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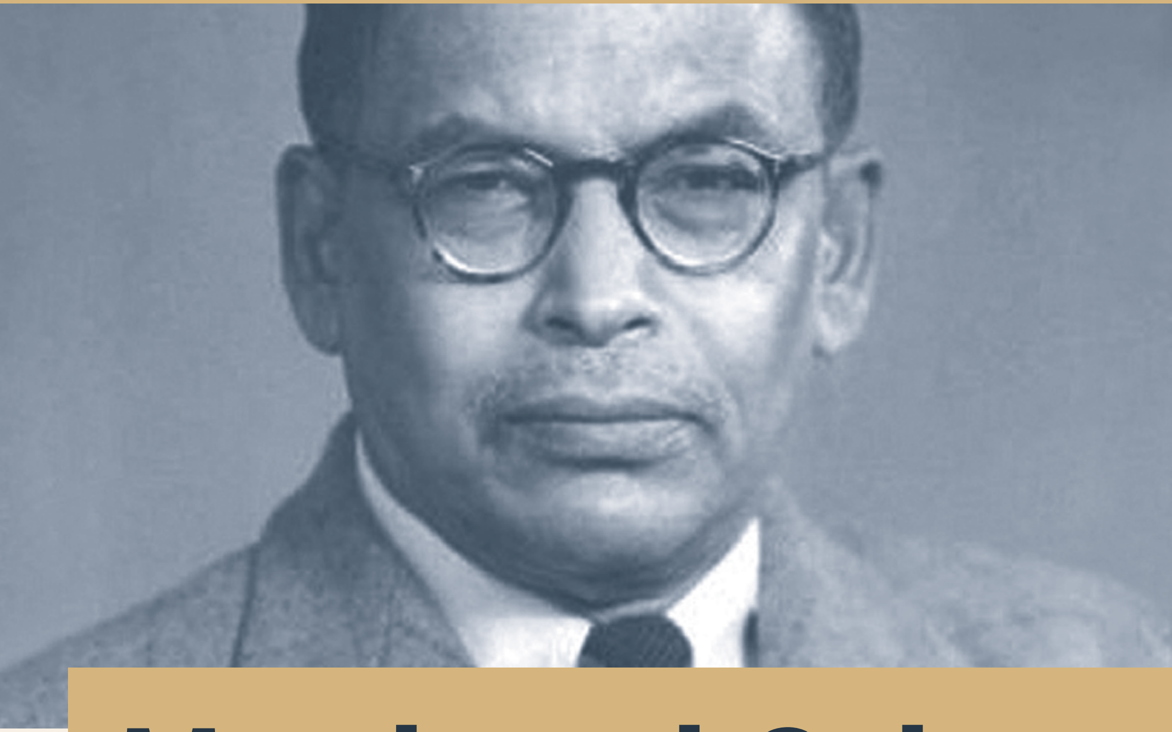

Meghnad Saha

His Life in Science and Politics

PRAMOD V. NAIK

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To
the late Aaee and Anna:
You could not see this book!
......Baban.

Preface

During the late 1980s I worked on my doctorate degree in Physics at the Department of Physics of the University of Bombay (now Mumbai). As a part of my work I studied plasma physics, and there I came across Saha's equation. My curiosity was aroused and I started researching Saha's life, his research, his writings, and so on. One of his students (the late) Prof. Santimay Chatterjee, edited and published many volumes of Saha's work. It was of immense help in understanding Saha. My interest widened and I resolved to write his biography.

Meghnad Saha is one of the architects of Indian science. He played a prominent role in building scientific institutions in India. His theory of thermal ionization was a breakthrough in astrophysics. He was elected as a fellow of the Royal Society of London at the age of 34. His name was even proposed for the Nobel Prize in Physics.

He extensively studied subjects such as higher education, river management, flood control, multipurpose river valley projects, power and fuel, state reorganization, large-scale industrialization, archeology, calendar reform, and so on. He also worked on the National Planning Committee of India before independence.

Saha was an eminent scientist with vision. His editorials and articles in *Science and Culture*, the periodical he had set up, testify to this. In later life, circumstances forced him to enter Parliament, though he was interested in neither politics nor power. His sole objective was to reconstruct an independent India using science and technology, and the progress of all sectors of society. He was of the firm belief that only scientific research, quality education, and technological development can raise India to the level of advanced countries.

After the first 3–4 years of independence, Saha realized no well-defined policy existed for large-scale industrialization. The river valley development projects were not managed properly. The fields of higher and technical education were neglected. National planning was not executed the way it was intended. These facts made him restless. He always discussed these issues with his colleagues and friends, and referred to them in *Science and Culture* as well as other periodicals. But it was not enough to reach the ears of countrymen or politicians.

Because of this situation and his friends' advice, he made up his mind to enter the House of the People to raise his voice in protest. If visionary national leaders would have involved him in an appropriate national reconstruction project with the necessary freedom, he probably would not have thought of entering Parliament.

His speeches in Parliament on diverse topics such as education, multipurpose river projects and flood control, planning, industry, atomic energy, refugees, and rehabilitation show his wide interests, depth of understanding, and sincerity. His speeches and discussions pointed out mismanagement of many programs of national importance and shortcomings of governance.

Saha had a multidimensional personality. His fervor about India's rapid progress in science and technology, the uplift of his countrymen, and optimization of the country's resources, was replete throughout the pages of *Science and Culture* and in his addresses, speeches, debates, and discussions in Parliament. Joseph Needham described Saha as one of India's most outstanding scientific men, who had intellectual interests much wider than the domain of natural science and an appreciation of the social responsibilities of scientists.

In this biography I have tried to convey his thoughts, beliefs, and work. The many topics he discussed and described, and the points he raised, are still relevant, even after 60 or 70 years. It shows his razor-sharp intellect and vision.

While reading this book, if something is too technical, please leave it and move ahead, for much information is given in the remaining text. I have no desire to belittle anyone or anything; if you find harsh words, they are the sincere opinion of a researcher.

I thank my editor Jennifer Satten for her tireless efforts and her excellent editorial skills. I also thank Azadeh Keivani for comments on the manuscript. Thanks to Ramon Khanna, Executive Editor Astronomy for his overall guidance in this project.

Saha Institute of Nuclear Physics (SINP) provided photographs related to Saha's life, and I am very thankful for these. Special thanks to Prof. M. S. Janaki of SINP for her efforts in procuring the photographs.

I also thank Mr. Ram Dhuri of Tata Institute of Fundamental Research (TIFR), Mr. Abhijit Bhattacharyya of SINP, the late Sanjay B. Gawde of TIFR, Prof. Kalyani Krishnamurthy, my sister Manda R. Gawde, and my brother-in-law Ramesh J. Gawde for helping me at various stages.

Thanks to my wife Neelam, who is a great source of inspiration and strength, and my son Nachiket, for his constant support.

Pramod V. Naik

In the original version of this book, the cover image credit was wrongly mentioned. This has now been updated correctly as "The cover photograph of Prof. M. N. Saha was taken by M/S Bourne & Shepherd around 1954. This photograph is provided by Saha Institute of Nuclear Physics, Kolkata, India."

Contents

Abbreviations

AEC	Atomic Energy Commission
ARC	Atomic Research Committee
BSIR	Board of Scientific and Industrial Research
CSIR	Council of Scientific and Industrial Research
DAE	Department of Atomic Energy
DRDO	Defence Research and Development Organization
FRS	Fellow of the Royal Society of London, England
IACS	Indian Association for Cultivation of Science
INP	Institute of Nuclear Physics (later SINP)
SINP	Saha Institute of Nuclear Physics
SRC	State Reorganization Commission
TIFR	Tata Institute of Fundamental Research
TVA	Tennessee Valley Authority
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPA	United Provinces Academy of Science

About the Author

Pramod V. Naik obtained his Ph.D. from the University of Bombay (now Mumbai) in theoretical astrophysical plasma physics and is a faculty member at Veermata Jijabai Technological Institute (VJTI) in Mumbai, India. His research interests are nonlinear physics and the history and philosophy of science in general and physics in particular. He is currently working on the project *Science in India: Past, Present and Future*.

Chapter 1
Introduction

Meghnad Saha is an illustrious name in the history of modern science in India. He was an extraordinary genius and carried out remarkable work as a physicist, teacher, educationist, institution builder, founder of the periodical *Science and Culture*, science administrator, and parliamentarian. His work in each of these disciplines makes him a notable figure in Indian history.

In his college days, Saha was a student of Mathematics. He learned physics on his own, without the help of any guide or mentor, and he excelled in it. As a young researcher at Calcutta, far away from Europe – which at the beginning of the twentieth century was the prime center of research in physics –he conducted latest research in physics, in spite of meager resources and poor means of communication, and he made outstanding contributions to this field. His theory of thermal ionization was a breakthrough in the study of stellar spectra. Rosseland [1] said that, "Although Bohr must thus be considered the pioneer in the field, it was the Indian physicist Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory."

Saha was not satisfied with only theoretical interpretation; he tried to verify thermal ionization experimentally, but owing to a lack of facilities, he could not complete the research. In Nernst's laboratory in Germany, Saha performed some experiments, but they were also left unfinished. Because of domestic pressure from Calcutta, he could not continue research in that direction.

His epoch-making contribution in Astrophysics – the theory of thermal ionization – at the age of 27 made him an eminent physicist. In the 14th edition of the *Encyclopedia Britannica*, Sir Arthur Eddington said "Prof. Saha's Theory of Thermal Ionization is one of the twelve fundamental landmarks in Astrophysics, since the discovery of the first variable star (Mira Ceti) by Fabricius in 1596." Saha was elected as a fellow of the Royal Society of London at the age of 34. He also was recommended for a Nobel Prize, but unfortunate circumstances[1] kept him away from winning it.

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[1] The circumstances are described in the chapter titled *Saha and a Symbol of Excellence*.

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As Friedman [2] observed, "... During the next few decades, leading astrophysicists who were nominated were generally summarily dismissed: Hans Bethe, Ira Bowen, Arthur Eddington, Edwin Hubble, Meghnad Saha, H. N. Russell. The [Nobel Prize] committee noted that regardless of how important the astrophysicists' achievements might be, for the speciality field of Astrophysics, these did not have sufficient significance for the field of Physics in general [as the committee defined it] to warrant a Nobel Prize. Notwithstanding the committee's desire to shrivel the domain of Physics, the disciplinary boundary line necessarily remained diffuse and the gatekeepers acted as overzealous guardians. Work by Saha and Bethe, for example, certainly could not justifiably be dismissed as being solely significant for Astrophysics, divorced from the mainstream of Physics."

This biography provides an overview of Saha's research contributions in context with contemporary views and theories with historical aspects. Here I emphasize how Saha developed the ideas and theories using prevailing knowledge.[2]

Saha had meager resources for research when he was working at Allahabad University in India, yet he nurtured a group of students who did notable work in their chosen fields. He was a teacher par excellence. His students included D. S. Kothari, B. D. Nagchaudhuri, N. K. Sur, S. C. Ray, S. Basu, G. R. Toshniwal, P. K. Kichlu, K. Majumdar, S. C. Deb, P. K. Sengupta, H. K. Trivedi, A. K. Datta, R. S. Sharma, L. S. Mathur, W. M. Vaidya, S. Malurkar, N. K. Saha, and many more. In Fig. 8.3, some of his students are shown in a group photograph taken at the Department of Physics, Allahabad University, in 1926.

Saha played an important role in national planning in India before independence. He was of the firm opinion that in a country like India, the problems of food, clothing, poverty, education, and technological progress can be solved only with proper planning using science and technology. Saha was a member of the core committee for national planning and chairman of two subcommittees: Power and Fuel and Technical Education.

It is difficult to determine which subject was dearest to him. Saha was a deeply committed educationist. As a member of the University Education Commission, he had firsthand information about the status of education in India. He observed that "The standard of Indian Universities had deteriorated to an abysmal level. There was not a single Indian University which was functioning satisfactorily." He said that "An independent India has to rebuild the country and for that we require scientists, technicians, a better type of engineers and lawyers who can not only earn fabulous sums of money but also be competent enough to frame laws in accordance with the needs of a changing society." His thoughts on education, not only theoretical but also practical, are described here in his parliamentary speeches on education and the University Grants Commission. Many of his ideas are still relevant.

Saha was the founder of the scientific monthly *Science and Culture*, which was modeled on *Nature*. It played a crucial role, as a wide variety of articles that appeared in it were of national and social importance. The scientific approach, thorough

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[2] Today certain topics seem so trivial and some require corrections, as we are ahead by a couple of decades.

discussion, and their relevance in the Indian context were characteristics of those articles – some of which are relevant even today. The hardship that Saha underwent in his formative years directly or indirectly inculcated in him an awareness of social responsibility that is reflected in his articles and speeches. Throughout Indian history, hardly any scientist of Saha's stature fought for social causes throughout his life. His concerns for national planning and the need for a hydraulic research laboratory, calendar reform, and higher and technical education are described here at length.

In 1932, the United Province Academy of Science was formed, and Saha was elected as its first president. He was a leading member in drafting objectives, rules, and regulations, and in the overall functioning of the Academy. He invited eminent personalities to address meetings. The Academy discussed and offered solutions for various issues of national importance. Later, in 1935, Saha was involved in the formation of National Institute of Science of India, which was renamed the Indian National Science Academy. His pivotal role in revamping the Indian Association for the Cultivation of Science was the only one of its kind.

By realizing the importance and the scope of nuclear science, he initiated a new course on the subject in 1940 at the University College of Science in Calcutta, immediately after the discovery of nuclear fission in 1939. In spite of a lack of funds; a paucity of good mechanics and laboratory assistants; and an absence of large engineering or manufacturing concerns producing machinery, electrical goods, scientific instruments, and chemicals, Saha dared to construct a cyclotron and succeeded, albeit late, overcoming all problems [3]. It was an achievement for nuclear science in India, especially in 1950.

Setting up an institute for studies in Nuclear Physics (later the Saha Institute of Nuclear Physics at Calcutta) revealed his long-term vision. It was a Herculean task because, as India was a poor country, philanthropy had limitations. The country's colonial status, societal indifference, and political and ideological differences with people in government also created obstacles. Yet he was successful in his endeavors.

The last 5 years of his life (1952–1956), until his sudden death, were dominated by his work as a parliamentarian. During the first few years after independence, when Saha realized that the country lacked clarity about priorities and a modus operandi for national planning, industrialization, and health and education, and mismanaged projects of national importance, such as river valley projects and multiple river schemes, he decided to raise his voice against it from the floor of Parliament. Because he thought that an entire nation could hear his appeal, he ran in the general election of Parliament from the Calcutta North-West Constituency and became a member of Parliament in 1952, defeating all political leaders. An eminent scientist winning election was unheard of in those days – and even today as well. Saha was not interested in politics but in social responsibility. Some of his speeches to Parliament [4], summarized here, show his sincere concern about various issues of national importance. The lack of proper planning, confusion about priorities, mismanagement of river valley projects, chaos in industrialization policy, the casual approach and apathy of ministers, a lack of systematic study of a subject by ruling party members during the immediate years after independence – all these were subjects close to his heart in the interest of a nation, and this is clearly reflected in his speeches.

Saha had studied calendar making, the history of calendars throughout the world, around 30 calendars prevailing in different parts of the country, and calendar reforms. He thought the calendar, as an indispensible part of civilized society, should be based on scientific principles and methods. He pointed out inconsistencies and superstitions in the Gregorian calendar and also proposed a world calendar. When the government of India appointed a calendar reform committee in 1952 under his chairmanship, Saha worked hard to develop a new calendar (the Saka Calendar) based on rational methods, which India accepted in 1956.

Scientists are often blamed for remaining in an ivory tower, cut off from the problems of society. But Saha was an exception. He was not only a vocal but an active participant in solving national problems.

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3. J. Phalkey, *Atomic State: Big Science in Twentieth-Century India* (Permanent Black, Ranikhet, 2013)
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Chapter 2
Science in India: Ancient and Modern

Indian Civilization

A lot of research has been conducted on the origin and development of Indian civilization.[1] Archaeological sites date from before 30,000 to about 10,000 B.C. In South Asia from the beginning of the sixth millennium B.C. and perhaps considerably earlier, wheat and barley were cultivated, and domestic sheep and goats were kept by the earliest settlements. The evidences show, around 5000 B.C., a stable agricultural community existed. People lived in mud brick houses. They knew of the smelting of copper, making fine colourful pottery and trading over great distances. The beginning of a continuous process of development of stability and agriculture resulted in the early stage of the Indus civilization around 3000 B.C.

An early or Pre-Harappan urban phase of the Indus civilization emerged in the period between c. 3000 and 2500 B.C., which shows the establishment of a uniform style of life and subsistence, which indicates an increase in trade and commerce.

India's cultural frontiers were closely defined. It was because of clearly marked physical frontiers. To the south, south-east and south-west, it is ocean which facilitated trade but isolated her culturally. To the north, north-east and north-west are massive mountain ranges that divided her from the rest of Asia. The access was not easy for traders and travellers, but it also screened her from the arctic winds and air currents of central Asia. As a result, the climate is hot and dependent on a monsoon cycle of seasonal rainfall. The northern mountains are not only physical or cultural frontiers but also climatic frontiers. Almost every type of tropical or almost tropical climate can be found within the subcontinent.

The pre-Neolithic cultures of India fall into three groups, which in general follow one another sequentially throughout the subcontinent, namely, Early, Middle and Late Stone Age. These three groups represent a continuous process of development. But there are also marked regional differences within these groups. Some regions

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[1] Here *Indian* means *Indian subcontinent*.

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lagged behind others in new techniques and tools. Some had developed new ways of life, while other continued old ways for longer or shorter periods of time.

In the Early Stone Age, the hand-axe industries developed was comparable to those in Europe. The tools from succeeding terraces of the *Soan* river, a tributary of the *Indus* (now in Pakistan), ranged from crude, heavy hand axes and chopping tools made on pebbles in the upper terraces to small finely worked hand axes, cleavers, discoidal cores, flakes and chopping tools in the lower terraces. The industries of hand axes and other tools are also found in the valley of the *Beas* river, another tributary of the *Indus*, on the Indian side of the frontier; in the south near Madras (now Chennai); in Adamgarh Hill in the *Narmada* valley; and at the gravel of the *Wainganga* river, a tributary of *Godavari* river.

The archaeological evidences show that during the Early Stone Age, man does not seem to have lived regularly in caves anywhere in the subcontinent.

The Middle Stone Age tools were made mainly from cryptocrystalline silica of various kinds such as agate and jasper, or chalcedony, which had a smoother and more regular conchoidal fracture than the granular quartzite favoured in Early Stone Age times. The material appears to have been obtained in the form of river pebbles.

The Late Stone Age throughout India is characterized by microlithic industries. The change from Middle to Late Stone Age, that is, from the flake to the microlithic tradition, appears to be a process of continuous development rather than a sudden change. The stone industry shows certain sequential changes and developments; the tools became smaller, more delicate and more varied. Pottery also makes an appearance at this period.

The Late Stone Age collections in both central and peninsular India also form a small proportion of the finished tools. Very often they are made on fragments of quartz even when the rest of the assemblage is made of cryptocrystalline silica. The quality of both the material and workmanship is considerably better. The technical perfection of these industries went beyond the demand for utilitarian purposes. Many of the semi-precious stones such as agates which were used for making microliths in Central India are still employed by jewellers and bead-makers who obtain many of their best stones from the gravels of the *Narmada* and other rivers – the same sources which supplied the Late Stone Age hunters [1].

Numerous rock shelters discovered in Central India are embellished with drawings on the walls and ceilings, using varying shades of purple, red and light-orange brown. Some belong to later times, but many of the drawings are associated with the hunting cultures of Stone Age or immediately post-Stone Age times. They reveal animals of many kinds: deer or antelope, wild pig, rhinoceros, elephant, buffalo, humped cattle and monkeys.

Pre-Harappan or rather Early-Harappan settlements in Sindh, Punjab and north Rajputana show that the Indian subcontinent was inhabited by tribal communities whose technology was based primarily on stone, and whose principal tools were the bow and arrow, the trap, the snare and the digging stick. There were many different local cultures based on fishing, hunting and foraging.

Around the end of the fourth millennium B.C. in the valley of *Indus* and its tributaries, signs of colonization appeared. The foundations of the first Indian civilization were laid at Amri (Sindh), Kot Diji (Sindh), Harappa (Punjab) and Kalibangan (Rajasthan). There is a remarkable cultural uniformity, both throughout the several centuries during which the Harappan civilization flourished and over the vast area it occupied. In larger settlements, cities or towns, there occurs oriented grid of streets, which intersect the blocks of dwellings. There was standardization of brick sizes, both of burnt and mud bricks. Great care was taken for domestic bathrooms and latrines and on the chutes which linked them to brick drains running down the streets. The drains were connected with soakage pits or sumps, and their good maintenance implies highly effective municipal authority. The tools and vessels were made of copper and bronze. There were numerous highly developed arts and crafts. The bead-maker's craft, long barrelled beads of carnelian, seal cutting, art of shell inlay and stone and metal sculpture are technical masterpieces. The technical uniformity over great areas was unparalleled in the ancient world.

The variations of house sizes and localization of groups and barracks indicate class differences even amounting to slavery. It may be the origin of the caste system which plays a dominant role even now. Some features of religion of *Vedic* times or later Hinduism were seen at this period.

Around 2000 B. C., the uniform culture of this great area broke up. The cause of decline is uncertain. Several causes have been forwarded, for example, calamitous alterations of the course of the *Indus*, repeated flooding of the city, invasion from the west, etc.

> The general opinion among scholars now is to ascribe the demise of the Harappan tradition to ecological factors, for instance, a prolonged spell of aridity. At the end of the mature phase, when new elements appeared on the scene (and prior to the demise of the Harappan culture), the resultant culture was still a derivative of the Harappan. But when the *Aryan* entry took place, the late Harappans were culturally overwhelmed and absorbed into the new mainstream. They contributed to its growth, but at the cost of losing their own identity. Probably, a fraction moved southwards, outside the initial *Aryan* zone of influence. [2]

Chronology of prehistoric India [2]

c. 7000 B.C.	Advent of (wheat and barley) farming, animal husbandry and settled life at pre-pottery, Neolithic Mehrgarh in Baluchistan
c. 4700 B.C.	Handmade and coated-basket pottery, appearance of cotton
c. 4000 B.C.	Wheel-made pottery, use of copper
c. 3500–2500 B.C.	Early-Harappan regional cultures
c. 2500–2000 B.C.	Centralized mature Harappan phase with urban centres and seaports. Double cropping in Gujarat
c. 2000–1300(?) B.C.	Late Harappan localized cultures. Double cropping in north-west India
c. 850–400 B.C.	Painted Grey Ware culture of pastoral agriculturists on merger with the local late Harappan culture. Limited use of iron
c. 600 B.C.	Beginning of Indian historical era
c. 700–100 B.C.	Northern Black Polished Ware culture with full-fledged use of iron and urbanization of the Ganga Plain

The proto-Indo-European speakers emerged as a prehistorical entity in the steppes, north of the Black and Caspian Seas with the domestication of the wild horse. By the time they started dispersing, the Indo-Europeans were already familiar with metal and were not only riding horses but also using wheeled vehicles. The similar Indo-Iranian-speaking groups moved southwards from the Eurasian steppes in c. 2000 B.C. and spread over central Asia, Iran and Afghanistan up to River *Indus*. The merger of the non-*Rigvedic* Indic speakers with the post-urban Harappans led to the establishment of the various late Harappan cultural phases, including the important Cemetery H culture in Punjab.

In c. 1700 B.C., another group of Indic speakers settled in south Afghanistan and took to the composition of the *Rigvedic* hymns in the region between the Helmand and the Arghandab. The description of *Saraswati* and *Sharayu* in the Rigveda, and even in *sutra* literature, fits the Afghan rivers *Helmand* and *Hari Rud* better than any river in India. In c. 1400 B.C., the Rigvedic people moved eastwards to the middle *Indus*. Eventually, they absorbed the Cemetery H people to found the Painted Grey Ware culture in c. 850 B.C. in Punjab and on the upper *Ghaggar*.

The Vedic people stayed back to the west of the Yamuna-Ganga doab until c. 850 B.C. The large-scale settlement of the Ganga Plain took place only when the use of iron became widespread and, perhaps, when population increased. During their migration, the Indo-Aryans carried with them not only their poetry and religious beliefs but also place and river names which they selectively reused [2].

Since no historical documents are available, history has to be extracted from religious texts. The available sources are the *Vedic* texts, the *Puranas* and the two epics, the *Ramayana* and the *Mahabharata*. Other sources are *Avesta*, the sacred book of the Zoroastrians, Buddhist and Jain literature.

