STELLAR ASTROPHYSICS: MEGHNAD SAHA.*** (3) Dr Sheo Gopal Mishra, Dr Satya Deo, Dr Anil Kakodkar and Dr Ashoke Sen releasing the book ***VIGYAN KE VIVIDH ADHAR*** (published by *Vijnana Parishad*, Prayagraj).

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