The *Vedic* texts are Holy Scriptures, composed by a large number of authors over a long period of time, which went through many revisions in the hands of a number of independent schools, resulting in a multidimensional corpus. There are three categories. The essence of corpus is made up of four *Samhitas* (collection of hymns (*sūktas*)) of *Rigveda*, *Samaveda*, *Yajurveda* and *Atharvaveda*. The *Brahmanas* are attached to *Samhitas*, which are prose texts devoted to an interpretation of the rituals. The *Aranyakas* (forest books) which contain mysticism and symbolism are appendices to *Brahmanas*. The *Aranyakas* form a natural transition to the philosophical texts of the *Upanishads*. The *Samhitas* and *Brahmanas* together are known as *sruti* (heard, implying revelation). The *Aranyakas* and the *Upanishads*, along with the philosophy in it, are called *Vedanta* (the end part of *Vedas*). The third category is *Kalpasutras*, which contains detailed instructions for performing rituals.

The hymns were memorized meticulously and transmitted orally to the forthcoming generations for many centuries. A number of devices were used for memorization and for the correct articulation of the sound, which determined its efficacy – a prime requirement in ritual texts. It was confined to a small, select group of *Brahmins*, who on the basis of knowing the *Vedas* claimed superior knowledge, and they alone were allowed to perform major rituals.

In the sixth century B.C., the establishment of kingdoms, oligarchies and chiefdoms and the emergence of towns brought about a historical transition in north

India. The emergence of *gana-sangh*[2] was a form of proto-state. There appeared a control over a defined recognized territory. The urban centre was the location of authority, which could also be the location of craft activities that were produced for both local consumption and commercial exchange. It was the emergence of the state system.

In the fifth century B.C., there was the rise of the *Magadha* Empire, which remained powerful and controlled nodal points in the Ganges river system that gave it access to the river trade. In 327 B.C., Alexander of Macedonia entered the Indian provinces. The subsequent period is the history of various empires, dynasties and invasions.

Ancient Science

When human beings formed a society, it became necessary for them to have knowledge of nature for their survival. The observations, interpretations and predictions gave birth to systematic branch of knowledge, which further spread into various branches of sciences. These natural sciences can be divided as ancient (or traditional) and modern. There are three main traditions in ancient sciences: East Asian (mainly Chinese), South Asian (mainly Indian) and Ancient Mediterranean-Islamic-European science.

Astronomy

The early man first encountered the motion of sun, moon, stars and seasons leading to the knowledge of astronomy and from food, diseases, health, etc. to medicine. So it is not surprising that in most cases, especially traditional sciences, most ancient branches are astronomy and medicine. India also has a long history of astronomy (*jyotisha-shastra*) and medicine (*Ayurveda*). Astronomy consists of mathematical astronomy (*ganita-jyotisha*) and astrology (*phalit-jyotisha*). The history of Indian astronomy can roughly be divided into the following periods [3]:

1. Indus valley civilization period (c. 2500 B.C.–c. 1700 B.C.)
2. Vedic period (c. 1500 B.C.–c. 500 B.C.)
3. *Vedāng* astronomy period (roughly around sixth and fourth century B.C.–third and fifth century A.D.)
4. Period of introduction of Greek astrology and astronomy (roughly second or third century A.D.–fourth century A.D.)

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[2] The *gana-sangh* or *gana-rajya* has the connotation of *gana*, referring to those who claim to be of equal status, and *Sangh*, meaning an assembly or *Rajya* referring to governance.

5. Classical *Siddhānta* period or classical Hindu astronomy period (end of fifth century–twelfth century A.D.)
6. Coexistent period of the Hindu astronomy and Islamic astronomy (thirteenth/fourteenth century–eighteenth/nineteenth century A.D.)
7. Modern period or coexistent period of modern astronomy and traditional astronomy (eighteenth/nineteenth century onwards)

The Aryans appeared in north-west India in c.1600 B.C. They produced four *Vedas*, namely, the *Rigveda*, the *Samaveda*, the *Yajurveda* and the *Atharvaveda*; each consists of the *Samhita*, the *Brahmana*, the *Aranyaka* and the *Upanishad*. The *Rigveda-Samhita* was composed in north-west India (present Punjab state) during c. 1500 B.C. and c. 1000 B.C. Basically it is a religious text, but it contains some astronomical knowledge. Its early portion deals with calendrical knowledge which was related to the local climate of India, annual monsoon and seasons. Agriculture was already developed by the Indus valley civilization, and there is a possibility that Aryans must have acquired some agricultural and calendrical knowledge from non-Aryans of India. The later portion of *Rigveda-Samhita* mentions the intercalary month of the year.

During c. 1000 B.C. and 500 B.C. (later *Vedic* period), the Aryans advanced towards the east, area between the *Ganga* and *Yamuna* rivers, where they composed later *Vedic* texts (except *Rigveda*). The *Atharvaveda* and *Yajurveda* explicitly mentioned the intercalary month. They also give the complete set of *nakshatras* (lunar mansions). The *nakshatras* were used to indicate the position of the full moon. The *Vedanga* (limbs of the *Vedas*) works were produced towards the end of the later *Vedic* period. The *Vedanga* consists of six divisions, namely, phonetics, metrics, grammar, etymology and ceremonial. In this period, astronomy (which was called *jyotisha* in *Sanskrit*) was established as independent learning. The *Jyotisha Vedanga* (or *Vedang jyotisha*) of Lagadha (first millennium B.C.) is the fundamental text of this learning. It contains a system of astronomy for calendar making. It is a lunisolar calendar. At the middle and at the end of the 5-year cycle, called *yuga*, two intercalary months were inserted. The *Vedang jyotisha* was composed sometime between the sixth and fourth century B.C., and the place was at the latitude 27–29° N, in north India without apparent foreign influence [3]. The Greek horoscopic astrology, zodiac signs, 7-day week, etc. entered India around the second or third century A.D. At this time, Greek mathematical astronomy was almost unheard of in India, and the *Vedang* astronomy was in use. Around the fourth century or so, Greek mathematical astronomy was introduced in India.

The end of the fifth century A.D. to the twelfth century A.D. is called *classical Hindu astronomy* period or *classical Siddhanta* period. The *Siddhanta* is the fundamental treatise of mathematical astronomy in *Sanskrit*. This period produced several renowned astronomers, namely, Aryabhata, Varahamihira, Bhaskara I, Brahmagupta, Lalla, Vatesvara, Manjula, Sripati and Bhaskara II. Some of their works are still considered to be an authority on the subject by traditional Hindu calendar makers.

The Kerala (south India) School also produced several good astronomers, namely, Madhava, Paramesvara, Damodara, Nilakantha, Jyesthadeva, Achyuta Pisarati, Puthumana Somayaji and Sankara Varman.

The *Jyotirmimansa* of Nilakantha has a unique place in the history of Indian astronomy, as it is the only work which focuses on epistemological issues concerning the science of astronomy and mathematics. It falsifies the claim of many scholars that Indian astronomy did not have a scientific methodology worth the name, in contrast to the Greek tradition [4].

From thirteenth/fourteenth century to the eighteenth/nineteenth century is the period of coexistence of Hindu astronomy and Islamic astronomy, which started after the establishment of Islamic dynasties.

Mathematics

Mathematics is found in scattered form – in sacred texts – the *Samhitas*, the *Kalpasutras* and the *Vedangas*. Information about enumeration, arithmetical operations, fractions, properties of rectilinear figure, (present) Pythagoras' theorem, surds, irrational numbers, quadratic and indeterminate equations, etc. is available in the *Sulbasutras*, which is the part of *Kalpasutras*. The *Brahmanas* and some *sutras* contain material about progressive series and permutations and combinations.

From town planning, architectural expertise and other aspects of civilization of Mohenjo-daro and Harappa, it can be concluded that Indus valley civilization had developed good degree of skills in measurements and computational techniques [5]. Vedic Hindus, like the Egyptians, adopted 10 as the basis of numeration. The various recensions of the *Yajurveda Samhita* give names as large as 10^{12}. The *Taittiriya Samhita* gives names as *eka* (1), *dasa* (10), *sata* (10^2), *parardha* (10^{12}), etc. The Jain mathematical work, the *Anuyogadvara Sutra* (c. 100 B.C.), mentioned large numbers up to 29 places and beyond. The fundamental arithmetic operations with elementary fractions are clearly indicated in *Vedic* texts. The *Rigveda* gives names of fractions such as *ardha* (one half) and *tripada* (three fourths). The *Maitrayani Samhita* mentions *pada* (one fourth), *sapha* (one eight), *kustha* (one twelfth) and *kala* (one sixteenth). The *Sulbasutras*[3] contains several instances of addition, subtraction, multiplication, division and squaring of fractions. The recurrence of arithmetic and geometric series with the correct statement of the results of their summation strongly suggests that the *Vedic* Hindus probably possessed some method of finding the summation of such series. The mathematician of the later period such as Mahavira, Bhaskara II, Narayana and others has framed general *formulae* for obtaining sums.

The various *Sulbasutras*, as parts of the *Srauta-sutras*, are *Brahmanic* geometrical manuals for the construction of sacrificial altars. The texts give several rules such as how to construct a straight line perpendicular to another straight line, a square with a given side, a rectangular with given sides and an isosceles trapezium of a given altitude, face and base. According to *Baudhayana's* definition, the theo-

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[3] The word *Śulba* means a cord, a rope or a string, and its root *śulb* means measuring or act of measuring.

rem of the square of the diagonal (in modern language Pythagoras' theorem) is 'The diagonal of a rectangle produces by itself both (the areas) produced separately by its two sides' [5]. By actually drawing the squares on the diagonal and the sides of a rational rectangle, dividing them into elementary unit squares and then counting them, *Vedic* Hindus might have arrived at the truth of this theorem.

The altar geometry of *Sulbasutras* contains the beginning of algebraic notions such as quadratic equations, indeterminate equations, surds, conception of irrational numbers and determinations of their approximate values.

Unfortunately a Jain mathematicians' work of pre-Christian era is not recorded; however, from a few fragments or insertions in canonical or other types of non-mathematical literature, their achievements can be assessed. About the first century B.C., the *Sthananga Sutra*, a Jain canonical work, listed several mathematical topics, which used to be developed at that time. These topics are *samkhyayana* (science of numbers), *parikrama* (fundamental operations), *vyavahara* (subjects of treatment), *rajju* (geometry, like *Sulba*), *rasi* (heap, solid mensuration), *kalasavarna* (fractions), *yavat-tavat* (equations, algebra), *varga* (square, quadratic equations), *ghana* (cube, cubic equations), *varga-varga*, etc.

The period of the second to eighteenth century A.D. is characterized by a wealth of material rich in range, depth and quality of mathematical investigations. The primary interest was problems concerning the reckoning of time. In India, like other civilizations, the substantial development of mathematics was related to astronomical works, for example, accurate positioning of the moon, sun and other planets and stars, calculations of their motions, predictions of their paths and positions and so on. This leads to refinements in algebraic solutions of indeterminate problems and various arithmetical operations. The expansion of trade and commerce, within as well as outside India, also must have played a vital role in the development of mathematics. Many mathematicians, from different schools, have done commendable works, for example, Aryabhata I, Bhaskara I, Brahmagupta, Mahaviracharya, Aryabhata II, Sridharacharya, Sripati, Bhaskara II, Narayana and many commentators. The Kerala school also produced many noted mathematicians: Govindsvamin, Sankaranarayana, Suryadeva Yajvan, Madhava, Paramesvara, Nilakantha, Citrabhanu, Sankara Variyar, Jyesthadeva, Achyuta Pisarati, Puthumana Somayaji and Sankara Varman.

A lot of work has been done on the manuscript that existed, scattered fragments, cross-references, translations, interpretations, chronology and so on [5]. For example, Madhava [4] gave the infinite series for $\tan^{-1} x$ in *Kriyakramakari* as

$$\tan^{-1} x = x - \frac{x^3}{3} + \frac{x^5}{5} - \ldots\ldots$$

which is the Gregory-Leibniz series for $\tan^{-1} x$. Similarly, the infinite series for the sine and cosine functions given in *The Yuktidipika* are attributed to Madhava as

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \ldots\ldots$$

and

$$\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \ldots\ldots$$

These results were used by Indian mathematicians more than 350 years before their rediscovery in Europe.

Medicine

It is quite obvious that medical knowledge must have grown out of necessity of overcoming pain, injury and sickness. The native medical science of India is known as *Ayurveda*. *Ayus* means ‘span of life’ and *Veda* means ‘unimpeachable knowledge’.

The evidence shows that medical knowledge possessed by Indus valley civilization was further developed by Aryans in their own ways. The evidence of existence of a high level of social sanitation and of public hygiene is observed from the archaeological excavation of pre-Aryan civilization of Mohenjo-daro, Harappa and many other sites in and outside the Indus valley. The water-proofed walls of baths, lined with impervious bitumen, arrangements for draining and refilling public bathing tanks through conduits, enclosed bathrooms and water-closets made of brickwork connected with central water supply and drainage, garbage chutes emptying into external masonry receptacles (presumably cleared on a municipal basis), an efficient and elaborate drainage system running beneath the paved streets, spaced brickwork manholes of drains with removable lids and soak pits suggestive of sanitary privies of modern invention, all show a remarkably high level of public health activity and universal consciousness of sanitation without parallel in contemporary civilizations and, in fact, most other civilizations of historic times [6].

The beginnings of the *Ayurveda* are traced first in *Rigveda* and then in the *Atharvaveda*. In earliest *Samhitas* of *Vedic* period, one can find logical speculations on the origins of diseases, use of healing drugs, treatment and surgery. The art of healing was not only a skill but also a social system including the power of magic, ideas gained by experience and experiments, compassion to human suffering, philosophical speculation and so on. This art of healing was a part of the sacramental duties of priests. Medical science was an *Upanga* (part) of the *Atharvaveda*, and *Ayurveda* was an *upveda* (secondary *Veda*) forming part of the *Rigveda*.

Vedic literature contains anatomical and physiological terms, methods of treatment, theories of the origin of life and of diseases, etc. It is a medley of accurate knowledge, rational ideas, superstitions and faith in supernatural. In spite of irrational notions, it contains so much of rational observations, inferences and accurate medical knowledge that it was almost at the level of science. At this time, there was no classification of anatomical and physiological information or diseases.

In succeeding centuries, it developed as a comprehensive and rational medical system. The knowledge of this science mainly comes from surviving written treatises, namely, *Bhela Samhita*, *Charaka Samhita* and *Susruta Samhita*.

The *Bhela Samhita* is fragmentary and does not provide a full exposition of Ayurvedic medical knowledge. The *Charaka* and *Susruta Samhita*, followed by commentaries and treatises in later centuries, provide complete representative works on *Ayurveda*. This period is in between A.D. 100 and third to fourth century A.D. The *Charaka Samhita* mainly deals with anatomy, physiology, aetiology and prognosis, pathology, treatment, objectives, influence of environmental factors, medicines and appliances and procedure and sequence of medication. The *Susruta Samhita* also follows more or less the same pattern, but it gives importance to surgery. It contains fundamental postulates, pathology, embryology and anatomy, therapeutic and surgical treatment, toxicology and specialized knowledge of earlier sections.

The curing of diseased conditions and the maintenance of health are not the only aims of *Ayurveda*. It is also concerned with harmonizing secular conduct and spiritual pursuit through a realization of the true relationship between the complex of the body, mind and soul and the eternal universe. There is a rigorous standard for the training of physicians and a meticulous code of personal ethics and social conduct for the medical profession [6].

Around the thirteenth century or so, the classical treatises of *Charaka* and *Susruta* had become hoary with age. It was necessary to revise the matter and restore its parts which were lost or misplaced. The intellectual efforts and active research needed in this direction, unfortunately, due to various reasons, were not in sight and it led to decay. The ruling people adopted Unani (originally *Arabic*) medicine and neglected *Ayurveda*. Slowly the prestige and popularity of *Ayurveda* were lost during the following centuries.

Decline and Fall

There are various reasons for the arrest of growth leading to decline and fall of ancient Indian science:

1. There was steady rise in rigidity of caste system, in which society was divided into four major sections, namely, *Brahmins* (learning/teaching professionals), *Kshatriya* (warriors/kings, etc.), *Vaishya* (trade, involved in commerce, etc.) and *Shudra* (people involved in various services). In the initial phases, the system was according to profession or ability to do a certain task, where cross-profession was also possible. Later on it became so rigid, that, according to birth in a certain section, one had to follow that profession only, irrespective of whether he is capable to do it or not! No cross-profession was allowed. Any intelligent youth eager and enthusiastic to learn was not allowed to acquire knowledge and pursue it further, if he did not belong to *Brahmin* family. There may be some merits of caste system, according to wise men of the prevailing society, but it arrested the progress.
2. One of the side effects of the caste system was that the learning/teaching process became mechanical. This rote learning resulted in slowing the growth and finally halting.

3. The traditional Indian learning-teaching process was oral. A student had to learn by heart from his teacher and, when he became teacher, pass on that knowledge to his disciples. This oral tradition restricted knowledge to some people. The probable reason was that knowledge should not fall in the wrong hands. He may exploit it for wrong reasons or misuse it against innocents. After stringent tests only, the teacher (or *Guru*) used to impart that knowledge to deserving disciples. This factor also limited growth.
4. Religious taboos (which may have some merits, according to wise men of the prevailing society) about crossing the sea or leaving the seashore (for any reason) stopped the process of exchange of knowledge with other civilizations.
5. The essence of religion was on *self-salvation*. Thinking about society at large became secondary or less important. The ideology of 'live with your sufferings or as it is or you are destined for this etc. (instead of finding solution) for better 'other world' (rebirth or life after death)' stunted society as a unit. 'Learn to tolerate, remain as it is, do not revolt, suffering is the punishment of your deeds of previous birth etc.' – this kind of thinking or ideology imbibed by scriptures and religion (which entered in it time to time) might had merits from the stability point of view of society in the beginning, but it killed curiosity, thinking, adventures, etc. in the long term. It was one of the obstacles of growth.
6. Due to regular monsoon cycle on the continent, easy and ample availability of food made people lazy and inactive. Often the hardship of life forces people to search for various options and 'necessity becomes the mother of invention'.
7. It was also the responsibility of rulers or administrators to monitor the progress of society by way of cultivating existing as well as forming new branches of knowledge. The absence of far-seeing vision of leaders and their advisers was also one of the factors.

Modern Science in British India

The discovery of direct sea route to India in 1498 was a major breakthrough for Europeans. The voyages to India were of great commercial value for Portuguese, Dutch, British and French. The British were more successful on all fronts. The 1757 battle of *Plassey* laid the foundation of the British colonial empire. For building, expanding and consolidation of empire, geographical and intellectual knowledge of the local terrain was very important. Several texts and travelogues appeared, about what was best in India's natural resources and technological traditions, that could be most advantageous to rulers, for example, W. Robertson, John Capper, Huge Murray, G. R. Wallace, J. M. Honigberger, F. Buchanan, B. Heyne, M. Martin, R. Heber and M. Jacquemont [7]. The East India Company immediately realized the importance of geographical, geological and botanical knowledge. For example, in January 1800, while proposing a survey of Mysore, Mackenzie stated his object was 'to obtain as soon as possible a clearer and better defined knowledge of the Extent, Properties, Strength and Resources of a Country … to elucidate many objects of Natural History, connected with commercial views and therefore interesting to the Company, exclusive of the advantage in the improvement of scientific knowledge' [8].

Rennell published his surveys as *A description of the Roads in Bengal and Bihar* (1779), *Memoir of a Map of Hindusthan* (1788) and *Memoir of a Map of Peninsula of India* (1793). Around 1799, Major Lambton proposed a project of Geographical Survey from Coromandel to the Malabar Coast based on geodetic principles. Colonel Wellesley pushed the project with the influence of his brother Lord Wellesley, the then Governor General. Thus, the Great Trigonometrical Survey of India (GTSI) was created. For maritime power, marine surveys were important. In 1770, Ritchie was appointed as the first Hydrographical Surveyor to the Company, and in 1809, a full-fledged Marine Survey Department was established in Bengal with Captain Wales as the first Surveyor General. Later on Horsburgh, Dominicetti, Ross and Haines surveyed coasts of peninsular India and the coasts and archipelagoes from Malaya to Madagascar.

Wallich, an avid plant collector, surveyed Bengal, Bihar, Assam and Nepal. In the mid-1830s, he carried to England 30 barrels of dried plants. He listed 40 scientists and institutions for further study of samples. It was the largest botanical collection brought to Europe by a single man. The botanical investigations continued in Calcutta and Madras. In 1848–1850, J. D. Hooker surveyed Bengal, Sikkim, Nepal and the Khasi Hills, and in 1855 he published his work as *Flora Indica* and the *Himalayan Journal*. Thus, administrators realized the commercial, military and scientific importance of botanical investigations.

The colonizers also recognized India's potential as an agricultural country. Experiments on tea and cotton were carried out.

The economic value of geological investigations was of immediate concern to the East India Company. In 1808, Lord Minto ordered investigation into the Raniganj coalfield. Colebrooke prepared a report on Sylhet coal and Franklin on coal mines in Palamu. Herbert investigated about occurrence of coal within the Indo-Gangetic tract of mountains. In 1845 Lieutenant Newbold published an article on minerals of south India, especially on manganese ore.

In India coal was known from time immemorial, but there was no recorded history of coal. Probably ample quantities of wood were available; therefore, nobody was bothered about it. John Sunner and S. G. Heatly discovered it in 1774 near Sitarampur in Bengal and requested Warren Hastings' permission for coal mines. The steam navigation and iron works necessitated the search for coal. In 1836, the Company appointed a committee for the investigations of the coal and mineral resources of India. This committee stands as a milestone in the evolution of colonial science in India, because here for the first time various types of coal and minerals were listed along with map illustrations of the sites as well and also for the first time the question of employing trained geologists in India to investigate coal formation in the country was raised [8].

In 1846, D. H. Williams was appointed as Geological Surveyor to the Company. He prepared two reports, one on the Damodar Valley and the other on the Ramgarh coalfields. In 1850, Thomas Oldham, who was earlier Director of the Geological

Survey of Ireland, established the continuous Geological Survey of India. He laid the foundations of stratigraphical classification in Indian geology.

For such a vast country, transportation and communications were the backbones of administration. The period of 1830s and 1840s was of technological revolution. For example, steamboats and railways were the major means of mass transportation. In India, these were largely initiated and financed by merchants for expansion of trade. Telegraph came to India ahead of railways basically for political reasons. Fast communication was the need of effective control on expanding imperial activities.

The electric telegraph was officially proposed in 1849. The need was so pressing that Calcutta, Agra and Attock and also Agra, Bombay and Madras were connected within a short span of 15 months from the start in November 1853. The telegraph played a crucial role in the revolt (mutiny) of 1857.

Sir John Laird Mair Lawrence who as chief commissioner 'saved Punjab' during the mutiny and later served as Viceroy of India said, 'The telegraph saved (British) India'. If the mutiny had come 10 years previously when the railways and the telegraph had not yet been introduced, it might have succeeded [9].

In the charter of 1813, it was mentioned that the grant of Rs. 1 lakh should be spent on education for introduction and promotion of knowledge of the sciences, among the inhabitants of British India. But it was not clear as to what kind of education should be imparted.

Hospital assistants, surveyors and mechanics were needed for fast-growing medical, survey and public work departments. Training local youths was much cheaper than hiring from abroad. Therefore, perhaps the government paid more attention to engineering than any other branch of science. The Calcutta medical college was opened in 1835 and an engineering class at Hindu College in 1843. An engineering college at Roorkee was established in 1847. But overall engineering and technical education remain confined to produce overseers, surveyors and mechanics.

In British India, there were people, like William Carey, Rev. Alexander Duff and David Hare, who tried to introduce western education in India. Warren Hastings set up the first educational institute, Calcutta Madrassa, in 1781 to impart English education. In the same year, with the initiative of Sir William Jones, *The Asiatic Society* was set up. The *Sanskrit College* at Varanasi was established in 1792.

Social reformers like Raja Rammohan Roy strongly demanded a more liberal and enlightened system of instruction including mathematics, natural philosophy, chemistry, anatomy, etc. with other modern sciences. Thus, the *Hindu College* was established in 1817 to promote liberal education. The Hindu College was renamed *Presidency College* in 1857. The *University of Calcutta* was founded on 24 January 1857, *University of Bombay* on 18 July 1857 and *University of Madras* on 5 September 1857.

The renaissance took place, when Indians of great mental abilities rediscovered their own heritage, helped to some extent by the western angle of vision. Raja Rammohan Roy, Iswar Chandra Vidyasagar, Bankim Chandra Chattopadhyay, Rabindranath Tagore, Swami Vivekananda and Aurobindo were some of those great minds who rediscovered India's philosophical and literary heritage and brought about the Bengal renaissance [10].

The real growth of modern science started from Mahendralal Sircar who is rightly called the *father of modern science* in India. He was born in a poor family at Paikpara near Calcutta (Kolkata). By education he was M.D. (medicine) of Calcutta University, but studied on his own the basic experimental sciences of physics and chemistry. He initiated a *science movement* in August 1869 by starting it as a science class at his residence every Sunday. He distributed an 8-page printed pamphlet to the public and the press. There was enthusiastic response from several newspapers. Over Rs. 80,000/- were received as donations. Thus, the Indian Association for the Cultivation of Science (IACS) came into being on 29 July 1876 with Mahendralal as the Secretary. The foundation stone at 210, Bow Bazar Street (Calcutta), was laid by Sir Richard Temple, the Lt. Governor of Bengal. Mahendralal relentlessly pursued his efforts at a time when there was no crowing for the pursuit of science [11].

IACS shifted to new premises in 1884. In the beginning, the staff included Mahendralal and Fr. S. J. Lafont, a Jesuit priest of St. Xavier's College. Asutosh Mukherjee developed his interest in science through the lectures of Mahendralal Sircar and Fr. Lafont. Later, Asutosh delivered lectures at IACS on Mathematical Physics from 1887 to 1890. P.N. Bose, student of Fr. Lafont of the Geological Survey of India, delivered lectures on Geology. It is said that P.N. Bose educated Jamsetji Nusserwanji Tata on the iron deposits of the area, which resulted in the establishment of the Tata Steel Mill at Jamshedpur in 1911 [9]. R. C. Dutta delivered popular lectures in *Bengali* for 14 years.

Sir P. C. Ray, then student of Presidency College, attended the IACS lectures and later delivered the lectures. J. C. Bose, professor of physics, Presidency College, assisted Mahendralal Sircar from 1886 to 1888 and delivered lectures at IACS.

Mahendralal could not raise funds for appointing paid lecturers and research scholars. He was very much disappointed. His reports in the IACS annual meetings during 1899–1903 were full of agony and lamentation that his mission had not succeeded. He felt Bengal had neglected its own institute of scientific research, which was 30 years old [11].

IACS remained a forum for popular and college-level lectures. The IACS was recognized by Calcutta University as a teaching centre in 1893.

Sir C.V. Raman, then Indian Government Official, did his part-time research in physics at IACS, which lead him to a Nobel Prize in Physics. Though IACS failed to materialize as a research institute, it played an important role in the development of Indian science.

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Chapter 3
The Nineteenth Century

By the end of the nineteenth century, the electromagnetic theory and thermodynamics were well developed fields with sound theoretical foundations. Their evolution was not in isolation but a story of interlinked topics such as atomic structure, concept of energy, conservation of energy and so on.

The initial work of electromagnetic theory was carried out in the seventeenth and eighteenth century. Robert Boyle, Stephen Gray, Jean Theophilus Desaguliers, Charles Francois du Fay, Benjamin Franklin and William Watson made systematic studies of electrostatics. Charles Francois du Fay first recognized the existence of two kinds of electrification. According to Franklin, a deficiency or excess of the electrical fluid or 'electrical fire' produced positive and negative electrification. He experimented with Leyden jar. His conclusion was that electric phenomenon resulted from the movement of electrical substance (charge) or its collection rather than its creation. Ulrich Theodor Aepinus surmised that electrical action might involve an inverse square force. In 1767, Joseph Priestly concluded that the force between two charges must be inversely proportional to the square of the distance. John Robinson experimentally found that the force law was approximately $1/r^2$ [1]. Henry Cavendish also found $1/r^2$ dependence in 1771. In 1785, Charles-Augustin de Coulomb verified $1/r^2$ dependence using torsion balance. In this period even Tobias Mayer and J. H. Lambert also felt that electric force was an inverse square law.

In 1820, Hans Christian Ørsted discovered the magnetic effect of electric current. In the same year, Jean-Baptiste Biot and Felix Savart experimentally determined force exerted on a magnetic pole by a current. They found that the force was inversely proportional to the square of the distance ($1/r^2$) and perpendicular to the line joining the magnetic pole and the current-carrying wire and to the axis of the wire. The inverse square dependence of distance had been established earlier by Coulomb, John Michell and Laplace.

Ørsted coined the term *electromagnetism*, indicating that electric and magnetic phenomena were inseparably intertwined. In 1831, Michael Faraday discovered the converse effect of this. The moving magnet (or change in magnetic flux) induced electric current in nearly metallic wire. When charge and/or magnet was in motion, they

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mix electric and magnetic phenomena. Maxwell showed that various experimental results about electric and magnetic phenomena can be seen as consequences of field equations (Maxwell's equations), which describe the evolution of electric and magnetic fields generated by charges and magnets, at rest or in motion, in space and time. The Ørsted and Faraday discovery can be described as 'an electric field, changing in time generates a magnetic field and change in magnetic flux (field) in time, associated with coil generates electric current'. Ampere put Ørsted results in quantitative form (Ampere's law). Maxwell's equations incorporated Ampere's law. A moving electric charge e created a magnetic field of strength B. The resulting magnetic force acting on a nearby compass needle was equal to the evB/c, where v was the component of the charge's velocity, which was perpendicular to B, and c, which was some other velocity. The c was also a universal constant and can be determined experimentally. Maxwell reported that the best experimental value known at that time of c was 3×10^{10} cm/s. The experimental value of velocity of light was somewhere between 3.14 and 2.98×10^{10} cm/s. The obvious question was why Ampere's c and velocity of light were the same. Maxwell said: '[This] seems to show that light and magnetism are affections of the same substance and that light is an electromagnetic disturbance, propagated through the field according to electromagnetic laws'. These lines may well be the crowning statement in the nineteenth-century physics. They record the unification of electricity, magnetism and light and define light the way it is done to this day [2]. It was Maxwell's prediction of the picture of light. In 1887, Heinrich Hertz generated electromagnetic waves and showed that like visible light, these waves can be reflected, diffracted, etc. and were transverse in nature and propagated with velocity c. In 1864, Maxwell wrote: 'We have some reason to believe, from the phenomena of light …… that there is an aetherial medium filling space and permeating bodies, capable of being set in motion and of transmitting that motion from one point to another…[3]. The researchers started investigating the existence of the omnipresent and elusive aether'.

The aether, through which light was assumed to be propagated, was an all-pervasive medium in a state of absolute rest. Maxwell's universal velocity c was the speed of light relative to this resting aether. As early as 1881, Michelson tried to measure the effect of earth's velocity v on the velocity c, due to earth's motion around sun, in two opposite directions, during one year, with respect to some fixed star. But this result was negative. He concluded about assumptions of aether as 'The result of the hypothesis of a stationary aether is …shown to be incorrect, and the necessary conclusion follows that the hypothesis is erroneous' [4].

Later on his experiment with improved precision, jointly with Morley (Michelson-Morley experiment), proved that 'the velocity of light is independent of the speed with which the light source moves relative to observer'.

Heat and Thermodynamics

Though heat was an inseparable part of many human activities since ancient time, its systematic study started in the seventeenth century with quantitative theory of the effects of heat on gases. Thermometry, the basis of experimental studies of heat, started in the eighteenth century. Heat was thought to be a result of the agitation (or motion) of small parts of bodies, the concept of atomism, which was not clear at that time. Gassendi, Galileo, Bacon, Descartes and Huygens studied heat. Even Newton, John Locke and Robert Boyle also treated heat as some kind of motion. Evangelista Torricelli showed that the weight of the air causes a column of water or mercury to rise. It was the foundation for a practical barometer. The concept of air pressure emerged from the work of Blaise Pascal, Marin Mersenne, Gilles Roberval and Valeriano Magni. In 1654, Otto von Guericke showed the power of the vacuum with his experiment of evacuated Magdeburg hemispheres. Guillaume Amontons discovered that increase in temperature increases gas pressure, and when water boils, its temperature remains constant. This led to the discovery of latent heat, almost a century later. The quantitative studies of gas, with respect to volume, pressure and temperature, led to the gas laws. This work was conducted by Henry Power, Richard Towneley, Robert Boyle, Edme Mariotte, J. A. C. Charles and Joseph Louis Gay-Lussac. In 1757, Joseph Black discovered latent heat. At this time, according to widely discussed theory of heat, it was an imponderable fluid that was passed from one body to another – the *caloric* theory. Lavoisier, Laplace, Gay-Lussac and Poisson were strong supporters of caloric theory, and Fresnel, Arago, Petit, Dulong and Ampere were opponents. The theory lasted up to around 1830.

The work of Clausius [5] in 1858 and Maxwell [6] in 1860 firmly established the microscopic basis for the observed properties of gases, and the caloric theory became irrelevant. The electrochemical theory of Berzelius was also responsible for it.

The discovery and development of the steam engine by Thomas Savery, Thomas Newcomen, James Watt, Sadi Carnot, Richard Trevithick, Davies Gilbert and so on advanced thermodynamics. It has been argued that science owes more to the steam engine than the steam engine owes to science and that all of the basic principles of thermodynamics, except for latent and specific heats, were discovered by studying the steam engine [1].

Fourier applied the analytical techniques of Mathematical Physics to the problem of heat diffusion or conduction. He treated heat conduction as a boundary value problem in the theory of partial differential equations. His (and Carnot's) work, done in the 1820s, provided theoretical foundation to thermodynamics. During the first two decades of the nineteenth century, the primary interest was in specific heats, equation of state (relation between pressure, temperature and volume of gas) and temperature scale.

Francois Delaroche and Jacques Etienne Berard measured specific heats of several gases, including air, hydrogen and oxygen. In 1819, Pierre Louis Dulong, who was a chemist, and Alexis Thérèse Petit, a physicist, discovered that the specific heat per gram multiplied by the atomic weight was the same for all gases (Dulong-Petit law).

At this time the problem of adiabatic expansion or compression was also important from the practical as well as the theoretical point of view. Poisson contributed significantly to this problem and obtained the relation PV^{γ} = constant, where $\gamma = C_p/C_v$, C_p and C_v were specific heats at constant pressure and constant volume, respectively.

Like Fourier, Sadi Carnot was also a pioneer of theoretical foundation of thermodynamics. His 1824 memoir contains (nearly complete) statement of second law of thermodynamics. He said *whenever work is done by a thermodynamic sys-*

tem in a cyclic process, heat must flow from a hotter to a cooler reservoir. The work on the 'conversion of heat into mechanical work' was his tremendous contribution. James Prescott Joule played a crucial role in advancing the idea that heat could be converted into mechanical work and vice versa. In 1841 he discovered I^2R heat loss due to current I, flowing through the resistor R, which is now known as *joule heating*. From the work of Carnot, Joule, Clapeyron and Thomson, in 1850, Rudolf Clausius obtained an explicit form, for the first law of thermodynamics, $dQ = dU + PdV$, and an analytical expression of the second law, involving a universal function of temperature. In 1854, he developed the concept of *entropy* (Greek word for 'transformation') and propounded the two laws of thermodynamics as (1) the energy of the universe is constant and (2) the entropy of the universe tends to a maximum.

In 1851, William Thomson framed a different statement of the second law but noted that the two forms were equivalent [1]:

1. It is impossible, by means of an inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects (Thomson).
2. It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature (Carnot-Clausius).

While studying Carnot and Joule's work, he realized that heat was wasted or dissipated in irreversible processes such as conduction and not available for work. Thus, he resolved the question of the nature of heat and the interconvertibility of heat and mechanical effect and arrived at Clausius' second law of thermodynamics.

The mathematical structure of classical thermodynamics evolved after the discovery of the law of energy conservation around the middle of the nineteenth century. Kuhn [7] gave (some) credit to twelve scientists for contributing to the law of energy conservation, namely, Mohr, William Grove, Faraday, Liebig, Carnot, Marc Séguin, Karl Holtamann, G. A. Hirn, Mayer, Joule, Colding and Helmholtz. But it was clear that all have not the same things in their minds. So clubbing them for the same concept of energy and energy conservation may not be correct. Joule and Hermann von Helmholtz discovered the law of energy conservation in 1847. Their proof shows thorough understanding of its principle.

Atoms and Nuclei

Any structure is made up of elastic solid or elementary discrete particles – this problem has a long history which goes back to the fifth century B.C. to Greek atomists. Till the seventeenth century, the discrete structure of matter was a hypothesis, not supported by any experiment. The kinetic theory of Daniel Bernoulli of 1738 was an attempt to explain gas properties in terms of atoms. John

Dalton is the *father of modern atomic theory*. In 1810, in the lecture to the Royal Institution, he described his discovery:

> This idea occurred to me in 1805. I soon found that the sizes of the particles of elastic fluids *must* be different. … The different sizes of the particles of elastic fluids under the circumstances of temperature and pressure being once established, became an object to determine the relative *sizes* and *weights*, together with the *relative number* of atoms in a given volume. … Thus a train of investigation was laid for determining the *number* and *weight* of all chemical elementary particles which enter into any sort of combination with one another. [1]

In 1819, Dulong and Petit showed that the specific heat of a body was directly related to its atomic weight – the product of specific heat and atomic weight was a constant. Around 1815, Jakob Berzelius accurately determined atomic weights, which also clarified many issues about atomic theory. Daniel Bernoulli and John Herapath were the founders of the dynamical theory of gases, based on atomic or molecular motions. In history, they are almost a century away from each other. In 1738, Bernoulli derived Boyle's law relating to the pressure and volume of a gas, which was compressed or rarified at constant temperature, and he also deduced from molecular motion that 'on account of the fact, that through this velocity the number of impacts and their intensity will increase equally at the same time', the pressure must be proportional to the velocity squared (at constant volume) [1].

In 1847, Herapath calculated the mean speed of atoms in a gas from the kinetic theory. The 1860 the Karlsruhe congress of chemists considered it necessary, to put at the top of the agenda points to be discussed, the questions 'shall a difference be made between the expressions *molecule* and *atom*, such that a molecule be named the smallest particle of the bodies, which can enter into chemical reactions and may be compared to each other in regard to physical properties - atoms being the smallest particles of those bodies which are contained in molecules?' More interesting than the question itself was the fact that even in 1860, no consensus was reached.

The rise of kinetic theory of gases led to estimates and measurements of the diameters of atoms and molecules, for example, Loschmidt in 1865, Stoney in 1868 and William Thomson in 1870. In 1873, Johannes Diderik van der Waals put forward an equation of state, $(P - a/V^2)(V - b) = nRT$ for real gas, which was the modification of the equation of state $PV = nRT$ for an ideal gas. In this equation, a and b were related to the intermolecular force and molecular size, respectively. Some people did not believe in atoms at all, for example, Wilhelm Ostwald and Ernst Mach.

By the late 1860s, the dynamic theory of gases, especially Maxwell's theory of viscosity, made it possible to calculate diameters of atoms. H. A. Lorentz introduced the hypothesis of an elementary electrical charge. Johnstone Stoney gave the name *electron* to this charge in 1891.

At the same time, from their experiments, people like J. J. Thomson, Curies and Rutherford were convinced of the reality of atoms. The year 1895 to 1905 was the decade of transition. While studying the cathode rays, Wilhelm Roentgen discovered X-rays in 1895.

In 1896, Antoine Henri Becquerel discovered the phenomenon of radioactivity. Later on Marie and Pierre Curie studied radioactivity quantitatively and achieved major results in the field. In 1898, Rutherford established that the Becquerel rays were inhomogeneous and there were at least two distinct types of radiations, one was α-radiation and the other of more penetrative power was β-radiations. (It took 10 years to establish firmly that α-rays were doubly ionized helium atoms.) In 1900, Paul Villard discovered γ-rays.

J. J. Thomson discovered the electron in 1897. Though Kaufmann, Zeeman and Lorentz guessed the electron, Thomson's good determination of the ratio e/m (charge to mass) for cathode rays was an important step towards the identification of electron. Thomson was the sole discoverer because he was the first to measure not only e/m but also the value of e, little later in 1899. In the same year, it was established that β-rays were electrons. The Zeeman effect was discovered in 1896, and Planck's hypothesis appeared in 1900. Then there was Albert Einstein. He published his special theory of relativity and the explanation of photoelectric effect with the help of light quantum in 1905.

Five years after the appearance of Planck's paper, Einstein proposed the light quantum hypothesis. The monochromatic light with frequency ν behaved, as if it consisted mutually independent quanta with energy $h\nu$, where h was Planck's constant. Einstein went further to state that the behaviour of light was not only applicable to radiation but also holds true for the emission and absorption of light by matter. Initially that proposal had strong resistance, but the Compton effect settled the issue in 1923. In the scattering of the light beam by electrically charged particles, light behaved like a stream of particles (photons). Arthur Holley Compton substantiated the collisions between photons and particles using laws of conservation of energy and momentum, which is now known as the *Compton effect*.

Towards Quantum Theory

Isaac Newton allowed sunlight to pass through a prism and observed different colours. He noted a continuous spectrum. The resolving power of his apparatus was not sufficient, to show that the solar spectrum consisted of a large number of discrete lines interspersed with darkness. In 1802, Wollaston observed dark lines in the solar spectrum. Later on Joseph von Fraunhofer rediscovered these lines and immediately identified the connection between these dark lines in flame spectra. He catalogued around 600 lines. These lines are now known as *Fraunhofer lines*.

In 1853, Ångström first observed the hydrogen spectrum, and in 1859, Pluecker studied it. Pluecker speculated that the spectrum determined the constitution of the gas or vapour in the discharge tube. In the same year (in 1859), Kirchhoff concluded that some of the dark Fraunhofer lines in the solar spectrum were due to sodium.

Later on he offered a theoretical interpretation. Now we call it the *Kirchhoff's law* of black body radiation. *The ratio of emissive to absorptive power of a body in thermal equilibrium with radiation is a universal function of frequency (ν) and temperature (T).* The spectral density was a function of only frequency and temperature. The search for that dependence of spectral density on frequency and temperature led to the quantum theory. Einstein wrote in 1913: *It would be edifying if we could weigh the brain substance which has been sacrificed on the altar of Kirchhoff's law.* In 1879, Stefan conjectured from the analysis of experimental data that this energy should be proportional to the fourth power of the temperature. In 1884, Boltzmann demonstrated theoretically that Stefan's guess was applicable strictly only for the energy emitted by a black body. From thermodynamics and Maxwell's theory, Wien discovered the displacement law in 1893. *The peak in the black body spectrum shifted to progressively shorter wavelengths as the temperature was increased.*

At the turn of the nineteenth century, the quantum theory was at the horizon. 'Planck's road toward meeting the challenge posed by Kirchhoff, to find the spectral function of black body radiation, provided one of the most striking examples of progress in science, resulting from the interplay of theory and experiment, and by the theorist's trial and error. It has in fact been said of Planck, that he made so many mistakes that eventually he had to find the right answer' [2].

In 1900, Max Planck developed his formula using thermodynamics and statistical mechanics. He proposed the formula as an empirical law, to fit the experimental data, and the constant h was adjusted in it. He called the fundamental constant *quantum of action*, because h had the dimensions of action, that is, energy times time. Later the h was called as Planck's constant ($h = 6.626 \times 10^{-34}$ J·s). The constant h played an important role in microscopic world, and its value, obtained from experiments, was not directly related to black body radiation. Planck's formula accounted for both the laws, Wein's and Rayleigh-Jeans', that is, classical result. They were the limiting cases: Wein's only for high frequencies and Rayleigh-Jeans' only for low frequencies. According to Rayleigh-Jeans' law, energy density should increase as square of frequency, but in reality, energy density falls to zero, as frequency tends to infinity. This discrepancy was known as *ultraviolet catastrophe*. After developing the formula, Planck searched for the theoretical justification, and it led to *quantization of energy*. An emission or absorption of energy occurred in packets, each of energy $h\nu$, where h was Planck's constant and ν was the frequency of radiation. The discrete packet of energy $h\nu$ was called quantum (the Latin word for *how much*). In fact, Planck had introduced quanta (plural for quantum) for *material* resonators; Einstein did it for *light*, in 1905 (called as *photons*). It was the genesis of quantum theory. In Planck's formula, there was no basic justification for the quantization of energy except to explain experimental data. The deeper meaning emerged with the development of *quantum mechanics*.

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Chapter 4
Early Years

The initial arrival of British was for trade and commerce, but slowly they conquered India. Due to British rule, there occurred immense changes in social, economic and cultural spheres of Indian society. The impact of modern Western culture gave birth to awakening in the minds of people. Some intelligent people realized that a vast country like India was colonized by a few foreigners due to internal factions, such as lack of unity, foresightedness, knowledge of science and technology, research and developments in various fields, rational vision, etc.

Some people were overcome by patriotism for their countrymen. They worked hard throughout their lives for social, religious, intellectual and political revival, for example, Raja Rammohan Roy, Jagannath Shankar Sheth, Balshastri Jambhekar, Debendranath Tagore, Ishwar Chandra Vidyasagar, Bhau Daji Lad, Gopal Hari Deshmukh, Dadabhai Naorojee, Jotiba Phule, Ramkrishna Gopal Bhandarkar, Vishnushastri Chiplunkar, Bal Gangadhar Tilak, Gopal Ganesh Agarkar, Swami Vivekananda, Ashutosh Mukherjee, Gopal Krishna Gokhale and many more.

The British regime had a profound economic impact on India. Almost all aspects of Indian economy were changed for better or worse. The earlier conquerors had overthrown only political powers, but they did not make basic changes in economic structure. The British changed the entire economy as per their needs. They totally disrupted the traditional structure of self-sufficient Indian rural economy. They exploited Indian resources and looted India's wealth.

The urban handicraft industry collapsed due to competition with cheaper imported machine-made goods from Britain. It was systematically destroyed. This deindustrialization of the country increased dependence of the people on agriculture. The increasing pressure on agriculture was one of the major causes of extreme poverty in British India.

> British economic exploitation, the decay of indigenous industries, the failure of modern industries to replace them, high taxation, the drain of wealth to Britain and backward agrarian structure led to the stagnation of agriculture and the exploitation of the poor peasants by Zamindars, landlords, princes, moneylenders, merchants and the State gradually reduced the Indian people to extreme poverty and prevented them from progressing. [1]

P.V. Naik, *Meghnad Saha*, Springer Biographies,
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A series of famines, which ravaged all parts of India in the second half of the nineteenth century, pushed poverty to its nadir. In general, the entire country was steeped in deprivation.

Seoratali was a small village, 45 km from Dhaka, now in Bangladesh and then in British India. The village belonged to the Muslim Nawabs of *Baliadi*. It was primarily a Saha settlement. Most of the settlers were small traders and businessmen. It was a village like other so many scattered villages. These villages were separated by 5 to 6 km from each other. The area was flood prone. The *Bansai* river, skirting a village, flooded its banks in the monsoon.

Jagannath Saha and his wife Bhubaneshwari Devi (See Fig. 4.1) lived in *Seoratali*. He owned a small grocery shop in the *Baliadi* market area. They had two sons and two daughters. The fifth child Meghnad was born on 6 October 1893. Shri Jagannath Saha's house in *Seoratali* where Meghnad was born is seen in Fig. 4.2. It was a stormy night with rain and thunder. The grandmother christened the child as 'Meghnad' in due reverence to the rain god, meaning the *roll of thunder*.

Meghnad's eldest brother Jainath discontinued education after failing in the matric (secondary school) examination. He worked in a jute company. Then father became less inclined to sending his other children to school. His second brother also left school to help his father in business. This family was not an exceptional case. This was common in most families. The poor and middle-class children obtained meagre education and joined either family business or start earning independently. For more than a hundred years ago, for villagers the importance of education was the last thing, on their minds.

At the age of seven, Meghnad joined the village primary school. His teachers immediately recognized the potential of this student. He had exceptional aptitude

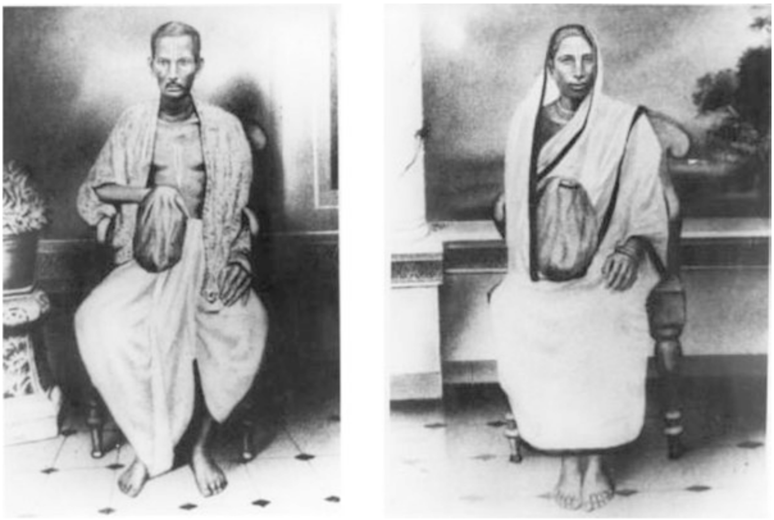

Fig. 4.1 Meghnad Saha's father Shri Jagannath Saha and mother Smt. Bhubaneshwari Devi Saha (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Fig. 4.2 Shri Jagannath Saha's house in village Seoratali, Baliadi, Dhaka District, East Bengal (now in Bangladesh). This is reconstructed house (early 1970s) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

for learning. He got up early in the morning and sat down for study. Books, pencils and slate were dearer to him than anything else. The family was not aware of the importance of education, and the studiousness of Meghnad was incomprehensible for them. They expected Meghnad to assist his father in his shop. But the little boy did not have any interest in selling groceries. His father would thrash him with a stick when his loud reading disturbed his sleep. But the boy was destined to make substantial contribution to Physics and carve a niche for himself.

Little Meghnad has to cross many hurdles. The first was family resistance for education. The next, there was no high school nearby so that he can attend the school and help the family also. The nearest middle school was at *Simulia*, 10 km away. His elder brother Jainath was very keen about Meghnad's education. He found a sponsor in *Simulia*, Mr. Anand Kumar Das, who was a doctor by profession. Mr. Das allowed Meghnad to stay in his house, free of cost provided; Meghnad washed his own dishes and attended to some minor household chores. Imagine India, more than a century years ago. The caste structure was very rigid. But the doctor and his wife were kind-hearted. Meghnad was happy as long as it helped to continue his studies.

His Mathematics teacher Prasanna Kumar Chakraborty instilled a love of Mathematics in his student. Meghnad was lucky to have such inspiring teachers in his formative years. He completed middle school securing a scholarship as a topper in the district.

Then this boy came to Dhaka to join a collegiate school. Again he was the topper in the Dhaka division and was awarded a scholarship of Rs. 4 per month. Brother Jainath sent him Rs. 5 per month from his earning of Rs. 20 a month. And *Purba Banga Baisya*

Samiti gave Rs. 2 per month. The total amount was hardly enough. During vacations he went home and helped his father in his work. Though he enjoyed boat racing and swimming, basically he was a studious boy, given to academic pursuits.

It was 1905. The entire atmosphere was charged with *swadeshi*, and there was a boycott of imported British goods on a mass scale.

Meghnad was caught up in the movement. Some people say senior students demonstrated during the visit of the Governor, Sir Bamfylde Fuller, and along with others Meghnad was punished. Some people say Meghnad had no part in the demonstration but was in school barefooted (as usual). The authorities thought it was a deliberate insult directed against the Governor. Meghnad was rusticated from the school along with his classmates. He lost his stipend and free studentship. Fortunately, another school, Kishori Lal Jubilee School, admitted him and resumed financial assistance.

From his subsequent writings and involvements, it can be easily guessed that he must have developed the interest in various subjects like astronomy, history, sociology, archaeology and many more in his school and college days, though physics and mathematics were his primary interests. Meghnad secured the first place among the students of East Bengal in an entrance examination. This entrance examination was equivalent to today's SSCE (Secondary School Certificate Examination).

In 1909, he entered Dhaka College as a student of intermediate science class. Here along with his own subjects, he learnt German language from Prof. Nagendra Nath Sen, who had returned from Vienna after completing his doctorate in chemistry. The knowledge of German was essential to read scientific journals and magazines. In the intermediate science examination, he was ranked third, with mathematics and chemistry aggregate marks highest in the university. In Dhaka College he was influenced by Prof. P. C. Sengupta and Prof. K. P. Basu. Prof. Sengupta introduced him to astronomy.

Meghnad had a strong bond with his village *Seoratali*. He was fully aware of the hardship of village life, problems of flooding or in general the lack of facilities in the village. Its reflections can be seen in his thoughts and behaviour throughout his life. In fact many people came from the village but, once they grew up and adopt modern life, forget their roots and social responsibilities. Meghnad was not one of these. In later life on every occasion and opportunity he came across, he utilized his abilities in the best possible towards the betterment of village life.

Some of his childhood memories were unpleasant. At a function of *Saraswati puja*, one priest rudely asked him to get down from the dais, because he was not from the upper caste (as per the foolish notions of Indian caste system). In reality, *Saraswati*, the *goddess of learning* had showered ample blessings on him. The boy was to make history in the field of knowledge. One can imagine the impact of this incident on a little proud boy! From that day onwards, Meghnad stopped taking part in rituals of worship.

A barefooted boy, trudging kilometres through mud and slush while either helping his father in his work or reaching school or home in vacations; rowing when the village was flooded; his elder brother Jainath's sense of duty towards his education; a kind-hearted doctor Das, who allowed him to stay in his house in *Simulia*; his mother's encouragement for education and offering her gold bangles to pay for his examination fees – all these memories not only accompanied him throughout his life but moulded him towards a great human being, mentor and guide. Till date he is a guiding star for innumerable boys and girls, crushed under the wheels of poverty and apathy on the Indian subcontinent.

College Life

Meghnad joined the Presidency College in 1911 for graduation in science. Satyendra Nath (S. N.) Bose was his classmate. Prasanta Chandra Mahalanobis was senior, and Subhash Chandra Bose was junior to him. Rajendra Prasad, who later became first President of India during 1950–1962, was an ex-student of Presidency College and a former resident of the Eden Hindu Hostel. He was 8 years senior to Saha and would often come to preside at the social functions in the hostel. He was practising in Calcutta.

Among the teachers, Jagdish Chandra (J. C.) Bose taught physics (J. C. Bose and his students are seen in Fig. 4.3); Prafulla Chandra (P. C.) Ray, chemistry (P. C. Ray and some of his students are seen in Fig. 4.4); and D. N. Mullick, mathematics.

Fig. 4.3 Jagdish Chandra Bose with his students (1930). From *left* to *right*: standing – S. Datta, S. N. Bose, D. M. Bose, N. R. Sen, J. N. Mukherjee and N. C. Nag. Sitting – M. N. Saha, Acharya Jagdish Chandra Bose and J. C. Ghosh (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Fig. 4.4 Prafulla Chandra Ray with some of his students (1916). From *left* to *right*: back row – M. N. Saha and J. C. Ghosh. Centre row – R. K. Das, Acharya Prafulla Chandra Ray and D. N. Sen. Front row – H. Sarkar and P. Sarkar (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Professor J. C. Bose was aloof, whereas Prof. P. C. Ray was student friendly. He took some of his favourite students with him, during evening walks. Meghnad was one of them. P. C. Ray was not only a devoted teacher and scientist but also a man who was highly aware of social responsibilities. Hence, Meghnad was drawn to him. In 1913, during the great Damodar flood, P. C. Ray took his students for relief work. Meghnad gained first-hand experience of the havoc and misery brought by a flooded river. In later life, this was one of the subjects of his studies and concern.

Meghnad completed his B.Sc. (honours) in mathematics and M.Sc. in mixed mathematics. He was second in rank in both B.Sc. and M.Sc. examinations (S. N. Bose was first).

At Calcutta, he stayed at Eden Hindu Hostel. Upper caste boys prevented him from eating with them. Such was the caste culture! Meghnad turned a blind eye to this humiliation. He had good friends also. In protest, with some of the hostel boys, a group led by Gyan Ghosh left the hostel. They set up a private mess at 110, College Street. Nil Ratan Dhar and Bhupen Ghosh joined them.

Meghnad brought his younger brother Kanai to stay with him. Other than stipend he took a few private tuitions to take care of himself and his brother. To cycle from one end of the city to the other, and coach students, was a part of his daily routine.

During this time he came in contact with revolutionaries like Pulin Das and Bagha Jatin (Jatindranath Mukherjee). The prefix *Bagha*, which means tiger, was attached to him because he had killed a tiger single handed with a dagger. Later he died in a guerrilla fight with the police at *Balasore*. Meghnad became member of *Anushilan samiti* (committee), started by Pulin Das. All samiti members were given training in sword fight and drills. Though Meghnad was sympathetic to the cause of freedom, he did not join revolutionary activities. His priority was to get a job and support his family which was (obviously) looking up to him. After college, he applied for permission to appear for the Financial Civil Services (FCS) examinations. But he was denied permission because authorities suspected that he had contacts with revolutionaries, apart from the boycott he had participated in, as a school student. It was a big blow for him. He continued private tuitions for some time.

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Chapter 5
Understanding the Atom

Primitive man must have worshipped the rainbow. Aristotle produced a theory. Descartes and later Newton grasped the true origin of the rainbow effect. Newton was the founder of spectral analysis. His equipment did not have sufficient resolution to detect spectral lines. The absorption and emission of spectral lines, extension of visible spectrum into infrared and ultraviolet regions date from the nineteenth century.

In 1853, Ångström studied the spark spectra of various gases enclosed in a glass tube. He was the first to observe hydrogen spectrum. In 1859, Plücker studied the discharge through a Geissler tube filled with hydrogen. It was the Balmer series. Gustav Kirchhoff in his October 1859 paper concluded that some of the dark Fraunhofer lines in the solar spectrum were due to sodium. He had arrived at this conclusion by interposing a flame containing kitchen salt between the solar spectrum and his detector. If the sunlight was sufficiently damp, then two luminous lines appeared at the position of two dark solar D-lines; if the solar intensity surpassed a certain amount, then the two dark D-lines appeared much more pronounced. The conclusion from the dark D-lines was that there was sodium in the solar atmosphere.

He gave a theoretical interpretation for it, which is now known as *Kirchhoff's law* of black-body radiation. After that, Kirchhoff and Bunsen's collaboration founded spectral analysis. They heated small amounts of various metals and salts in flames of varying constitution and at varying temperatures. They compared flame spectra with spark spectra, using a Ruhmkorff coil. It took many years and much effort to understand various issues related to spectra, viz. elementary substances, unanticipated impurities and lines and bands in the spectrum corresponding to atomic, diatomic, triatomic and ionic spectra. The details of atomic structure were remote in time. Before the end of the nineteenth century, spectral methods had played crucial roles in the identification of ten more elements: thallium, indium, gallium, scandium, germanium and five stable noble gases. There was no clue to the structure of the atom and, therefore, to the origin of spectra. Kirchhoff and Bunsen said that the spectral analysis opened the chemical exploration of a domain, which till then had

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been completely closed. It was possible that the technique was also applicable to the solar atmosphere and the brighter fixed stars.

Lewis Morris Rutherfurd and William Huggins were the pioneers of stellar spectroscopy. In 1864, Huggins discovered spectroscopically that a number of nebulae were luminous gas clouds. The first comet spectra were also discovered during that decade. In 1875, Maxwell wrote that the discovery of particular lines in a celestial spectrum, which did not coincide with any line in a terrestrial spectrum, did not weaken the general argument but rather indicated that a general substance existed in the heavenly body, not yet detected by chemists on earth, or that the temperature of the heavenly body was such that some substance, indecomposable by their methods, was there split up into components not known to them in their separate state.

In 1869, the noted astrophysicists Joseph Norman Lockyer, after analysing his data on solar prominences, observed a mysterious yellow line, which he named D_3. Soon he became convinced that the line belonged to a new element which he called helium. In 1895, William Ramsey confirmed it from terrestrial data. In 1864, Huggins had discovered lines in the spectrum of nebulae indicating the presence of nitrogen, hydrogen and a substance unknown. The unknown material was assumed to be a new element, *nebulium*. After more than 60 years, it was still elusive. These lines were finally identified in 1927 by Ira Bowen. They were due to transitions from metastable states of oxygen and nitrogen. These lines had never been seen under terrestrial conditions, where pressures were such that those states more readily lose energy through collisions of the second kind or collisions with walls. The other hypothesized stellar element was *coronium*, which turned out to be very highly ionized iron. The spectral analysis played a vital role in the understanding of atomic structure.

The atomic model of the twentieth century was the result of efforts of many physicists. Though the discovery of electron in 1896 led towards a realistic model, it has roots in earlier theories such as vortex atomic theory and Alfred M. Mayer's experiment of equally magnetized needles, floating in water subjected to the attractive force of a central electromagnet.

Lord Kelvin first formulated vortex atomic theory in 1867, and it was further developed by many British mathematical physicists. According to this theory, the atoms were vertical modes of motion of a primitive, perfect fluid ether. J. J. Thomson extended it to solve chemical problems, including affinity and dissociation. The theory was also applied to electromagnetism, gravitation and optics.

In Mayer's experiment, needles took up equilibrium positions on concentric circles. Using this analogy, Thomson developed the vortex theory in great mathematical detail. He studied the stability of a number of vortices arranged at equal intervals, around the circumference of a circle. There was a clear analogy between his vortex arrangement and his subsequent arrangement of electrons. He thought of the atom as a composite system of primordial elements, years before the discovery of electron. In his 1897 paper, he suggested that the atom consists of a large number of corpuscles (electrons), possibly held together by a central force.

Two years later he presented a more definite hypothesis, which was known as Thomson's model of the atom. 'I regard …… negative charge on the corpuscles' [1].

He proposed rotating rings of electrons, confined in a plane and subject to the elastic force from a homogeneous sphere of positive electricity. From calculations he studied the mechanical stability of equilibrium configurations and ruled out those which were not stable. His calculations showed that the electrons would be arranged in a series of concentric rings in such a way that the number of electrons in a ring increases with radius.

Since accelerating electron radiates electromagnetic energy, the atom would be unstable. To overcome this difficulty, Thomson applied a formula derived by Larmor and showed that radiation decreased drastically with the number of electrons in the rings which was neglected. Thus the atomic model was stable mechanically and radiation wise also. Many physicists used this model in the period of 1904–1910. This model could explain qualitatively the phenomena such as radioactivity, photoelectricity, dispersion, the emission of light and the normal Zeeman effect.

One of the weak points was the positive electricity, which was assumed as frictionless, massless and ultimately the manifestation of negative electrons. Thomson could not explain the positive electricity in the atom. In 1906, from different experiments, he concluded that the number of electrons was comparable with atomic weight. Further evidence proved that the number might be even smaller, possibly corresponding to the ordering number in the periodic system. This conclusion was troublesome for the model.

Around 1910 it was clear that the hydrogen atom contained only one electron, the helium atom two, three or four electrons and so on. It was becoming clear that the model did not correspond to reality. Besides this, the model could not explain regularities in line spectra, such as Balmer's formula. According to Thomson, light was emitted by the vibrations of electrons. It means the number of electrons should be equal to the number of observed spectral lines, and this number was tens of thousands. The question was how to account for these many electrons!

Thomson explained the scattering of beta particles, as the collective result of many individual scatterings by atomic electrons. But the model failed to explain the scattering of alpha particles. Thus when anomalies accumulated, the model became slowly unattractive for most of the physicists. During this period, that is, around the first decade of the twentieth century, many atomic models were proposed which were partially successful in explaining some experiments. Notable among these and with some modifications were models proposed by Lord Kelvin, Philipp Lenard, James Jeans, Lord Rayleigh, Jean Perrin, Hantaro Nagaoka and John Nicholson [2].

From 1898 to 1907, Ernest Rutherford was not interested in atomic models. He was in favour of Thomson's model which was useful in explaining radioactivity. His major interest was the behaviour and nature of alpha particles. In 1908 he showed that alpha particles were identical with a doubly charged helium ion. In the same year, Hans Geiger working with Rutherford reported results of the scattering of alpha particles by metal foils. The next year, he investigated alpha particle scattering thoroughly in collaboration with Ernest Marsden. They found that heavier metals were more effective as reflectors of alpha particles than lighter metals. A thin platinum foil reflected 1 of every 8000 of the alpha particles, striking it with scattering angle more than 90°.

Rutherford investigated alpha particle scattering by comparing the results of Thomson's theory of beta particle scattering. According to Thomson, an alpha particle was of atomic dimensions and contained about ten electrons, but Rutherford concluded that the alpha particle was doubly ionized helium and it should be treated as point particle. This led him to propose a nuclear atomic model in 1911. The Geiger-Marsden observations of large-angle scattering of alpha particles were possible with the model, where positive charge and mass is concentrated at the centre. In Rutherford's words, 'Consider an atom which contains a charge ±Ne at its centre surrounded by a sphere of electrification containing a charge ∓Ne supposed uniformly distributed throughout a sphere of radius R …… for convenience, the sign (of the central charge) will be assumed to be positive' [3]. Not much attention was paid to this model. It explained the scattering theory but did not mention how electrons were arranged. It looked provisional. For simplicity, he assumed the negative charge formed a homogeneous atmosphere around the nucleus. It could not explain spectral regularities or periodic table or chemical questions. The concept of nuclear model was also not new. Nicholson and Nagaoka had already proposed nuclear models. Even Rutherford used the words 'central charge'. The word *nucleus* was used first by Nicholson. The model was not complete or reasonably satisfactory till it included the details of the electron system.

While working with Rutherford in Manchester, the Danish physicist Niels Bohr was attracted towards Rutherford's atomic model. He realized that for the completeness and stability of the atom, details of an electronic structure have to be worked out.

In 1913, Bohr started with the hydrogen atom. To account for stability of the atom and calculations of the frequencies of lines in the hydrogen spectrum, he introduced postulates – (1) there were some stationary states where ordinary mechanics was valid but electrodynamics was invalid and (2) the radiation was emitted or absorbed whenever there was transition between two stationary states. The frequency of radiation ν was given by

$$\nu = \left(E_\mathrm{f} - E_\mathrm{i}\right)/h$$

where E_i and E_f were energies of initial and final states and h was Planck's constant. From his assumptions, he derived Balmer's formula for the frequencies of the hydrogen spectrum and Rydberg's constant also. From his calculations, other than Balmer and Paschen series, he predicted other series also which were subsequently discovered and named after discoverers, Lyman, Brackett and Pfund.

In 1913–1914, Henry Moseley showed that, in characteristic X-rays emitted by different elements, the square root of the frequencies was proportional to atomic number (Z). The Moseley graph was used as a tool. It placed elements in periodic table at proper places, as well as predicted undiscovered elements also. The values that Moseley had obtained for the frequencies of the characteristic X-rays matched with those calculated from Bohr's atomic theory. It was the first experimental support to Rutherford's nuclear atom and it confirmed Bohr's atomic theory. As George

Trigg said, Moseley's experiment was one of the landmark experiments in twentieth-century physics.

In 1914, James Frank and Gustav Hertz observed that an electric current passing through mercury vapours contained in a vessel increased, after increasing the voltage between two electrodes, until it became 4.9 V. Then the current dropped suddenly. When the voltage was increased beyond 4.9 V, the current again increased but again dropped suddenly at 9.8 V. The drop occurred at all voltages with a value of an integral multiple of 4.9 V. They also observed that when voltage was increased beyond 4.9 V, mercury emitted a light of frequency given by Bohr's formula $\nu = (E_\mathrm{f} - E_\mathrm{i})/h$.

The mercury atoms were bombarded by electrons. When the energy of electrons was greater than the first excited level (but less than second excited level), the atoms were pushed to the first excited state and so on. The Frank-Hertz experiment was one of the first experimental proofs of Bohr's atomic model. It proved that energy was either absorbed or emitted by atoms only in discrete amounts, and it confirmed the connection between stationary energy states and the frequency of radiation.

The red line of the hydrogen spectrum had a doublet structure. It had no place in Bohr's theory. In 1915–1916, Arnold Sommerfeld introduced the special theory of relativity in the mechanics of Bohr's model. According to that the electronic orbits were described by a principal and an azimuthal quantum number. There were many more stationary states than in Bohr's model and it explained the fine structure. The agreement between theory and experiment was considered a great success of the Bohr-Sommerfeld theory and also of the theory of relativity.

However, the theory allowed calculations only of frequencies of spectrum but not of intensities. It failed for the hydrogen molecule and bigger atoms also.

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Chapter 6
Saha the Physicist

In British India, around 1850, there was a general unrest in society due to various reasons. The heavy land revenue assessment; relatively low pay scales for locals than European counterparts; the doctrine of lapse, which refused to recognize the adopted children of princes as legal heirs; etc. created civilian disquiet and resulted in the mutiny of 1857. The soldiers refused to obey the orders of superiors. It started from Meerut and spread to other parts of the country. But the British finally suppressed it.

After successful tackling the 1857 mutiny, administrators realized the need for change in attitude towards the various classes in the country. There was a lack of interaction between European officers and Indians of all classes. The British people were aloof and thinking about their own well-being.

> It had been assumed that it was only necessary to place the better western institution or innovation beside the traditional eastern customs for Indians to welcome the former. Superstition would give way to reason and ignorance to new knowledge. But it was now sadly admitted that this was not so. The citadels of religious tradition and customs were stronger than had been thought. [1]

The government's public works provided the means for the growth of Western influence in commerce, industry, irrigation, education and science. The roads and railways were outstanding public works. The canals, hydroelectric projects, harbour works and new bridges improved the lifestyle of Indians considerably. There was a rise of westernized middle class comprising an English-speaking group of clerks, lawyers, teachers and officials.

The dissemination of Western education and establishment of modern industry were increasing. The rise of plantation industries of jute and cotton and of the coal and iron industry occurred in this period. Though all these establishments and activities were the need of imperial machinery, Indians benefited from it.

Sir Ashutosh Mukherjee, a product of Western education, was a leading personality in Bengal. In 1906, he was invited by Lord Minto to take over as the Vice-Chancellor (VC) of Calcutta University. He served as VC till 1914 and again in

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1921–1923. One of the major aspects of his efforts and contributions was ‘converting Calcutta University from an examining and affiliating organization to a centre of post-graduate research and teaching; and raising funds for this purpose from Indian philanthropists and attracting the most talented persons to carry out independent research and teaching.’

In his convocation address in 1912, he said

> That in order to bring the post-graduate teaching up to the standards of the best of western universities, more diversification and specialization in the post graduate courses was necessary. The lecturer selected for such teaching should be specialist in their particular branches of studies, who could give the students, the results of the latest studies on the subject; these were not to be found in the textbooks but had to be gathered from specialist journals. [2]

The government was not ready to provide funds for education, especially for post-graduate studies. The fundraising for higher education at the start of the twentieth century in India was a difficult task. But Asutosh succeeded in it.

In 1912, Sir Taraknath Palit donated Rs. 13.66 lakhs to the University for two professorships, one for physics and one for chemistry. Palit also donated a plot of land at 92 Upper Circular Road (now Acharya Prafulla Chandra Road) and at 35 Ballygunge Circular Road (now it houses various departments, viz. botany, zoology, etc.) in Calcutta.

Prof. P. C. Ray was requested to become the first Palit professor of chemistry. But he was working in Presidency College. He took premature retirement and joined as Palit professor in 1916. The physics professorship was offered to C. V. Raman, who was working in the Indian Finance Department and published many research papers. By leaving the Finance services, Raman joined as a Palit professor of physics in 1917.

In 1914, Sir Rash Behari Ghosh donated Rs. 10.46 lakh. From this sum, four professorships were created, one each in mathematics, physics, chemistry and botany. Prof. Ganesh Prasad, Prof. D. M. Bose, Prof. P. C. Mitter and Prof. S. P. Agharkar were the four Ghosh professors in the respective subjects. In 1919 and 1921, Sir Rash Behari Ghosh made another donation of Rs. 14 lakhs. With the money obtained by endowments and grants from the Indian Government, the foundation stone of University College of Science was laid down in 1914. It started functioning in 1916. Sir P. C. Ray wrote in his autobiography:

> After the puja vacation of 1916 I joined the Science College. Ashutosh Mukherjee could foresee at that time that the young talents: Jnan Ghosh, Jnan Mukherjee, Meghnad Saha and Satyen Bose would go very far in their pursuit of science, if proper opportunities were provided to them. They were all offered lecturerships. But at this initial stage there was a big problem. The conditions laid down in the Trust Deeds executed by Palit and Ghosh could use only the interest accrued and could not spend any portion of the capital. The conditions clearly stated that, the university should provide from its own funds for the maintenance of buildings, the purchase of scientific equipments and their upkeep. But the university ran out of its research funds. In the department I had taken charge of Inorganic Chemistry and my colleague, Prof. Prafulla Chandra Mitter, took charge of Organic Chemistry. We made use of equipments we already had. But there were no equipments available for Physical Chemistry and in Physics department. The First World War had begun and no equipment could be imported from Europe. Ashutosh Mukherjee was in a dilemma. A special fund was created out of the savings from the ‘fees’ collected from the

> examinees. This fund provided for the building of the Science College had been exhausted. So Asutosh had to build a structure only with bricks, without the use of mortar. He came to know that Sir Mohindra Chandra Nandi, the Maharaja of Cossim Bazar, had purchased a number of valuable equipments to start an Honours course in Physics at the college founded by him at Berhampur, but the plan did not come through. At the request of Asutosh, the Maharaja donated all the equipments to Science College. Prof. Bruhl of the Sibpur Engineering College loaned a few equipments. I personally went to the St. Xavier's College and collected a 'conductivity bridge.' [3]

The teaching and research in inorganic and organic chemistry was functioning smoothly, but physical chemistry had no required equipments. The start of the Physics Department was not satisfactory. C. V. Raman (Palit professor) had not joined immediately and D. M. Bose (Ghosh professor) was interned in Germany during the First World War.

The young lecturers, S. K. Mitra, P. N. Ghosh and S. K. Acharya, had to organize the Physics Department. Sir Asutosh offered lecturerships to both Meghnad Saha and S. N. Bose in the Department of Applied Mathematics under Prof. Ganesh Prasad. Bose recollected the days when Saha, he and others joined Calcutta University to teach.

> Meghnad, Sailen and I went up the steep stairs to the library, to the special chamber where Sir Asutosh sat. We were meek and submissive and overawed by his august presence. He had heard that the younger generation wanted more modern subjects to be introduced in the University curriculum. He asked …. "What subjects are you competent to teach, boys?"
>
> "Sir, we will try our best to teach whatever you want us to." He smiled, we had only heard of the many new discoveries in Physics, most of them made in Germany… new developments and new discoveries. Planck, Einstein, Bohr …. We Bengalis had only heard of them. To know more about them one had to read German books or research journals in other languages. During the War most of these journals did not come to India.
>
> At long last, as the first step to a new career, we were given a special allowance of Rs. 125/- per month. Meghnad was to study quantum theory and I had to learn Einstein's relativity theory. We came away committing ourselves to being prepared to teach within a year. But where were we to get books from? There were some books in English on relativity … we got hold of them. But where could we get hold of Boltzmann, Kirchhoff, Planck? Suddenly, I thought of an idea. Dr. Bruhl was the answer.
>
> Bruhl was then teaching Physics at Sibpur College…. He was fond of reading and had an excellent collection of science books in his library, where we discovered many rare books. We borrowed Planck, Boltzmann, Wein ….. we could not have asked for more. Meghnad had taken great pains to learn German and even passed the Intermediate Examination. I had just started. But I read French….
>
> But the chemists did not approve of these schemes hatched by the younger generation….. In their opinion, prompted by a few immature youngsters, Asutosh was being too hasty…. He ought to wait for Deben Bose and Raman to come; the youngsters were hardly capable of carrying the heavy burden.
>
> Ashutosh felt that if he could win over Acharya (P. C.) Ray to his side, he would not have any difficulty in carrying out his plans in the Senate. Not that Dr. Ray had much faith in us, but fortunately our classmate Jnan (J. C. Ghosh) had already earned the Acharya's appreciation by taking the step towards his famous theory. The old man had faith in the capability of the youngsters. So Asutosh had no problem in winning him over. The new system was introduced from 1917, when postgraduate courses in Applied Mathematics, Physics, Chemistry etc., were to commence in Science College as well. Of course, Presidency College would continue with its old syllabus. [4]

But they could not get along with Prof. Prasad. Sir Asutosh shifted both, Saha and Bose to the Physics Department. Both were very promising students of mathematics, and Asutosh wanted to use their talents for the benefit of the university.

These young physics lecturers collected equipments from constituent colleges, designed their own curriculum and started teaching. They had done an excellent job. Finally when C. V. Raman joined, the department was running smoothly.

Meghnad was basically a student of mathematics; but very soon he studied and mastered physics on his own. He studied Planck's *Thermodynamics* and Nernst's *Das Neue Warmesatz*. He acquainted himself with Bohr and Sommerfeld's papers on quantum theory of atom. The knowledge of German language that he obtained when he was in college was useful for him. At this time, Saha, along with his friend and colleague S. N. Bose, translated Einstein's theory of relativity in English. Calcutta University published it in 1919.

Meghnad continued his research in the field of his interest. His initial papers were on diverse topics. In 1918 he submitted his thesis 'on origin of line in stellar spectra'. He was awarded the degree of Doctor of Science (D.Sc.) by Calcutta University.

On June 16, 1918, Meghnad married Radharani Roy. She is seen in Fig. 6.1. Radharani's father had business interests in *Barisal*, from where his forefathers came to settle in *Narayanganj*. Radharani had lost her mother at an early age and

Fig. 6.1 Smt. Radharani Saha, wife of Meghnad Saha (1920) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

was brought up by her grandmother. The old lady was against this marriage, because Saha's family was poor. But Radharani's father wanted the bright and promising Meghnad as a son-in-law. In spite of the grandmother's opposition, the marriage took place. The old lady remarked to her son 'Why don't you drown your daughter in the river Padma instead?' When Saha was well settled in Allahabad, he took the grandmother for a pilgrimage to Mathura, Vrindavan and Prayag. 'How do you think your grand-daughter is doing now? Is it better than being drowned in the River Padma?' Saha asked. She retorted 'Radha has brought you luck'.

Saha was working very hard, since he joined as a lecturer. Teaching and research went hand in hand. He was carefully studying thermodynamics, atomic physics and the quantum theory. After the end of the First World War, journals were available to them. As he had studied German (on his own), he could read the latest research papers of the pioneers in physics. He was well acquainted with current problems in physics. At this time he took up one problem and solved it. Now it is known as *theory of thermal ionization* or *Saha's ionization formula*.

Visit to Europe

There was no direct research guide as such for Saha. He started research on the basis of knowledge acquired by his own studies. His initial papers were on diverse topics: 'On Maxwell's stresses – a study of the electromagnetic theory of radiation', 'On the limit of interference in the Fabry-Perot interferometer', 'On a New Theorem in Elasticity', 'On the Pressure of the Light', 'On the Dynamics of the Electron', 'On a New equation of State with S N Bose', 'On the Mechanical and Electro-Dynamical Properties of the Electron', 'On the radiation Pressure and Quantum Theory' and 'On the Fundamental law of Electrical Action'.

While pondering over the problems of astrophysics, and teaching thermodynamics and spectroscopy to the M.Sc. classes, the theory of thermal ionization took a definite shape in his mind in 1919. He was a regular reader of German journals. In his studies he came across a paper by J. Eggert in the *Physikalische Zeitschriff*, in December 1919, on *Uber den Dissoziationzustand der fixsterngase*. In explaining the high ionization in stars due to high temperatures, he missed the significance of the ionization potential of atoms.

While reading Eggert's paper he saw at once the importance of introducing the value of ionization potential in the formula of Eggert under any combination of temperature and pressure. He thus arrived at the formula, now known as *Saha's formula*. He communicated his work for publication in the *Philosophical Magazine*. He submitted the following four papers.

1. Ionization of the Solar Chromosphere (4 March 1920)
2. On Elements in the Sun (22 May 1920)
3. On the Problems of Temperature-Radiation of Gases (25 May 1920)
4. On the Harvard Classification of Stars (May 1920)

Fig. 6.2 Felicitation of Prof. Meghnad Saha at University College of Science & Technology, Calcutta, on the eve of his departure for England (1920). From *left* to *right*: Standing – H. Mitra, G. Datta, D. D. Banerji, S. K. Mitra, S. K. Acharya, A. C. Saha, A. N. Mukherjee, B. B. Ray. Sitting – S. N. Bose, P. N. Ghosh, C. V. Raman, M. N. Saha, D. M. Bose, B. N. Chakravarti, J. C. Mukherjee (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Saha was very keen to go to Europe to verify his theory of thermal ionization in a suitable laboratory. He obtained 'Premchand Roychand studentship', and patronage given by the Brahmo Samaj Education Society made it possible for him to take a trip to Europe.

In India he was working in isolation, as no expert or advisor was around. He was (probably) eager to visit laboratories in Europe, for verifying his theory as well as to discuss his research with contemporary physicists. He was well versed with the ongoing research through journals from Europe. He set sail for Europe in September 1920. On this occasion he was felicitated by his colleagues (Fig. 6.2).

After reaching London he realized that the fellowship amount was inadequate to visit and sustain him at European universities. In England he met his classmate Snehamoy Datta (see Fig. 4.3), who advised Saha to meet Prof. A. Fowler instead of going to Oxford or Cambridge. Saha decided to stay on in London. He met Prof. Fowler at Imperial College and showed him his (prize winning) essay. (The Imperial College of Science and Technology is seen in Fig. 6.3.) He permitted Saha to work in his laboratory. Under Fowler's guidance, Saha rewrote his essay with new title as "On a physical theory of stellar spectra". Fowler communicated this paper to the Royal Society and published it.

In his own words

> I had no personal acquaintance with Prof. A. Fowler except that I had read his paper on the spectrum of ionized helium.
>
> On my arrival in England, I saw Prof. Albert Fowler, who at first thought that I had come to work for the D. Sc. degree of the London University like other Indian students working

Fig. 6.3 Imperial College of Science & Technology, London, UK (1920), where Meghnad Saha worked for about 5 months during 1920–1921 in Prof. A. Fowler's Astrophysics Department (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

under him. But when I explained to him that I wanted to work there only for a short period to obtain verification of my theory, he did not seem very enthusiastic, but allowed me to read and work in his laboratory. Probably he had not much time to listen to me at the first meeting. This was the November of 1920. If you look at the records of Imperial College, you will find that I never got my name registered for my degree work. In the mean time, my first paper 'Ionization in the Solar Chromosphere' communicated from India had appeared in the *Phil. Mag.*, thanks to a personal call which I made on Mr. Francis, the Publisher of the Journal. After its publication, Prof. Fowler began to take a more lively interest in my work and in my views. I showed him the paper 'On a Harvard classification of Stellar Spectra'. He read it very carefully, and argued with me that the Harvard Astrophysicists including Prof. Pickering and Miss Cannon were not the only persons who had made contributions to these subjects, but the pioneering credit for such researches must be given to Lockyer. He gave me all the papers of Lockyer and his pupils and of himself to read, and from their perusal, I was convinced of the soundness of Fowler's views, and at his suggestion the title of the paper was changed to 'On a Physical Theory of Stellar Spectra'. The original paper was withdrawn from the office of the *Philosophical Magazine* and Fowler was kind enough to communicate it to the Royal Society where it was published. Papers (2) and (3) were published in the *Phil. Mag*.

I took about four months in rewriting this paper, and all the time I had the advantage of Prof. Fowler's criticism, and access to his unrivalled stock of knowledge of spectroscopy and astrophysics. Though the main ideas and working of the paper remained unchanged, the substance matter was greatly improved on account of Fowler's kindness in placing at my disposal fresh data, and offering criticism wherever I went little astray, out of mere enthusiasm.

For example, he would repeatedly say that hydrogen in stellar spectra and helium in the solar chromosphere, does not at all obey the ionization theory. These facts later on gave rise to the idea of hydrogen excess in stars, but I do not think that for the helium anomaly any satisfactory hypothesis had yet been put forward. I have suggested one in my paper 'On a

> Physical theory of the Solar Carona'. The paper, 'On a Physical theory of Stellar Spectra' was read at a meeting of the Royal Society, and there Prof. Fowler spoke very enthusiastically about the work. He said that it was the greatest contribution in Astrophysics since Kirchhoff's discovery of the spectrum analysis in 1859, and predicted a great number of works being stimulated by it.

Saha found a physical explanation of the gradation in the spectra of stars. He had developed the theory of thermal ionization and thermal radiation in his earlier papers – "Ionization in the solar chromosphere", 'Elements in the sun', 'On the temperature-radiation of gases' and 'On electron-chemistry and its application to problems of radiation and astrophysics'. He considered second-step ionization, in which, for example, Ca^+ lost another electron and acquired a net double positive charge and calculated the energy of second-step ionization by using the formula:

$$U = \left(eV_{\mathrm{i}}N / 300J\right)\mathrm{cal}$$

where N was Avogadro's number, V_{i} was ionization potential and J was the mechanical equivalent of heat. He assumed that the fractions x and y of the total Ca-atoms were dissociated to Ca^+ and Ca^{++} atoms, respectively, and calculated the percentage of the second-step ionization of the alkaline earths at pressures of 1 and 10^{-1} atm. Then he calculated the second-step ionization of helium. It was too small even in stars having the highest temperature. Consequently, He^+ lines should be observed even when temperature reaches 40,000 K, but actually they disappear from the Pc-class of gaseous nebula, the temperature of which was not probably so high. Maybe that was an effect of low pressure. According to Emden, pressure is 10^{-5} atm. in nebulae. Hence, the temperature of the completion of the ionization of He^+ was 29,000 to 30,000 K, which was not improbable. From the ionization calculations of hydrogen, it was observed that hydrogen should definitely disappear when the temperature reaches the value of 22,000 K, but it was not the case for, according to the *Harvard Annals*, the Balmer lines occur not only up to the Oa-class but also in the Pa-class of nebulae, the temperature of which was probably very large. He considered Ca *g*-line and Ca^+ K-line. The *g*-line appeared in maximum intensity from the very stage when the star began its effective life. There was no trace of the K-line at the lowest stages. It just began to appear at the Mc-stage, showing that calcium had just begun to be ionized. At a higher level, the ionization was increased (*g*-line fade up and K-line became more intense). The *g*-line completely disappeared at the B8-stage, showing that all calcium had been ionized to Ca^+. The K-line reached a maximum intensity at the G5-stage and then steadily diminished, showing that a second-step ionization had begun. It disappeared completely at the Oc-stage showing that all Ca^+ had been further ionized to Ca^{++}.

The disappearance of Balmer lines from a certain class did not mean that hydrogen was absent from that class, but rather that stimulus was not sufficiently high to bring out the lines lying within the range of observations. Helium could not be identified by its 1 s-mp lines, but by the 2p-md lines. It took place only when a sufficient proportion of He atoms had been converted to the 2p state. Due to the higher value of ionization potential of helium, it took place at a much higher stage than that of hydrogen, viz. at the Ao-stage. Thus, at the stage Ao...... 2p orbits of He just appear, $T = 12{,}000$ K. The helium lines were very persistent. They occurred faintly in the Ob- and Oa-class and even in the gaseous nebulae up to the Pd-stage. The calculations showed that at pressure 1 atm., helium was not completely ionized even at temperature of 30,000 K. For a pressure of 10^{-1} atm., the temperature of complete ionization was 25,000 K. The ionization of helium was marked from the Bz-stage, as was shown from the appearance of the 4686 Å line. According to Fowler it was 3d-4f line of He^+, and according to Saha's theory, it required for its absorption, not only a greater stimulus, than that which suffices for mere ionization, but also a greater concentration of He^+-atoms. Therefore, Saha assigned to the stage, B2A ...... ionization of He considerably advanced, $T = 17{,}000$ K. A serious discrepancy was shown by hydrogen, which, as shown by the presence of Balmer lines, was present even beyond the Oa-stage. The modern spectroscopic work had shown that the lines represented by the Balmer formula $\nu = N\,[(1/2^2) - (1/m^2)]$ could not only be due to hydrogen but might be due to He^+ and to Li^{++}. If the lines were due to He^+, they should have the same intensity as the Pickering lines $\nu = 4\,N[(1/4^2) - (1/(2\,m + 1)^2)]$, they form the even members of the 4f-mk series of He^+. The observations showed that it was actually the case from the Oa- to the Oc-class, but in Od- and Oe-class, while the Pickering lines were fading away, the Balmer lines were gaining in intensity. This fact, taken along with the results that at 20000 K, 10^{-1} atm. pressure hydrogen was completely ionized, led to the conclusion. The Balmer lines due to hydrogen disappear from the Ob-class; those occurring in the Oa- and Ob-class were due to He^+. In the Oc-, Od- and Oe-class, there were merger of H and He^+ lines, but below B2A they were entirely due to hydrogen.

Due to slightly different values of N in the case of hydrogen and helium, the wavelengths of the Balmer lines in the different spectral classes were slightly different. The line $\nu = N\,[(1/2^2) - (1/m^2)]$ also occurs in the highest class of gaseous nebulae, Pa, which was far higher than the class from which He^+ disappear. There was thus a certain anomaly attached to the Balmer lines.

Eventually, Saha made a concluding remark that the work, thus, corroborates Russell's view that the continuous variation of stellar spectral types was mainly due to the varying values of the temperature of the stellar atmosphere, and the classifications B, A, F, G, K and M, which had been adopted by the Harvard astrophysicists, as the result of long years of study and observation, were therefore seen to acquire a new physical significance. Then he noted some minor differences.

Later it was learnt that Saha had forestalled Prof. F. A. Lindemann, Clarendon Professor of Physics at the Oxford University, and the Late Prof. H. A. Kramers of the Leiden University, Holland, to whom this problem was referred to by Niels Bohr and R. C. Tolman of California Institute of Technology.

Saha's stay in London was very fruitful. There he met S. S. Bhatnagar, who made a monumental contribution to the Indian science and technology by establishing a chain of Council of Scientific and Industrial Research (CSIR) laboratories. Fowler's lab was a very good place for Saha. He could interact with many experts in spectroscopy and astrophysics and get the latest news from Europe very quickly. Saha was interested in verifying his theory of thermal ionization experimentally. The high-temperature facility was not available in England, but Nernst's laboratory in Berlin was the most suitable place. Fowler advised Saha to write to Nernst.

That was the period when the First World War was over. Germany was under the agony and humiliation of defeat, and in general, there was a strong dislike of the British and their dependents. Nernst had refused admission to many British and American students. Saha being Indian, Nernst allowed him to work in his laboratory. He set up an experiment for verification of the theory of thermal ionization. The results were promising but not conclusive. He spent 1 year in Nernst's laboratory.

His attempts to measure the conductivity of Cs vapour, contained within an evacuated quartz tube heated by the electric furnace, were unsuccessful. Then he adopted a different configuration. The apparatus consisted of the platinum tube furnace and the thermocouple. The platinum tube furnace was vertical and had its lower end closed with a conical shaped quartz tube, having a narrow opening, which was overlaid with a layer of fused pieces of pure magnesia. The quartz tube was connected by rubber tubing to a hydrogen generating apparatus. The thermocouple, inserted in platinum tube, consisted of a capillary porcelain tube of Marquardt mass, carrying platinum, platinum-rhodium junction. The hydrogen was allowed to stream through the furnace displacing the air, and the furnace was heated up to 1200 °C. Then a piece of caesium, rubidium or potassium was dropped from a pincette into the furnace. The metal completely vaporized, and the vapour, on account of its heaviness, displaced hydrogen. Thus, there was an atmosphere of caesium vapour, which was partly ionized due to the high temperature.

The space within the furnace, containing a fair proportion of free electrons and caesium, was compared with an electrolytic cell. The conductivity of the cell was measured by using the walls of the furnace as one electrode and the pyrometer as the other electrode, according to the ammeter-voltmeter method. Thermo-emf was calibrated to measure temperature. The current that passed through the ionization space was measured by milliammeter. By removing a cell out of circuit, a post office box was inserted in the circuit. It was adjusted till the same deflection was observed as with the cell. Thus the resistance of the post office box was the direct resistance of ionization space. The measurements of temperature and conductivity simultaneously were not possible; therefore, readings were taken separately. The hydrogen gas was made anhydrous, by passing it through sulphuric acid. The maximum temperature used was about 1200 °C. The observations showed that the conductivity of vapour space became almost double, when the temperature was raised from 1050 to 1250 °C. Due to the nature of the experiment, the conclusions were qualitative. The conductivities observed with caesium, with ionization potential 3.88 V; rubidium, 4.16 V; and potassium, 4.32 V, were in the reverse order of their ionization potentials, just as expected from the theory. This led to the conclusion that the conducting free electrons owe their genesis to the ionization of the atoms of those metals by heat alone. Saha published that research, with Paul Gunther, in the *Journal of the Department of Science of Calcutta University* in 1922.

When he was in Berlin (see Fig. 6.4), he attended regularly the weekly colloquium on physical sciences held in Physikalische Institute of the University, next to Nernst's laboratory at the Reichstagsufer. Here he met and made friends with

Fig. 6.4 Meghnad Saha in Berlin, Germany (1921) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

scientists like Max Planck, von Laue, Einstein, Rubens, Pringsheim, Grotrian, Westphal, Kohlschutter, Eggert and many others. He sent a copy of his paper on stellar spectra to Sommerfeld, who invited him to Munich to deliver a seminar.

At that time, Rabindranath Tagore was in Munich. But Saha and Tagore did not know each other. Sommerfeld introduced them. Tagore invited Saha to visit *Shantiniketan* in Calcutta. From Germany, Saha went to Switzerland and then back to England. He met Arthur Eddington at Cambridge, who introduced Saha to Milne who was Eddington's assistant. Milne told Saha that he had seen his paper on radiation pressure in *Nature* and he was extending Saha's work in collaboration with R. H. Fowler.

Saha was in search of spectroscopical data of stars. But unfortunately it was not available either in England or anywhere in Europe. It was only with Mount Wilson Observatory where George Ellery Hale was in charge. Saha wrote to Hale but received no reply.

Saha received a letter from Sir Ashutosh Mukherjee, stating that a new chair of physics, Khaira professorship, was created, which would be offered to him if he could return immediately. Saha had limited resources when he was in Europe. The travel fellowship was drawing to a close, and he had to return to Calcutta giving up his experiments.

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Chapter 7
Saha's Ionization Formula

Lord Kelvin and Hermann von Helmholtz proposed that the tremendous weight of the sun's outer layers pressing inward from all sides causes the sun to gradually contract. This gravitational contraction causes the sun's gases to become hot enough to radiate energy into space. The sun appears to have a surface because there is a layer in the sun's atmosphere from which most of the visible light comes. This 100 km thick layer is called the *photosphere* (sphere of light). Its average temperature is about 6000 K. The cool region (~ 4000 K) immediately above the photosphere is the lowest layer of *chromosphere* (sphere of colour). The core of the sun is very hot and it radiates at all frequencies. This radiation (or light) passes through the sun's (solar) atmosphere. There are various atoms (elements) present in the solar atmosphere, and they selectively absorb radiation of certain frequencies. Thus, these dark lines is an absorption spectrum.

It was known for a long time that the higher level chromosphere is generally distinguished by those lines, which are relatively more strengthened in the spark spectrum than in the arc. J. N. Lockyer called them *enhanced* lines. About their origin and the extraordinary height reached by these lines in chromosphere, there was no satisfactory explanation. The element corresponding to H- and K-lines was present up to the height of 14,000 km, whereas hydrogen reached the height of only 8000 km in the solar atmosphere. The conclusion was that the element lighter than hydrogen must be present in the solar atmosphere. But soon it was realized that these twin lines were of calcium. The problem was how to explain the presence of calcium, which was 40 times more massive than hydrogen, in the upper solar atmosphere (chromosphere)! Lockyer's conclusion was that H- and K-lines were the so-called enhanced lines, which were produced under high temperature. He further concluded that the temperature of chromosphere was higher than photosphere (lower atmosphere). One more question was why were some elements not observed in the solar spectrum, for example, rubidium and caesium?

In his paper in 1920, Saha pointed out that according to Lockyer, the passage from the arc to the spark means a considerable, though localized, increase of temperature, to which mainly the enhancement of the lines was to be ascribed. But apart

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from its physical incompleteness, Lockyer's theory places researchers into great difficulties, as far as the interpretation of solar phenomena was concerned. It would lead researchers to the hypothesis that the outer chromosphere was at a substantially higher temperature than the photosphere and the lower chromosphere and that the temperature of the sun increased, as one passed radially outwards. This hypothesis was, however, quite untenable and was in flagrant opposition to all accepted theories of Physics.

Saha said that a much more plausible explanation was that the lines in question were not due to radiations from the normal atom of the element but from 'an ionized atom', that is, one which has lost an electron. The high-level chromosphere was, according to this view, the seat of very intense ionization. The 'enhanced lines' were due to the ionized atoms of the element. As an example, Saha explained the case of the calcium H-, K- and g-lines. The H- and K-lines were of the enhanced type, while g-line was of the normal type. The H- and K-lines were the leading members of the principal pair-series of the system of double lines of calcium, while the g-line was the first member of the system of single lines of calcium. Lorenser and Fowler had shown that the series formula of the double lines was of the type

$$\nu = 4N\left[\frac{1}{\left(f(m)\right)^2} - \frac{1}{\left(\phi(n)\right)^2}\right] \tag{7.1}$$

while the series formula of the single lines was of the type

$$\nu = N\left[\frac{1}{\left(f'(m)\right)^2} - \frac{1}{\left(\phi'(n)\right)^2}\right] \tag{7.2}$$

where $f(m)$ and $\phi(n)$ were functions of the form $m+\alpha$ according to Rydberg and $m+a+b[t(n)]$, according to Ritz, $t(m)$ being a function of m which vanished with increasing values of m. In the series formula of the enhanced lines, the spectroscopic constant was 4 N instead of the usual Rydberg number N. In the light of Bohr's theory, that was to be understood in the sense that during the emission of the enhanced lines, the nucleus and the system of electrons (excluding the vibrating one) taken together behave approximately as a double charge, so that the spectroscopic constant, $(2\pi^2e^2E^2m)/h^3$, became 4 N, as $E = 2e$. It means that if the nuclear charge was n, the total number of electrons was $(n - 1)$, and the system had been produced by the removal of one electron from the normal atom.

Saha further pointed out that the explanation of the calcium H- and K-lines was also true for the strontium pair 4216 Å and 4078 Å and the barium pair 4934 Å and 4554 Å, that is, they were caused due to the ionized atom of those elements. The principal lines of the system of single lines of those elements also occurred in the flash spectrum, but they reached a much lower level.

No satisfactory series formula was known for the other high-level chromospheric elements, viz. titanium, scandium, iron and other elements. But the remarkable work of Kossel and Sommerfeld made it quite clear that the spark-lines of those elements were due to the ionized atom. The spark-lines of alkalies had not been much investigated and lay in the ultraviolet region beyond 3000 Å, so that, even if they were present in the high-level chromosphere, researchers would have no means of detecting them. As regards hydrogen, ionized hydrogen would mean simply the hydrogen core and that probably by itself would be incapable of emitting any radiation. But as H_α and H_β lines occurred high in the chromosphere, hydrogen probably was not much ionized in the chromosphere.

The case of helium was very interesting. It was well known that the Fraunhofer spectrum did not contain any helium lines, which were obtained only in the flash spectrum. But those lines were all due to normal helium, and the highest level reached by the second line of the so-called principal series was some 8500 km, while the better known D_3 reached a level of 7500 km. The lines due to ionized helium were represented by the general series formula:

$$\nu = 4N\left[\frac{1}{m^2} - \frac{1}{n^2}\right] \tag{7.3}$$

and the best known of them, in the visible range, were the Rydberg line 4686 Å and the Pickering system

$$\nu = N\left[\frac{1}{2^2} - \frac{1}{\left(m+(1/2)\right)^2}\right] \tag{7.4}$$

once ascribed to cosmic hydrogen. Mitchell stated that 4686 Å occurred in the flash spectrum and reached a level of 2000 km. The helium would present a seemingly anomalous case, whereas other elements were ionized in the upper strata; it was ionized in the lower strata of the chromosphere.

The alkaline earths and the heavier elements were ionized throughout the whole of the solar atmosphere, but the ionization was complete in the chromosphere, which seemed to contain no normal atom at all. But hydrogen and helium were probably unionized throughout the whole chromosphere, and in the case of helium, there was probably some slight ionization in the lower parts – a rather anomalous case.

Nernst calculated the energy of ionization from the ionization potential of elements. He used the method based on Eggert's work in 1919 (on the state of dissociation in the inside of fixed stars – *Phys. Zeitschrift*, Dec. 1919). Eggert had shown that by applying Nernst's formula of 'reaction isobar'

$$K = \frac{p_m^{\nu_m}\, p_n^{\nu_n} \cdots\cdots}{p_A^{\nu_A}\, p_B^{\nu_B} \cdots\cdots} \tag{7.5}$$

to the problems of gaseous equilibrium in the inside of stars, it was possible to substantiate many of the assumptions made by Eddington (*M. N. R. A. S. vol. lxxvii,* pp. 16 and 596) in his remarkable theory of the constitution of stars. Those assumptions were that in the inside of stars, the temperature is of the range 10^5 to 10^6 degrees and the pressure is about 10^7 atm., and the atoms were so highly ionized that the mean atomic weight was not much greater than 2. The equation of the reaction isobar was

$$\log K = \log \frac{p_m^{\nu_m} p_n^{\nu_n} \cdots\cdots}{p_A^{\nu_A} p_B^{\nu_B} \cdots\cdots} = -\frac{U}{4.571T} + \frac{\sum \nu C_p}{R} \log T + \sum \nu C \tag{7.6}$$

where K = the reaction isobar, U = heat of dissociation, C_{p} = specific heat at constant pressure and C = Nernst's chemical constant, and the summation was extended over all the reacting substances. The case was treated as a sort of chemical reaction in which ionization was substituted for chemical decomposition.

The ionization of a calcium atom took place as

$$\mathrm{Ca} \leftrightarrow \mathrm{Ca}^{+} + e - U \tag{7.7}$$

where Ca was the calcium atom (in vapour state), Ca^+ was ion, e was electron and U was the amount of energy liberated in the process. The quantity considered was 1 g atom.

The value of U can be calculated from the value of the ionization potential of elements as determined by Frank and Hertz, McLennan (*Proceedings of the Physical Society of London*, Dec. 1918) and others. Let V be the ionization potential. To detach one electron from the atomic system, an amount of energy is to be added to each atom, equivalent to that acquired by an electron falling through a potential difference V, where V (in volt) was given by quantum relation

$$\frac{eV}{300} = h\nu_0 \tag{7.8}$$

where ν_0 was the convergence frequency of the principle series. When that quantity was multiplied by Avogadro's number N and expressed in calories, we got U.

The equation of gaseous equilibrium was

$$\log K = -\frac{U}{4.571T} + \frac{\sum \nu C_{\mathrm{p}}}{R} \log T + \sum \nu C \tag{7.9}$$

where the reaction proceeded according to the

$$\nu_{\mathrm{a}} A + \nu_{\mathrm{b}} B + \cdots\cdots = \nu_{\mathrm{m}} M + \nu_{\mathrm{n}} N + \cdots\cdots \tag{7.10}$$

and K was the reaction isobar:

$$\frac{p_m^{\nu_m} p_n^{\nu_n} \cdots\cdots}{p_A^{\nu_A} p_B^{\nu_B} \cdots\cdots} \tag{7.11}$$

$p_m^{\nu_m}, p_n^{\nu_n}$ ...... were the partial pressures of the reacting substances –M, N, ……, etc. In the case of calcium,

$$\mathrm{Ca} \leftrightarrow \mathrm{Ca}^{+} + e - U$$

$$\sum \nu C_{\mathrm{p}} = \left(C_{\mathrm{p}}\right)\mathrm{Ca}^{+} + \left(C_{\mathrm{p}}\right)e - \left(C_{\mathrm{p}}\right)\mathrm{Ca} \tag{7.12}$$

can be written as

$$\left(C_{\mathrm{p}}\right)\mathrm{Ca} = \left(C_{\mathrm{p}}\right)\mathrm{Ca}^{+} \text{ and} \left(C_{\mathrm{p}}\right)e = \left(5/2\right)R \tag{7.13}$$

The electrons were expected to behave like a monoatomic gas. Eggert calculated the chemical constant from the Sackur-Tetrode-Stern relation

$$C = \log \frac{\left(2\pi M\right)^{3/2} k^{5/2}}{h^{3} N^{3/2}} \tag{7.14}$$

$$= -1.6 + \left(3/2\right)\log M \tag{7.15}$$

where M was the molecular weight and pressure was expressed in atmospheres. The C had the same value for Ca and Ca^{+}. For the electron, $M = 5.5 \times 10^{-5}$ and $C = -6.5$. Thus,

$$\sum \nu C_{p} = -6.5 \tag{7.16}$$

To calculate the reaction isobar K, assume P as the total pressure and a fraction x of the Ca atoms was ionized. Therefore,

$$\log K = \log\left(\frac{x^{2}}{1 - x^{2}}\right)P = -\frac{U}{4.571\,T} + 2.5\log T - 6.5 \tag{7.17}$$

Equation (7.17) was *Saha's ionization formula*. The degree of ionization for any element, under any temperature and pressure, can be calculated, when the ionization potential was known. The pressure has a very great influence on the degree of ionization.

Then Saha calculated the degree of ionization of calcium, strontium and barium under varying conditions of pressure and temperature. The observations were consistent with the theory. As the temperature was increased, the 'enhanced lines' began to strengthen until at the temperature of the arc, they were comparable in intensity to the lines of the normal atom. Saha presented and analysed observations of King about Ca, Ca^{+}, Sr, Sr^{+}, Ba and Ba^{+}. Unfortunately the data about pressure was not available in those observations.

About hydrogen, he said that it existed in the sun only in the atomic state, for if there were molecular hydrogen in the sun, it would have been detected some of the lines of the secondary spectrum. The hydrogen combined with calcium and magnesium in the sunspot but probably did not form its own molecules. From reaction isobar Saha calculated the dissociation of hydrogen under different pressures and temperatures. The dissociation was complete. Even in the umbra of sunspots, assuming that the temperature was 4000 K and the pressure was of the order of 1 atm., the dissociation was almost complete (96.5%). Then he considered ionization of hydrogen and showed that at a point where $T = 6000$ K, hydrogen could be completely ionized if pressure was 10^{-11} atm. Thus only at the highest points of the chromosphere, where the partial pressure was 10^{-11} atm., the ionization was complete and the vanishing of H-lines was expected.

The calculations for helium showed that the ionization was too slight under the conditions in the solar atmosphere, both in the reversing layer ($T = 7500$ K, $P = 1$ atm.) and in the high-level chromosphere ($T = 6000$ K, $P = 10^{-6}$ atm.). But somewhere between the two ($T = 7000$ K, $P = 10^{-3}$ atm.), there might be slight ionization (1 in 10,000) which might account for the occurrence of the line of ionized helium $\lambda = 4686$ Å, which had been detected by Mitchell. The calculations were of the roughest nature. The investigation also showed that the Pickering lines and the Rydberg line 4686 Å could occur as absorption lines only in stars, having the highest temperature, exceeding 16,000 K. That seemed to be independently borne out by the investigations of Eddington and Russell.

In his paper 'Elements in the sun' in 1920, Saha said that the varying records of different elements in the Fraunhofer spectrum might be regarded as arising from the varying response of these elements with regard to the stimulus existing in the sun. The stimulus existing in the sun was the same for all elements, viz. that arising from a temperature of about 7500 K, but owing to a different internal structure, elements would respond in a varying degree to this stimulus. Saha extended his theory and calculated the degree of ionization for sodium, potassium, rubidium, caesium, oxygen, magnesium and nitrogen under varying conditions of temperature and pressure. It was observed that 60% of sodium atoms were ionized in the photosphere, and ionization was practically complete at a level where the pressure dropped to 10^{-3} atm. The result was in concurrence with observational facts, for according to Mitchell the D_1 and D_2 lines reach a level of only 1200 km. Over this height, only ionized sodium atoms were present, the main emission lines of which lie, according to Goldstein, in the remote ultraviolet and so escape detection. Taking the temperature of the sunspot as 5000 K, as given by Emden, Fowler, Hale and others, it was seen that only 6–19% of the atoms were ionized. So over the spot, there was a great increase in the proportion of unionized sodium atoms, and he expected a much stronger absorption of the D_1 and D_2 lines. Kayser's data showed that Saha's prediction was correct. The intensity in the sunspot spectrum of D_1 line (5896.15 Å) was 60% and that of D_2 line (5890.19 Å) was 90%.

The ionization potentials of rubidium and caesium were low, 4.16 V and 3.88 V, respectively. Both these elements were completely ionized in the chromosphere. Hardly were there any neutral atoms of rubidium and caesium in chromosphere;

therefore, no absorption or emission lines were observed. They were detected at sunspots, where temperature was comparatively low. Later on improved techniques of observations also confirmed Rb^+ and Cs^+.

Saha was up-to-date about Bohr's atomic model in 1913, which put forward the idea of discrete levels of atom and Frank-Hertz experiment in 1914, which confirmed the existence of discrete (or quantized) energy levels (or states) of an atom. After many years, in a letter dated 19 December 1946 to Prof. H. H. Plaskett of University Observatory, Oxford, Saha narrated:

> It was while pondering over the problems of Astrophysics and teaching Thermodynamics and spectroscopy to the M. Sc. classes that the theory of thermal ionization took a definite shape in my mind in 1919. I was a regular reader of German journals which had just started coming after 4 years of First World War, and in the course of these studies I came across a paper by J. Eggert…. In which he applied Nernst's Heat Theorem to explain high ionization in stars due to high temperatures, postulated by Eddington in the course of his studies on stellar structures.
>
> Eggert, who was a pupil of Nernst and was at that time his assistant, had given a formula for thermal ionization, but it is rather strange that he missed the significance of the *ionization potential* of atoms, the importance of which was apparent from the theoretical work of Bohr and the practical work of Frank and Hertz which attracted a good deal of attention in those days…. Eggert used Sackur's formula of the chemical constant for calculating, that of the electron, but in trying to account for multiple ionization in the interior of stars on this basis he used artificial values of the ionization potential.
>
> While reading Eggert's paper, I saw at once the importance of introducing the value of the ionization potential in the formula of Eggert, for calculating accurately the ionization, single or multiple, of any particular element, under any combination of temperature and pressure.
>
> I thus arrived at a formula, which now goes by my name. Owing to my previous acquaintance with chromospheric and stellar problems, I could at once see its application. I prepared in the course of 6 months and communicated them for publication in the *Philosophical Magazine* from India.

Another problem was that heavier element like calcium was present up to a greater height compared to light element hydrogen. The gravitational acceleration on the sun was 28 times, the acceleration on the surface of the earth.

Saha published three papers on this topic: (1) On Radiation-Pressure and the Quantum Theory: A Preliminary Note, (2) On Selective Radiation Pressure and the Radiative Equilibrium of the Solar Atmosphere and (3) The Stationary H- and K-lines of Calcium in Stellar Atmospheres, along with his theory of thermal ionization.

On the basis of continuous theory, Nicholson and Klotz had worked out the value of the radiation pressure, when the size of the obstructing mass was gradually decreased, ultimately being reduced to the scale of the wavelength of light. The effect of repulsing light pressure gradually preponderated over any gravitative force, to which the particle may be subjected to, but at the same time, it appeared that there was a limit to this process of reduction. If the particle was too small, it was no longer capable of acting as a barrier to the advancing lightwaves and consequently experiences no radiation pressure. For particles of molecular size, the effect of light pressure was totally evanescent. The conclusion from continuous theory was contradictory to the requirements of astrophysics, in order to explain tails of a comet, solar prominences and corona which take place on the surface of luminous heavenly bodies. It was necessary to assume the existence of certain repulsive forces and levity, acting on the ultimate gaseous molecules and thus reducing the gravitational attraction on them. Lebedew had experimentally demonstrated the existence of radiation pressure on molecules of absorbing gases like carbon dioxide, methane, propane, etc. Thus, though classical theory could not explain, molecules did experience a radiation pressure.

Saha applied the quantum theory instead of continuous theory of light. When a pulse of energy $h\nu$ (h = Planck's constant and ν is frequency of radiation) encountered a molecule and was absorbed by it, the molecule was thrust forward with an impulsive momentum of $h\nu/c$ (c = velocity of light). Suppose the pulse has the mass $h\nu/c^2$ and the momentum $h\nu/c$, the absorption of the pulse by the molecule was taken as a case of inelastic impact; the whole momentum was communicated to the molecule. The velocity with which the molecule moves forward was $h\nu/mc$, where m was the mass of molecule. The velocity imparted due to absorption of a H_α line of the hydrogen atom was

$$v = h\nu / mc = 60\,\mathrm{cm/s}$$

Though that was small, it was impulsive velocity and was of the nature of an acceleration. The total velocity acquired by a hydrogen atom per second depended upon the number of kicks of light it experienced per second, and that may result in enormous values. It explained Lebedew's results and gave general explanation of the radiation pressure. The pressure was

$$(1/c)\sum\sum h\nu$$

where the summation was extended over all the pulses absorbed in unit time, within unit area. It thus equalled to AI, where I was the intensity of light and A was the fraction absorbed. The aggregate effect remained unchanged, but it was now concentrated on a few active molecules; the inactive molecules remained unaffected. The number of kicks of light experienced by the hydrogen atom or molecule depended upon density of pulses of light in the region traversed by the molecule and the time of retention by the molecule or the atom of the capacity for the absorption of light.

Ladenburg and Loria experimentally found that hydrogen absorbed its characteristics radiation only when it was in an active state (in modern language *excited* state). It was also in accordance with theoretical investigations of Bohr. The active H-atom picked up from the continuous spectrum the pulse corresponding to H_α and H_β lines with an instantaneous velocity of 60–31 cm per second. The pulses which were absorbed travel radially outward; hence, if the particle continued active for a sufficient length of time, it may ultimately acquire a velocity exceeding the critical (escape) velocity of 6.12×10^7 cm/s (from the gravitational influence of the sun).

From general considerations, Saha said that radiation pressure may exert an effect on the atoms and molecules which were out of proportion to their actual sizes.

It also showed that the radiation pressure exerted a sort of sifting action on the molecules, driving the active ones radially outward along the direction of beam. The cumulative effect of the pulses may be sufficiently great to endow the atoms with a large velocity – the velocity with which the tops of solar prominences were observed to shoot up. The velocities of the red prominences were sometimes found to be as high as 6×10^7 cm/s. The solar prominences had sometimes been explained on the assumption that they were due to the convection of hot masses of vapour from the solar photosphere, which, after reaching the atmosphere, were supposed to expand adiabatically and develop large velocities with which the prominences were observed to shoot up. But both Pringsheim and Nicholson had pointed out several insuperable difficulties in the way of the acceptance of that hypothesis, including the deduction that the maximum velocity obtainable from adiabatic expansion was less than 1/45 of the velocity with which the prominences were observed to shoot forward (6×10^7 cm/s). Nicholson had suggested that some unknown forces of electrical origin might be the cause of those large velocities, but even granting that the electric fields existed in the sun, it was difficult to see how that can act upon the luminous hydrogen particles, which were most probably not charged.

According to Saha's theory, the effect of radiation pressure on the separate particles was altogether disproportionate to the dimensions of the particles and may cause them to be endowed with a levity, long sought for the explanation of the prominences, the corona and other solar phenomena, including the extension of the solar atmosphere. Saha applied the idea to the explanation of the tails of comets. The tails of comets were undoubtedly caused by some sort of repulsive action, exerted by solar light, but since, in the older theory, the effect was found evanescent on particles of the molecular size, the tail was supposed to consist of some sort of cosmic dust. But the spectroscopic examination of the light from the tails showed that they consisted, at least partly, of luminous gases, CO and CO_2. Saha said that as the comet approached the sun, more and more pulses of light from the sun traverse the nucleus and the coma. The light pulses of suitable frequency were picked up by the gaseous particles, which thus gradually gained in velocity in a direction away from the sun. The cumulative effect of the absorbed pulses may endow the particle with a velocity, sufficient for its escape from the main mass of the cometary matter, and form into the tail.

In Saha's own words (a letter dated 19 December 1946, to Prof. H. H. Plaskett, University Observatory, Oxford):

> By the end of 1917, I had written a long essay on 'Selective Radiation Pressure', elaborating on theory of the role of radiation pressure acting on the atoms selectively and compensating the action of gravity on solar atoms. This paper was sent to the *Astrophysics Journal* for publication, but the editors replied that as the paper was rather long, it could be published only if I were willing to bear a part of the printing costs, which ran to three figures in dollars. Much as I would have liked to do so, it was not possible for me to generate so much money as my salary was small (about rupees one hundred fifty per annum) and I had to maintain my old parents and younger brother who was studying within this salary. So I wrote to the editors of the *Astrophysical Journal* expressing my inability to pay the costs of printing, but never heard anything more about the publication of this paper nor was it returned to me. Years afterwards, in 1936, when I visited the Yerkes Observatory, Dr.

> Morgan showed me the manuscript, which was still being kept there. I got a short note published in the *Astrophysical journal* and submitted a duplicate of the original article on 'selective Radiation Pressure and Problems of Solar Atmosphere' sometimes afterwards for publication in our own university journal which had no circulation worth mentioning. I am mentioning these facts because I might claim to be the originator of the *Theory of Selective Radiation pressure*, though on account of the above discouraging circumstances, I did not pursue the idea and develop it. E. A. Milne apparently read a note of mine in *Nature*, because in his first paper on the subject 'Astrophysical Determination of Average of an Excited Calcium Atom', in *Month. Not. R. Ast. Soc.*, he mentioned my contribution in a footnote, though nobody appears to have noticed it. His exact words are: 'Theses paragraphs develop ideas originally put forward by Saha. [1]

S. Rosseland in the introduction to his well-known *Theoretical Astrophysics* (Oxford University Press, 1936) has observed:

> Although Bohr must, thus be considered the pioneer in the field, it was the Indian physicist Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory. Saha's work is in fact the theoretical formulation of Lockyer's view along modern lines, and from that time, the idea that the spectral sequence indicates a progressive transmutation of the elements has been definitely abandoned. From that time dates the hope that a thorough analysis of stellar spectra, will afford complete information about the state of the stellar atmospheres, not only as regards the chemical composition, but also as regards the temperature and various deviations from a state of thermal equilibrium, the density distribution of the various elements, the value of gravity in the atmosphere and its state of motion. The impetus given to Astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas. [2]
>
> Unfortunately a number of ill-informed writers have been insinuating that the suggestion about thermal ionization was given to Saha by Prof. Albert Fowler. This is absolutely incorrect, as a reference to contemporary literature will show. The law of thermal ionization was first published in a paper entitled 'Theory of the Solar Chromosphere' communicated to the *Philosophical Magazine, London*, from India, before Saha had even contacted Fowler. In the meantime, Saha had gone to England (1920) and it was published while he was there. The most important paper 'On a Physical Theory of Stellar Spectra' was first written in India under the title 'On the Harvard Classification of Stars' and was communicated from India, but at Fowler's suggestion, it was withdrawn from the *Philosophical Magazine*, rewritten at the spectroscopic laboratory of the Imperial College of Science and Technology, and was communicated by Fowler to the Royal Society. The magnitude of Fowler's help has been indicated. The third paper 'Elements in the Sun' was also communicated from India.
>
> Probably these controversies would not have been raised, and better recognition would have been given to Saha if the facts were better known. If Prof. Lindemann, Kramers or R. C. Tolman were the authors of these works, they would have received far better recognition. [3]

References

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2. D. S. Kothari, *Meghnad Saha: Biographical Memoirs of the Fellows of the Royal society*, **5,** 217 (1960)
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Chapter 8
Saha at Allahabad

On returning from Europe, Saha accepted the Khaira professorship in November 1921. The Guruprasad Singh Khaira chair was created from a donation. At the university, Ashutosh was collecting funds, starting departments, revising curricula, etc. The Governor, Lord Ronaldshay, who was also the Chancellor of the University, praised the work done by Ashutosh's postgraduate departments but said immediately:

> In a poor country there are obvious limits to the extent, to which such studies can be financed by public funds. The legislature will, I hope, be prepared to make some additional contribution towards the university in the present difficulties. But the legislature itself with extremely exiguous resources is faced with many urgent demands. And under the circumstances it appears to me that the University, may have to consider whether it is bound to provide post-graduate teaching on every subject in which it is prepared to examine and confer awards.

The 1922–1923 budget provided Rs. 9 lakhs for Dhaka and 1.41 lakhs for Calcutta University. In the 1922 convocation address, Sir Asutosh said: 'the plans for expansion were neither casual nor arbitrary. The government informed its willingness to give a grant of Rs. 2.5 lakhs, subject to certain conditions'. But Asutosh declined this offer saying:

> we shall not be a part of the secretariat of the government….If you give me slavery on the one hand and money, on the other, I despise the offer. We will not take the money. We shall retrench and we shall live within our means. We shall go from door to door and make the people of Bengal realize their responsibility. Our post-graduate teachers will starve themselves rather than give up their freedom. [1]

It was like a declaration of war with signs of intensifying further. Saha was caught in this situation. He could not get research assistant and buy equipment and had problems with laboratory space.

Amidst the trials and tribulations, Saha was working on thermal ionization of elements. His paper 'On the temperature ionization of elements of the higher groups in the periodic classification' published in *Philosophical Magazine* in 1922 was important for the studies of atomic physics. In his earlier papers, he had given the theory of thermal ionization of gases and its application to problems of radiation and astrophysics.

P.V. Naik, *Meghnad Saha*, Springer Biographies,
DOI 10.1007/978-3-319-62102-9_8

The theory was limited to the ionization of gas consisting of atoms of a single kind. Milne and Russell had extended the theory to mixtures of elements. By a comparison of the sunspot and the solar spectrum, Russell found that the predictions of the theory, with reference to the relative intensity in the hotter and the cooler spectrum of lines associated with ionized and non-ionized atoms, were found to be in general agreement with the facts. Russell had also shown that the temperature of the sun and the sunspots came out to be much more according to the figures obtained from general intensity measurements, when mixtures of different elements were considered instead of one single element. But discrepancies had also been pointed out by Russell.

Sodium and barium had got practically the same ionization potential, 5.11 V and 5.12 V, respectively, yet both in the sun and in the sunspot, barium was a good deal more ionized than sodium. The resonance line of barium, 5535.93 Å, was absent or very faint both in the solar and the spot spectrum, and it was represented only by the enhanced lines (Ba^+, $\lambda = 4934.07$ Å, 4554.04 Å) which showed that barium was completely ionized not only in the sun but also in the spot. The resonance lines of sodium, $\lambda = 5889.97$ Å and 5895.94 Å, on the other hand, were very prominent in the solar spectrum and were greatly intensified in the spot, which showed that in the sun, a large percentage of sodium was unionized and in the spot the percentage was increased due to a lower temperature.

The relative intensities of the lines of alkalies (Na, K, Rb, Cs) and the alkaline earths (Mg, Ca, Sr, Ba) in the sun and the spot spectra showed that barium was at least as highly ionized as rubidium. Strontium was only slightly less ionized than rubidium, both in the sun and the spot. Calcium was less ionized than potassium.

When Saha compared the intensity of the lines of calcium and sodium, he found that in the sun, they were almost equally ionized and calcium a bit more, but in the spot, the recombination between Ca^+ and electron was much less marked than between Na^+ and electron.

Saha suggested that according to accepted theory, the elements of the first group, Li, Na, K, Rb and Cs, had only one electron in the outermost orbit, while metals of the second group, Mg, Ca, Ba and Sr, had two electrons in the outer orbit. Besides, those two electrons were equally situated – in other words, whenever a calcium atom is subjected to the action of any physical agency, tending to tear off the elements, it would act equally on both of the valence electrons. In the case of alkalies, it would act on one electron only. It was assumed that the strength of the ionizing agent was not so large as to tear off any one of the inner electrons.

He considered the case of electrolytic solutions. The electrical forces acted equally strong from all directions, and the calcium atom lost both electrons, whereas sodium atom lost under the same conditions only one electron. It proved that in the normal case, both the valence electrons in calcium occupied nearly identical positions in the atomic system – they were positioned in the same part of the atomic volume and were fixed to the system with forces which were either identical or very nearly identical. He considered that a sodium atom and a calcium atom were subjected to the same ionizing agencies, say, bombarding electrons, light pulses or thermal collisions. He assumed it was the case of same-strength bombarding electrons; Ca gas would be roughly twice as highly ionized as Na gas.

The recombination of Ca^+ and e was more difficult than between Na^+ and e. Since there was already one valence electron in outermost orbit of Ca^+, it appeared, as per the language of Stark, there was a negative patch on one side. An electron could not be captured if it approached Ca^+ from that side. Thus, the probability was less than in the case of Na^+.

Then Saha considered the presence of two species and, applying thermodynamic equations, calculated effective ionization potentials. Taking temperature of spot and sun as 5000 K and 7000 K, respectively, he proved that in the sun, Ba was ionized like Cs, in the spot like Rb. It explained the complete ionization of Ba, in the sun as well as in the spot. In the sun, Ca was more ionized than Na, while in the spot it ought to be a bit less ionized than Na. That explained satisfactorily the behaviour of the Ca-lines in the sun and spot. Then he applied the theory to group IV and V elements.

Saha was planning for an experimental setup in X-rays. The Physics Department was ill equipped. Professor C.V. Raman was head of the department. He carried out his experimental research at the Indian Association for Cultivation of Science (IACS). There arose a serious difference of opinion between Saha and Raman. Sir Asutosh preferred Raman which compelled Saha to look for an opportunity elsewhere.

Saha was getting Rs. 500 per month plus house allowance as a Khaira professor. In a letter to the Syndicate, he made an appeal for financial assistance. 'I am, however, willing to continue to serve my alma matter, provided the university is willing to grant me a graded scale of pay, namely Rs. 650-50-1000 plus Rs. 15,000 to be placed immediately at my disposal as my personal research grant'. The syndicate's reply was, '…..in view of the present financial position of the university and in view of the claims of other university teachers, his request can not be complied with' [2].

Saha decided to leave the university. In the hostility between Asutosh and the university authority, public opinion was in favour of Asutosh. Saha's decision to quit had an adverse effect among the public. The *Calcutta Review* also criticized Saha.

When we think from Saha's point of view, Saha had justifiable reasons for his decision. A young scientist, hardly 30 years old, who earned considerable reputation and wanted to do some research and set up a laboratory, was caught up in unfortunate circumstances. There was no alternative other than to quit Calcutta and search for an opportunity somewhere else, where he could renew his research.

He received offers from Aligarh Muslim University, Banaras Hindu University and Allahabad University. He preferred Allahabad. It was one of the oldest universities in India, set up 30 years after Calcutta, Bombay and Madras. Another probable reason was that two of his senior friends, A.C. Banerjee and N.R. Dhar, were already working there. Even the pay scale of professors was higher at Allahabad, plus he was also to be the head of the Physics Department. He left Calcutta for Allahabad in 1923.

At this time, Saha was young and he did not have any experimental facilities. The overall atmosphere was not favourable for research in India under British rule. It seems, therefore, Saha must have selected theoretical research. In the 1920s, physics was undergoing radical changes. There was no dearth of bright students, but university education was in the dismal state. Many physicists were mere spectators due to lack of facilities, encouragement and recognition.

Meanwhile he continued his work on the physical properties of elements at high temperatures. From the expression of the reaction isobar of the ionization of the H-atom, Saha concluded that the ionization of the H-atom or association of the proton (H^+) and the electron seldom or never occurred without the absorption or emission of the appropriate radiation.

A mass of gas at ordinary temperatures and not subjected to ultraviolet light, Roentgen light or any other familiar ionizing agent possessed no electrical conductivity, because there were no free charge carriers of electricity present. But when the gas was raised to a high temperature and partially ionized, it would acquire considerable conductivity. For this Saha cited the examples of J.J. Thomson and McLennan's experiment on mercury vapour and his own experiment, performed in Nernst's laboratory in Berlin. In that paper, he calculated the electric conductivity from the Drude-Thomson theory, which showed that the electrical conductivity varied inversely as square root of concentration of atoms. But in his experiment, he found that conductivity diminished gradually as the vapour content diminished.

Therefore, he concluded that either one cannot calculate the percentage of ionization from the law of reaction isobar at very low concentrations or the Drude-Thomson theory of conduction, which made the conductivity proportional to the percentage of ionization and not to the total number of ionized particles present, failed to give a true picture of the phenomenon. In representing the complicated reactions, which occur when a free electron encountered a Cs^+ or Cs-atom in normal or higher orbits, the idea of elastic collision was of no avail; the exchanges of energy through radiation must be taken in to account.

To present more experimental proof for his theory of thermal ionization, he set up a furnace, which was adapted from Prof. Compton's furnace with some modifications. Due to limited resources, the apparatus had limitations. The temperature could not be raised higher than 1250 °C. With his devoted friend N. K. Sur, he performed the experiment on that furnace and proved that vapour of Zn, Cd and Hg was not ionized at all by heat up to temperatures of 1250 °C. It was expected as the ionization potentials of these elements were rather high, namely, 9.45, 9.40 and 10.45 volts, respectively. The ionizations of sodium, calcium and magnesium were observed at 900 °C, 1100 °C and around 1300 °C, respectively. He published that work in 1924.

In the same year, he worked on 'active modification of nitrogen'. He was up to date with theoretical as well as experimental research in physics, in spite of a heavy teaching load and poor working conditions. Lord Rayleigh had performed a series of experiments on an active modification of nitrogen. The nitrogen was well known to be an extremely inert gas, but Rayleigh showed that if a condensed spark discharge was sent through nitrogen gas, the glow persisted in the gas flowing out of the region of the discharge, which showed considerable chemical and spectral activities. One of the points to be explained was that chemically pure nitrogen showed no afterglow at all. Saha explained it as in various experiments performed by Rayleigh, Tiede and Domcke and Pirani, authors seemed to have looked only for the after luminescence of the chemically pure gas as a test of activity. They did not evidently apply the chemical tests. That point was of some importance, because the afterglow was simply the sign of the return of the molecule from the higher quantum state to one of the intermediate unstable states; it did not indicate the reversion to the normal state. Hence, if under certain conditions the intermediate orbits, that is, final orbits of the afterglow band, were not stable, those would not be emitted at all, though the gas would exhibit all the chemical and spectral activity recorded by Rayleigh.

It seemed to be a general occurrence that the activated atom, when left to itself, had always a tendency to fall to the lowest (energy) quantum state, without stopping at the intermediate stages. Hence, only the primary bands would be emitted. Their explanation of the absence of afterglow in active nitrogen, if true, would mean that nitrogen may be loaded to energy of about 8.5 volts, without being luminous, and therefore would still possess all other properties associated with active nitrogen.

The United Provinces had accepted the recommendations of the Sadler Commission and according to that Allahabad University had changed from the affiliating type to the teaching type. But the earlier staff was of service system mentality. New recruits superseded them, and it was a source of trouble in almost all universities. Due to its central position and tradition, Allahabad University received good students not only from United Provinces but also from Central Provinces and Rajasthan. The University authorities were expecting research from the teachers and not merely teaching which was difficult for the older teachers.

Apart from this, Saha found that the atmosphere at Allahabad was totally different from Calcutta. In Calcutta University, teachers were expected to take M.Sc. classes and conduct research work, but in Allahabad, teachers had to manage teaching of B.Sc. classes as well as M.Sc. classes, and the number of students was ever increasing. A considerable amount of time was spent in administration. The only advantage was that Saha being head of the department, his authority was final in the departmental work, and there were no frequent arguments like in Calcutta.

The physics laboratory was well equipped for B.Sc. students, but there were no apparatus for higher-level research. The workshop had no electricity. Saha had to build everything from scratch. The library needed updating. Saha ordered many new books for the library because it had mostly very old publications. The University treasurer Pandit Kanhaiyalal Dave, a retired High Court judge, asked Saha, ‘Have you read all these books available in the library?’ Saha replied ‘No and nobody can do it’. Then the treasurer said, ‘Better read the books available and then only ask for new books!’ Everywhere there were people who wielded power but had no appreciation of academics. Even after 90 years, the situation has hardly changed!

At Allahabad, Saha spent some of his initial years in reorganizing the department and preparing lectures and experiments. He regularly lectured to the undergraduate and postgraduate classes. Even in those days, he used lantern slides. He made use of demonstrations frequently.

Calcutta University had a research atmosphere, which was lacking in Allahabad. He encountered stiff resistance from authorities for improving the workshop, the laboratory and the library. The teaching load was so heavy that during the regular session, there was no time for other activities. Only the summer vacation was available for research. The temperature of north India in summer was around 47 °C. It was like working in a furnace. But his collaborators, mainly his students, continued the work. Saha put new life and enthusiasm in the Physics Department. In a few years, Allahabad's contribution towards research became considerable which earlier was almost negligible. Many young talented and promising students from all parts of Northern and Central India gathered around Saha. His time was spent in teaching and guiding inexperienced young men. Hardly was there time for research.

In 1925, Saha was elected president of the physics and mathematics section of the Indian Science Congress. He spoke on *thermal ionization*. While introducing the subject, he said:

> … we are living in an Augustan age of discovery in the physical sciences. Even leaving spectacular achievements of our science aside, you will probably agree with me, that no period in the history of or science has been so rich in discoveries of the first magnitude as the period 1895–1920: X-rays, radioactivity, the electron theory of matter, the quantum theory of radiation, and the last, though not least, the Theory of Relativity – all these taken together constitute a revolution in human thought, a revolution which can not but profoundly modify the future of mankind.

Then he described the theory of thermal ionization and its use in the study of sun and stars.

He was closely following the developments in physics, especially quantum and atomic physics around 1925. In his paper of 1927, 'On the detailed explanation of spectra of the metals of the second group', he used Stoner's rule of 1924, Pauli's exclusion principle of 1925, etc. When the atom was excited, one electron was supposed to be at rest and the others run through all the higher levels. The spectrum observed was due to the combination of the orbits of those two outermost electrons. The rules of combination of orbits were first given by Pauli and developed by Hund and Heisenberg. Saha developed a very convenient method of representation with a complete structure diagram. He showed that the scheme of electron arrangement, which was a modification of Stoner's scheme, combined with the rules of synthesis of complicated spectra from the elementary component double spectra, gave a very satisfactory explanation of the fundamental as well as of all the higher terms regular and anomalous of the alkaline earths. Even the detailed differences, for example, occurrence of large D terms in Ca, Ba and Cr and its absence in Mg, were readily explained. His theory gave a clue to the origin of barred terms. They were aroused when the stationary electron was in the metastable orbit and the running electron was in the same orbit or in the higher homologous orbit. When both electrons in Ca were in M_3 levels, they got ^3F, ^3P, ^1G, ^1D and $^1S_0$ terms. Their order of value was the same. But if the running electron was in a higher shell, it would give rise to higher Rydberg terms: the values would decrease approximately as N/m^2, $m = 1, 2, 3$, respectively. The investigation also showed that differences were expected between the spectra of Ca and Ba. It was also apparent that for the calculation of the higher Rydberg terms, Pauli's exclusion principle was not necessary, and there was no need of the complex calculation involving the magnetic quantum number.

After studying the spectra of neon, he had shown that the complicated spectrum of neon was very simply explained, on the theories of complicated spectra. The theory accounted for not only the fundamental levels but also for all the higher levels, the Rydberg sequence and the order of values observed in each case. It also gave a very cogent explanation of the origin of the barred terms and explained such transitions apparently break the selection principle.

In those days, the means of communication and networking were very poor. For a young researcher, working in isolation with limited or almost nil resources in pre-independent India was really difficult. It took almost 1 year to publish a paper. Therefore (probably), Saha published some of his papers in Indian journals.

In 1928, he extended Millikan and Bowen's arithmetic progression rule, that is, irregular doublet law in optical region, to the case of complex spectra and had shown to hold good results. He also made predictions regarding the spectra of certain elements which were unknown at that time, for example, S^{++}, Mg^{+}, etc.

Along with the complex spectra, he studied the origin of the solar coronal spectrum. Milne had shown from transition probabilities of the Ca^{+} atom that Ca^{+} emitting the H-K lines was subjected to such a large radiation pressure and that it almost overcomes the force of gravity. Saha extended the argument to other elements. He left out H and He because their resonance lines were in the extreme ultraviolet and their normal atoms would be subjected only to slight radiation pressure. But the case of Li was not like that. The resonance line of Li was at 6708 Å, the corresponding $E_{\lambda} = 0.8\ E_{\mathrm{m}}$, and the maximum emission E_{m} of the sun was regarded as a black body at 6500 K; hence, the force of radiation would be more to balance the force of gravity and it would be expelled entirely from the solar atmosphere. It could be retained only in the ionized form. The entire absence of Li-lines from the Fraunhofer spectrum seemed to support that view. If Li^{+} would be present, it may or may not be detectable, as the fundamental lines were in the Schumann region and the excitation required to bring out the next important line would be too large. The only favourable line was 5484.69 Å or 5484.90 Å, which belonged to the singlet system of Li^{+} ($2S$–$3P$). Similar considerations would apply for Be^{+} and B^{+}.

Before considering the case of carbon, he discussed the case of silicon, because the full details of silicon's spectrum were known to researchers. From Fowler's data, it was seen that the $3P$–$3P$ lines were the most fundamental, but their wavelength was at 2514–2528 Å, while the less fundamental ${}^{1}S_{0}$–${}^{1}P_{1}$ and ${}^{1}S_{0}$–${}^{3}P_{1}$ lines were at 4103 and 3905 Å. In fact the silicon was detected in the sun by those two lines, some other subordinate lines and some lines of Si^{+}.

Majumdar and Kichlu had performed experiments with thallium and not with silicon, because the former was more easily manageable. From their studies, they made conclusions about silicon. The emissivity of the sun was almost a maximum at 4102 Å and 3905 Å; at 2500 Å, the emissivity was about 0.57 of the maximum. When silicon atoms were traversed by a radiation field, the transitions corresponding to the emission of ${}^{1}S_{0}$–${}^{1}P_{1}$ and ${}^{1}S_{0}$–${}^{3}P_{1}$ of silicon would be very frequent, while the transitions ${}^{3}P_{012}$–${}^{3}P_{012}$ would be too small. The proportion between the fundamental ${}^{3}P$ and metastable ${}^{1}D_{2}$ and ${}^{1}S_{0}$ levels would be maintained by the prohibited transitions ${}^{3}P_{1}$–${}^{1}S_{0}$ and ${}^{3}P_{12}$–${}^{1}D_{2}$. If the transitions from the excited ${}^{1}P_{1}$ and ${}^{3}P_{1}$ states to the ${}^{1}S_{0}$ state were as numerous as in the case of calcium, then silicon, being much lighter than calcium, would be thrown out into the corona in the metastable state ${}^{1}S_{0}$. Hence, the coronal spectrum would show the prohibited transition.

Then he considered the example of carbon. It had an ionization potential of 11.3 volts, and the spectrum was in all respect similar to silicon. The fundamental ${}^3P$–${}^3P$ lines were at 1656–1658 Å, but the metastable ${}^1S_0$–${}^1P_1$ line was probably the line 2478 Å. Hence, it could be stated that metastable carbon atoms, being very light, would be thrown into the corona and there give rise to prohibited transitions ${}^3P_1$–${}^1S_0$ and ${}^3P_{12}$–${}^1D_2$. The electric field in the corona would increase the number of transitions. The frequencies of such lines were of the same order as the frequencies of the more intense coronal lines. He further suggested that similar prohibited transitions between the fundamental levels of N and O, P and S and P^+ and S^+ may account for some of the coronal lines.

In 1927, at the age of 34, Saha was elected as a fellow of the Royal Society (FRS) of London. This was a big incentive for him as well as the university. The problems and difficulties at work were the same as usual. But fortunately Saha found one ray of hope. He received a letter of congratulations from Sir Williams Morris, the Governor of United Provinces (Uttar Pradesh). Saha thanked the Governor and, being aware that he was a classmate of Lord Rutherford, told him of the pathetic state of the laboratory. The Governor was a real gentleman. He immediately sanctioned a research grant of Rs. 5000/per year. In 1927, this was a considerable amount. Something was better than nothing.

In 1927, the Italian government invited Saha to the Volta centenary celebrations. He attended it and later wrote a report in the *Bengali* journal *Prabasi* in 1928. (He is seen in his family photograph before leaving for Europe in 1927. See Fig. 8.1.)

Fig. 8.1 This photograph was taken on the eve of the departure for Europe of Meghnad Saha (1927). From *left to right* – Ranjitkumar Saha (second son), Meghnad Saha, Ajit kumar Saha (eldest son), Mrs. Radharani Saha (wife) and Usharani Saha (eldest daughter) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Though Saha was involved in research work, he was interested in teaching undergraduate and postgraduate classes also. He published *Text-book of Heat* in collaboration with B. N. Srivastava in 1931. The second enlarged edition in 1935 was renamed as *Treatise on Heat*. The Patna University invited Saha to deliver a series of lectures on *Atomic Physics*. Later in 1931, these lecturers were published as a monograph, *Six Lectures in Atomic Physics*, by the Allahabad University.

In 1930 Saha was working on the interpretation of X-ray spectra. He gave a radically different interpretation of the X-ray term values. The lines of X-ray spectra showed the same structure as alkali spectra, and that had given rise to the widespread belief that the X-ray term values and their differences can be calculated in the same way as term values for hydrogen or the alkalies, after the introduction of suitable screening constants. But Saha and Ray had pointed out in 1927 that the apparent analogy of X-ray spectra to alkali spectra was rather misleading. It was due to the function of the Pauli's exclusion principle, which said that the defect of a single electron from a closed shell gave rise to the same spectroscopic levels as the presence of one single electron outside a closed shell. Thus, $2p^5$…… 5 electrons in the L shell gave rise to the spectroscopic level $^2P_{1/2}$ and $^2P_{3/2}$, while one p electron also gave rise to the same levels. Since the X-ray spectra were due to the removal of an electron from some level and the subsequent jumping of an electron from some outer level to that of another, it followed that the term values had to be calculated in a widely different way than was usually followed. Saha collected, calculated and observed values of screening constants for K level for known elements. In Sc, the $3D$ shell was beginning to form. The value became approximately constant for Rb (37) to Ba (56), 3.54–3.64–3.48, and gave rise to an earlier belief that σ_k was constant for all elements. But beyond Ba, σ_k rapidly diminished, and at U (92) σ_k became negative, that is, there was no screening at all. Then he calculated screening constants for L_1 and L_2 levels.

That work was rather a survey of the then existing problems. The problems suggested were to obtain a theoretical expression for the ionization potential of atoms stripped to the Be-core and Ne-like atoms, screening effect of outer electrons in the general case, potential inside the atom, negative squared terms in the screening constant and doublet separations, to calculate energy values for removing two electrons out of the atoms simultaneously and to extend the same treatment to the other X-ray levels.

Initially at Allahabad, Saha resided in a rented house, but later on he built his own house *Science Villa* at 7 Beli Road (see Fig. 8.2). It was an open house for his students. Kichlu, Kothari, Majumdar and many others, had stayed there for some time or most of the time. About his memories, N.K. Saha wrote:

> At an emotional moment, I, a complete stranger to Meghnad Saha wrote a letter to him, expressing my keen desire to go to Allahabad and work under him as a humble research student. The reply came promptly, a most unexpected event in my life. It was a long letter in clear and bold handwriting, in which he had pointed out the difficulties of a research career in our country and asked me, rather bluntly, to shed any sense of glory, or illusion of idealism that I might have entertained about the research career, which, he warned me, was as prosaic and exacting as any other career. He held out no promise for a research scholarship, but pledged reasonable help if I could prove my worth. To my sensitive young mind,

Fig. 8.2 Meghnad Saha's house at 7 Beli Road, Allahabad (1923) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

> the letter appeared to have a hard exterior, but had an undertone of sincerity and sympathy. Encouraged by my friends, I decided to go to Allahabad and one evening, after about a week; I arrived at 7, Beli Road, Allahabad; with my meager belongings. Saha was sitting in the lawn in front of his house and reading. He guessed my identity quickly, said a few kind words of welcome and simply asked me to stay in one of his ground floor rooms and make myself comfortable. Next morning at the tea-table, he asked me a few questions about my studies and tried to assess my knowledge of Physics. Immediately he chalked out a daily programme of work for me....

Whenever Saha observed that any student was capable of doing research independently, he encouraged him to continue with it. For example, P. K. Kichlu, D.S. Kothari and R.C. Majumdar followed independent lines of research. Some of his students are seen in Fig. 8.3.

Saha was eager to set up an experiment to verify the law of thermal ionization and various deductions from it. It was painstaking work, because the laboratory was not well equipped and the annual grant was also too inadequate. In 1931 he secured a special grant of £1500 from the Royal Society of London for purchase of apparatus. Earlier he had approached a very high ranking officer in the Government of India with a letter of introduction from a distinguished citizen of Allahabad, Sir Tej Bahadur Sapru, for a research grant from the Government of India. The officer who was a representative of the British Government and later on of the Government of independent India kept him in suspense for 2 years and finally remarked that the government cannot spend money for research work to be done at a provincial university.

Nobody will doubt that, in British India and even in an independent India, the bureaucracy, lacking in imagination and which could not see the things in perspective,

Fig. 8.3 Meghnad Saha's colleagues and students at Department of Physics, Allahabad University (1926). From *left to right*: Standing – B. L. Gupta, P. K. Kichlu,?, G. R. Toshniwal, R. A. Nirmal, G. R. Jain and K. B. Mathur. Sitting – K. Majumdar, N. K. Sur, Prof. M. N. Saha, S. Bhargava, B. N. Das (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

must have destroyed the spirit of science.[1] Saha never received strong and continuous support for scientific research from the government.

The apparatus he designed was fully described in the book *Treatise on Heat* (third edition). B. N. Srivastava and A. N. Tandon were involved in this work. Saha had applied a lot of thought on this apparatus. After Saha's departure from Allahabad, B. N. Srivastava continued to work with it. He proved the law of thermal ionization, verified several deductions and determined the electron affinity of the halogens. H. N. Russell, C. G. Darwin, R. H. Fowler and E. A. Milne continued and expanded Saha's theory of thermal ionization. It was a fundamental contribution to physics. It has been used in explaining the conductivity of flames and arc formation, in studying the inside condition of stars and in studying explosions.

In 1929, Arnold Sommerfeld was in India on a lecture tour. At that time, he was Saha's guest at his Allahabad home for 2 days (Fig. 8.4).

In Indian history, we find very few scholars or scientists who could see science, society and other human endeavours in the right perspective. Saha was one of them. He could correlate social problems and their probable solutions with science. He was quite aware of it right from his school and college days and constantly thinking

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[1] Thirty-two scientists, all holding high posts at research institutes and laboratories, have written to the Prime Minister of India and asked him to 'free' the management of science and technology from the thickets of bureaucracy. A part of their note says, 'eliminate bureaucracy which dominates the management of science and technology today so that the sector is freed from serious impediments' [3].

Fig. 8.4 Professor Arnold Sommerfeld was on a visit to India (1929). From *left to right*: Standing – Dr. K. Majumdar, Dr. G. R. Toshniwal,? and Shri. D. S. Jog. Sitting – Dr. B. N. Prasad, Prof. M. N. Saha, Prof. A. Sommerfeld, Shri. K. M. Basu and Dr. P. K. Kichlu (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

about it. Around 1930, he decided to do something fruitful in this direction, for example, to bring scientists together at a common platform to exchange ideas or to collaborate. Many people worked in isolation with very little communication. Those were the days when main frame and personal computers, Internet, search engines, etc. were imaginary things and far away in the future.

The meeting of the Indian Science Congress association was held in 1930 at Allahabad. Scientists from the United Provinces gathered. The Governor, Sir Malcolm Hailey, was the chief patron. He observed:

> Now I am well aware that there are definite limits to the extent, to which the efforts of our research workers or students can be directed to these problems (of economic and utilitarian value), and I am also well aware that coordination of their labours, can not be directed from outside. It must be a voluntary effort, or at the most, it must be advice given by some Academy of Science, which will contain authoritative representatives of all the specialized branches of scientific activity, now at work in the Province. But if some form of visible coordination could be attempted, and if it could be proved to the public, that science workers were contributing at least some of their energies in the direction I have suggested, then I believe we should have a far more effective case in calling for that public support and private liberality on which the further progress of scientific work must depend.

After this speech, a committee of scientists from United Provinces (U.P.) was formed. The United Provinces of Agra and Oundh was renamed as (today's) Utter

Pradesh. Later on, it was renamed as the U.P. Academy of Science (UPAS). Saha as a member of the committee was a leading person in drafting objectives, rules and regulations of the academy. He had studied the pattern of organizations and institutions in different countries. The academy was actually inaugurated on 1 March 1932 at Allahabad, in the presence of scientists and public, and presided over by Sir Malcolm Hailey. In spite of the economic depression of 1931, Governor Hailey sanctioned a grant of Rs. 4000 per year to the academy at Prof. Saha's request by realizing the importance of work. The academy unanimously elected Saha as the first President. In his presidential address, he stressed on the application of science and technology to solve the economic problems of India. In the concluding parts of his address he said:

> In fact it has appeared to many thinking men, that many of the evils of the present day world, are due to the non-adaptation of the human organizations to the changing conditions of the world. Owing to improved methods of communication and to much better contact between its different parts, the world is fast becoming one economic and cultural unit. But politicians still persist in their Olympian attitudes.
>
> Before the great World War, the politician was at a stage where the physicist found himself before the time of Archimedes, or better in the days of Homer and Hesiod. His country was his Olympus, his own people were his gods, all others were demons, barbarians, fit only to be secured against the stroke of the sword, or exploited as helots. The Great War (World War I), and all other wars before it, were the result of such a mentality, but the Great War exceeded all previous wars in the intensity of destruction and havoc, because science placed more power in the hands of men. But it did one great thing; *it exposed the absurdity of international quarrels*. When the late M. Clemenceau visited Egypt, and was taken round the Pyramids, he commented rather sarcastically on the vanity of the Egyptian Pharaohs, who built huge stone monuments with slave labour for the sake of housing their Ka (Soul). He was reminded by a Cairo paper, that if the *Soul of Cheops*, the builder of the Great Pyramid could be released from his stony sepulcher, he could have retorted, that the Treaty of Versailles and the expenditure on Dreadnaughts, and on military armaments and sacrificing the finest youths of the country, before the bloody alter of Nationalism, were far greater absurdities; as one-tenth of the money wasted in the war, if spent on internal development of the natural resources, would have given every belligerent country a far greater amount of security and prosperity than the politicians ever dream to achieve by methods peculiar to them. [4]

At UPAS Saha invited eminent personalities to address the meetings. At these meetings, scientists discussed educational as well as national problems and their solutions.

Along with his activities with UPAS, he was busy with his research also. While studying complex X-ray characteristic spectra, he focused his attention on the existence of characteristic lines which were due to double ionization and double transition. He assumed that in one single act of bombardment of the anode by electrons, two electrons were removed simultaneously from an internal level, say, one from L_1 and another from L_2, and those places were filled up by simultaneous passage of electrons, from higher levels, say, one from M_1 and another from M_3. It could be shown from quantum principles and from analogy with optical spectra that one of the transitions would be allowed, and the other would be forbidden, so that the transition might be written as $L_1L_2 \leftarrow M_1M_3$; it was a composite transition and was the sum of the two transitions (1) $L_2 \leftarrow M_3$, which was allowed, and (2) $L_1 \leftarrow M_1$, which was forbidden. The lines due to such transitions were quite common in optical spectra, for example, the case of Ba, $6s^2.{}^1S_0$–$5d.6p.{}^1P_1$, $\lambda = 3501.1$ Å cited by Russell and Saunders.

The frequency of double transitions would be approximately twice as that of the usual L-lines, and since the electron configuration in that case was $2\ s.2p^5 \leftarrow 3\ s.3d^9$, the lines would form a multiplet (1P, 3P) ← (1D, 3D) provided the Russell-Saunders coupling would continue to hold. The double frequency characteristic marked them as a distinct class.

In Saha's laboratory for tungsten anode, they obtained two lines with the wavelengths $\lambda = 723$ and 682 X.U. They were diffuse lines imposed on a continuous ground. The wavelengths were approximately half the wavelength of tungsten L-lines. In 1923, Rogers noted the lines from tungsten as $\lambda = 1450$, 1373, 1321, 1248.7, 1230, 1114 and 1086 X.U. The lines had been traced to the tungsten levels or identified as satellites or non-diagram lines and could not be ascribed to any other element. It would be seen that the wavelengths of the first two of Rogers' lines were very nearly twice as that of the lines obtained by Saha and his co-workers (S. Bhargava and J. B. Mukerji). Hence, they concluded that the lines obtained by Rogers were the same double transition lines obtained in the second order. They established the possibility of getting double transition lines constituting complex spectra in the X-ray region.

Around this time, Saha was deeply preoccupied about many national and social problems. He said 'before embarking on any large scale mission first study that problem in the laboratory with all details and then proceed'. In his presidential address of 1934, at the Indian Science Congress, held at Bombay, he emphasized the need of better organization of scientists in India to try to impress upon the government, states and other public bodies, for encouragement of scientific research and for scientific handling of economic and industrial problems of the country. He pleaded for the formation of an Indian Academy of Science.

'The Indian Academy will therefore be a Central Society, on which all branches of science will be represented, or to borrow a simile, it will be similar to the Royal Society in England, or The Prussian Academy in Germany, the apex of a pyramid of societies devoted to particular subjects. It should therefore have limited membership. Its membership should be regarded as a mark of distinction and honour, and the academy should be associated with the state in a number of responsible duties involving scientific work. If the Academy is started on the above lines, I think it may undertake the following works:

(i) It will publish *Comptes Rendus* or proceedings like those published by the National Academy of Sciences, United States of America, which will contain only the results in long or short abstracts. It should not in general undertake the publication of a journal devoted to a particular subject. These will be left to the societies and services. It may in addition publish memoirs and transactions.
(ii) It should take over the organization of the Indian Science Congress.
(iii) It should try to persuade the state to form National Research Committees, in which the academies should have fair representation.

(iv) It should secure and manage funds for scientific research.
(v) It may act as a liaison body, between societies for various branches of science, provincial academies, universities, services and private organizations for scientific research.
(vi) It may undertake and promote enquiries regarding problems of national welfare.
(vii) It should represent India on International Bodies for International Cooperation [5].'

The Indian Science Congress Association accepted the idea and formed a Committee to formulate the constitution of the academy. Sir L. Fermor (director of the Geological Survey), president of the Asiatic Society, who was elected as the next general president of Science Congress, was chairman of this committee, and 80 scientists from all over India were named as members. Professor Saha and S.P. Agharkar were organizing secretaries. The committee faced one serious problem. Sir C.V. Raman resigned from the committee and announced the formation of the *Indian Academy of Science* at Bangalore. The UPAS was renamed as the *National Academy of Sciences* in 1934. But Saha's proposals eventually led to the establishment of the *National Institute of Sciences of India* in 1935. The Central Government gave recognition to it, as the main institution empowered to act as the highest body for co-coordinating the activities of other academic and scientific societies.

On 7 January 1935, J. H. Hutton, the president of the Indian Science Congress for that year, formally announced the formation of National Institute of Sciences of India. Sir L. L. Fermor was the first president. Saha became the second president for the term 1937–1939.

In 1944–1945 on Saha's initiative, the headquarters of the National Institute of Sciences was transferred to Delhi. Later it was renamed as the Indian National Science Academy (INSA).

In 1934, Saha developed interest in ionospheric research. He studied the ionization by ultraviolet light, the ultraviolet spectrum of the sun, the passage of ultraviolet light through the earth's atmosphere, the atomic nitrogen in the night sky spectrum and the oxygen and the ozone problem.

The radio methods for the quantitative investigation of the ionized layers showed that the ionization of upper atmosphere was not uniform, but there were marked discontinuities at different heights, where the electron density changes rather suddenly and radio waves were very strongly reflected, as first postulated by Kennelly and Heaviside in 1902. Four ionized regions E_1, E_2, F_1 and F_2 had been found. In addition to these layers, further claims had been made of a D layer at a height of 55 km by S. K. Mitra and P. Syam and of a G layer by Kirby and Judson. The ionization of the E_1, E_2 and F_1 layers was mainly due to the ionization by the solar ultraviolet light. It was proved by the observations made in Canada by Henderson during the total solar eclipse of 1932; the ionization of the E layer was found to diminish within the eclipse zone simultaneously, with the beginning of totality.

Further support was given by the observation that the variation of the ion content with the time of the day for the E_1, E_2 and F_1 layers followed closely the laws, deduced by Chapman, Pedersen and others, who ascribed the ionization to ultraviolet light from the sun. But there was a great difficulty in accounting for the origin of the F_2-layer ionization on that basis. Saha showed that though the mathematical works of Chapman, Pedersen and others gave the correct formula for the variation of the electron content of the atmosphere, with the time of the day and season, the physical assumptions regarding the cause of ionization required revision, in view of the latest laboratory work on the molecular and atomic spectra of oxygen and nitrogen. The main constituents of the upper atmosphere were molecular O_2 and N_2 and probably atomic O and N; hydrogen appeared to be definitely excluded and no helium had been found. Even if it existed, the argument would not be changed much. The ozone had been found to be confined between 20 km and 50 km and played some important part in the phenomena observed in the lower layers.

Chapman's calculations were based on two assumptions:

1. The sun radiated like a black body at a temperature of 6000 K, even for the ultraviolet region.
2. The solar radiation below $\lambda = 1350$ Å (energy 9 eV) was capable of producing ionization of some constituents of the upper atmosphere.

The total intensity of radiation from the sun, having a wavelength less than 1350 Å, was 1.61×10^{-5} times the total solar energy. So the total intensity of ionizing radiation received from the sun was

$$\frac{1.61\times10^{-5}\times1.93\times4.16\times10^{7}}{60} = 22\ \mathrm{erg/s}$$

The energy required for producing a pair of ions was given by

$$(9/300)\times4.77\times10^{-10} = 1.4\times10^{-11}\ \mathrm{erg}$$

So the solar rays can produce

$$\frac{22}{1.4\times10^{-11}} = 1.6\times10^{12}\ \text{ion pairs/s}$$

when they were normally incident on the atmosphere.

The equation of ion equilibrium was given by

$$dn/dt = I - \alpha n^2$$

where I, α and n were rate of production, coefficient of recombination and number of ions per c.c., respectively. Chapman calculated $\alpha = 10^{-9}$, using the data of variation of the electron density obtained by radio methods. At midday, the stationary conditions were reached, $I = \alpha n^2$. For $n = 10^3$ per c.c., $I = 10^3$. Taking the depth of the atmosphere as 300 km, the total number of ions produced per second was $3 \times 10^7 \times 10^3 = 3 \times 10^{10}$. That was much less than 1.6×10^{12}, the number which the solar rays was capable of producing.

After going through Chapman's calculations, Saha found that no constituent of the atmosphere had a low ionization potential such as 9 volts. He gave the reaction potentials of all the constituents. It was seen that O_2 had the lowest ionization potential, viz., 12.1 volts. An intensity of sunlight consisting of quanta whose energy content was larger than 12.1 eV was 1.5×10^{-7} times the total energy. But the whole of it was not equally effective in producing ionization. The spectrum had been assumed to extend from $\lambda = 1019$ Å to $\lambda = 0$. It would not be wrong if one assumed that only one third of the amount, that is, 0.5×10^{-7}, was effective. Then the energy of ionizing radiation falling on one square cm of the earth's surface was 0.11 erg/s. Hence, repeating Chapman's calculations, Saha found the number of ions which could be produced was 0.6×10^{10}. By considering the obliquity of the rays and other factors, it was to be still further reduced. That number was less than the 3×10^{10}, which was required, according to Chapman's calculation to maintain the ionization of the upper atmosphere.

There was no direct evidence that O_2 was ionized by the solar rays to O_2^+, because no lines due to O_2^+ had been discovered in the night sky spectrum, though that evidence alone was not conclusive against the presence of O_2^+ ions. But the N_2^+ bands, the first negative bands of nitrogen, had been found in the night sky spectrum. Those bands were very prominent in the polar light, and they were rather feeble in the night sky. As the excitation potential and the electron structure of the state giving rise to these bands were very accurately known, they were very helpful in understanding the mechanism of ionization of the upper atmosphere.

Slipher observed N_2^+ bands from the evening and morning sky, whereas Sommer, Vegard, Du Fay, Cabannes and Gauzit observed on the quiet night sky. Saha inferred from Slipher's observation that sunlight produces N_2^+ in the excited state directly, and in course of the night, the de-excitation by emission of the lines of negative band continues.

Saha further said that all experimental evidences showed that the sunrays were capable of ionizing the constituent molecules of the upper atmosphere, at least N_2. At the same time, it was found that the sun, when regarded as a black body at a temperature of 6000 K, was incapable of emitting in sufficient intensity radiation of such short wavelength as would maintain the ionization.

Saha gave a detailed summary of the night sky spectrum and discussed the ionization of N_2 and the occurrence of band lines of N_2^+ in the night sky. He concluded that the occurrence of the bands in the night sky was merely a consequence of recombination of N_2^+, produced by sunlight with free electrons during the night, and all its details were explained by the peculiar spectral properties of the N atom and the N_2^+ molecule. The emission of N_2^+ band was due to de-excitation of excited N_2^+, which was produced by sunlight to normal N_2^+. As the recombination continued throughout the night, the bands were observed throughout the night.

Then he discussed the occurrence of oxygen spectrum, but he was less sure because the knowledge of molecular spectrum of neither O_2 nor O_2^+ was as satisfactory as that of N_2.

In 1936, the Royal Society of London gave some grant to Saha for his research. From that grant, he designed and constructed a new model of a demountable vacuum furnace. He described its design in the Proceedings of National Academy of Sciences (India), 1936. It was a vacuum graphite furnace, suitable for high temperature research. Its special feature was that the parts could be taken out and reset for experimental work in a very short time. It could attain a temperature of 2500 °C very quickly within the vacuum of 10^{-4} mm. Saha used that furnace for experimental determination of the electron affinity of chlorine. The method consisted vaporizing of the alkali halide in an electric furnace and then bringing it to a region of higher temperature, where the vapour molecules suffer thermal dissociation into atoms as well as into ions. The products of dissociation were made to pass through a narrow circular opening and then through a circular diaphragm into a Faraday cylinder, where they were collected, and the current was measured by a galvanometer. The process of dissociation inside the high-temperature region, where free electrons were also present, was given by a set of equations, for sodium chloride, as

$$\mathrm{NaCl} \leftrightarrow \mathrm{Na} + \mathrm{Cl} - D$$

$$\mathrm{NaCl} \leftrightarrow \mathrm{Na}^{+} + \mathrm{Cl}^{-} - Q$$

$$\mathrm{Na} \leftrightarrow \mathrm{Na}^{+} + e - I$$

$$\mathrm{Cl}^{-} \leftrightarrow \mathrm{Cl} + e - E$$

$$\mathrm{Cl}_2 \leftrightarrow 2\mathrm{Cl} - \mathrm{D}'$$

where D was the heat of dissociation of NaCl, Q was the heat of dissociation into a sodium and a chlorine ion, I was the ionization potential of sodium, and E was the electron affinity of chlorine. The D' was the heat of dissociation of chlorine into atoms. He performed experiments with three salts: KCl, NaCl and LiCl.

Using the formula for thermodynamic potential given by Gibson and Heitler and experimental observations taken from his new apparatus, he calculated the electron affinity for chlorine. The value determined experimentally was 86.6 kcal, and the theoretical value given by Born, Mayer and Helmholtz was 86.5 kcal. The result was in total agreement with the theory.

Visit to Europe

In 1936, Saha received a fellowship of the Carnegie Trust of the British Empire. With that fellowship, he visited many laboratories in Europe and the USA. He took with him his eldest son Ajit, who was just 13 years old.

He proceeded from Bombay to Basra by boat and from Basra to Baghdad by train. He visited the ruins of Ur of the Chaldees, because he was interested in the study of ancient times. From Baghdad he went to Beirut and Haifa by the desert motor route. Then he took a boat to Trieste, which was full of Jews returning from Jerusalem, and many of them were victims of Nazi oppression.

In Europe, he visited Munich at the invitation of his friend Arnold Sommerfeld. He was given a reception at the Deutsche Akademie.

In London he attended a meeting of the Centenary of the London Physical Society. The guest of honour was Max Planck, who dwelt on the needs of mutual understanding between different nations, as the best way of keeping international peace. At Oxford he spent a month along with his ex-student P. K. Kichlu, discussing astrophysics with his friend E. A. Milne.

Then he went to the USA at Harvard College Observatory, where he was a guest for about 2 months. There he came in contact with Harlow Shapley, director of the Harvard College Observatory, H. N. Russell, Donald A. Menzel, Mrs. Cecilia Payne-Gaposchkin and other researchers. He visited Lowell Observatory, Flagstaff, Arizona, where he met Slipher, who was working on atmospheric studies. He stayed as a guest in the Mount Wilson Observatory and came in contact with Director Adams, Hubble, S. Nicholson, S. A. Mitchell and Ira Bowen. Returning to Harvard, he attended the tercentenary celebration of the Harvard University (see Fig. 8.5). At Harvard he prepared a paper 'on the action of ultraviolet sun light upon the upper atmosphere' which was published in 1937.

The disappearance of sunlight below wavelength of 2900 Å had long been known, through the researches of Fowler and Strutt, Fabry and Buisson and others, to be due to the absorbing action of a layer of O_3 formed in the upper atmosphere. The works

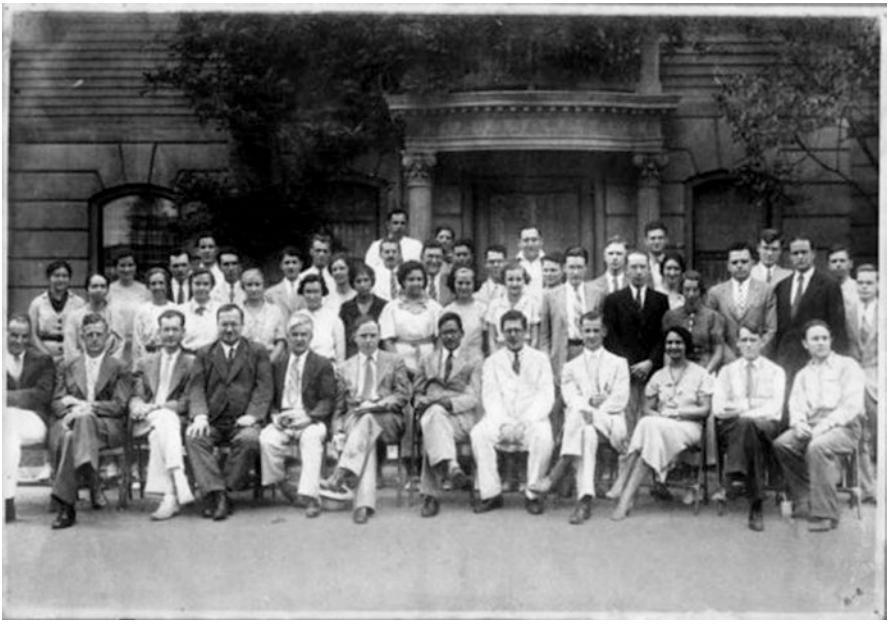

Fig. 8.5 Tercentenary celebrations of Harvard University (1936). From *left to right*: Sitting –?,?, Dr. Menzel, Dr. Lundmark, Dr. Campbell, Dr. Shapley, Prof. M. N. Saha,?,?, Dr. Cecilia Payne-Gaposhkin(?) and Dr. Merril,? (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

by Götz, Meetham and Dobson and Regener had shown that a layer extends from about 20 km, reaches a maximum concentration at 30 km and, probably, does not extend beyond 50 km. The principal photochemical reactions in N_2 and O_2, including ionization, were produced only by a light of wavelength less than 3000 Å.

He discussed the negative bands of nitrogen in the spectrum of the night sky. The negative bands of nitrogen in the spectrum of the upper atmosphere when illuminated by sunlight were very intense in the spectrum of the polar aurora, when they were produced by the bombardment of N_2 gas by electrons. The lines were also found in the spectrum of the night sky. Slipher observed these bands at sunrise and sunset. He developed the detailed energy level diagram of N_2 and N_2^+. The energies of excitation of two levels, corresponding to the first negative bands, had been obtained from both cathode ray bombardment and from spectroscopic analysis, both of which yielded concordant values. The first ionization potential (excitation of the level) was 15.55 V, and the second ionization potential (excitation of the level) was 18.68 V. But Slipher's observations showed that excitation level of N_2^+ was produced by sunlight acting directly on the N_2^+ molecules of the upper atmosphere. The bands were produced by direct photochemical action of sunlight, without the intervention of any bombarding electron.

Many researchers had subsequently discovered that, many diatomic molecules showed a similar type of strong absorption, leading to one or more higher ionization potentials; the absorption leads to the lowest ionization potential, being very feeble or sometimes totally absent.

Hopfield's experiment had proved that a light of wavelength 794 Å could not directly ionize N_2 to the N_2^+ normal state, that is, a quantum having energy content of 15.55 V (wavelength 794 Å) had no direct action on N_2, though the energy was sufficient for raising N_2 to the lowest state of N_2^+. But the quantum of energy content of 18.68 V (wavelength 661 Å) can directly ionize N_2. It supplied the clue to the interpretation of Slipher's results. Sunlight of a wavelength less than 661 Å produced direct ionization of N_2 to the excited state of N_2^+, emitted negative bands and reverted to the normal N_2^+ state. It explained the flash of negative bands at sunrise and sunset. After the withdrawal of sunlight, the excited N_2^+ ions speedily reverted to the normal state and left only with N_2^+ normal ions. They were incapable of radiating and, in the course of the night, may be neutralized by the direct capture of an electron in different excited states of N_2, but it was quite probable that when the colliding electrons had sufficient velocity, a number of N_2^+ ions might be further excited. That process might account for the feeble emission of negative bands during the night observed by Sommer and some other researchers.

The N_2 was ionized above a height of 200 km directly to N_2^+ by the direct action of sunlight. The number of N_2^+ excited molecules produced was difficult to estimate, without photometric measurement of the intensity of the bands and other relevant laboratory experiments. But Saha got an idea of the number of free electrons in that region, from the measurement of the F_2 layer ionization. Appleton and others had estimated it to be nearly 5×10^5 electrons per cm^3, and Saha assumed that a fair production of those electrons was done by the direct ionization of N_2 to N_2^+ by the action of ultraviolet sunlight. Apart from that evidence, the very intensity of N_2^+ bands during daylight flash and their intensification in a sunlit aurora, according to Störmer, was definite proof that sunlight produced considerable ionization of N_2 to N_2^+. Saha calculated the number of quanta available having an energy content greater than 18.68 V and excitation potential of N_2 to N_2^+, assuming the radiation from the sun, as that given by a black body at 6500 K, was inadequate for the purpose. It was around 10^4 ions of N_2^+ per second per square centimetre in the whole depth of the atmosphere.

But according to the calculation by Chapman, the total number of ions to be produced per second for maintaining the total ionization was 3×10^{10}. The total ionization was not entirely due to N_2^+, probably the greater part was due to ionization of O_2^+. But the intensity of N_2^+ bands showed that at least a substantial part, say one tenth, was due to ionization of N_2. Hence, Saha concluded that the solar ultraviolet light of wavelength less than 660 Å was about a million times more intense than that given by a black body at a temperature of 6500 K, and it appeared probable that when solar spectrum was observed outside the atmosphere of the earth, it would appear like those of planetary nebulae, that is, composed of a faint continuous background, superimposed with bright emission lines of H, He and He^+, Fe^+, Fe^{++} and other elements which were abundant in the atmosphere of the sun and which had their resonance lines in that part of the spectrum. He discussed the ionization of O_2 also.

Saha's prediction was verified nearly after 18 years, when German V-2 rockets were used to obtain the spectrum of the sun at a height of nearly 150 km. The Lyman α-lines had been found in the spectrum as predicted by Saha.

Then he visited E. O. Lawrence's cyclotron laboratory. He was personally acquainted with Lawrence when they had spent a few weeks together at Copenhagen and Berlin in 1927. After that he visited Yerkes Observatory near Chicago and returned to Cambridge, Massachusetts, USA. He had a friendly visit from A. H. Compton and K. T. Compton. While leaving the USA, he was entertained by his American and European friends in the USA at an Indo-Ceylonese restaurant, in New York, and was given an affectionate farewell, which was presided by B. Saklatwala, a famous metallurgist, who had settled at Pittsburgh, USA. Also present were Langmuir, Warren, Weaver and other distinguished Americans. Returning to Europe, he attended the International Conference on Nuclear Physics at Copenhagen where he stayed for about 15 days. At that conference, he came across research and problems in nuclear physics.

In January 1937, the third annual general meeting of the Indian Physical Society was held at Hyderabad. Saha delivered the presidential address *The mission of the physicist in national life*. He said: 'As a matter of fact, science which is playing such a great part in the evolution of human civilization has certainly a great claim on society and governments. The material prosperity and political safety of countries are intimately connected with the active cultivation of our science'.

The address briefly discussed various avenues of employment for physicists and stressed the need of endowments for research in physics.

> …the lot of meritorious Physics students, who are being trained as research workers is very disappointing at present. On account of the unsympathetic attitude of the Government towards scientific research, there are practically no avenues of employment, in which the special knowledge of trained scientists can be utilized. I would, therefore, plead that the rich men in this country should come forward with endowments in the different Universities for fellowships, so that these promising students can devote a number of years in solving particular problems. It is no exaggeration to say, that the few active centres of research in India are mostly functioning due to private endowments. The University College of Science, which started scientific work on a new basis after the war, in Calcutta, was established by the princely donations of Sir T. N. Palit, Sir Rashbehari Ghosh, the Raja of Khaira and the Indian Association for the Cultivation of Science; it developed in to an active centre of research under Professor Sir C. V. Raman, and was established in 1876 by a private medical practitioner of Calcutta, Mahendralal Sircar. The Indian Institute of Science, which now contains a department of research in Physics owes its existence to the princely donation of the late Mr. J. N. Tata. The Physical Laboratory in the Andhra University is due to the munificence of the Maharaja of Jeypore in the Madras Presidency. The Physical Laboratories in the Muslim and the Hindu Universities are largely the results of private benefactions…. The Indian Physical Society is only a child of three years. It has still to develop and to prove its worth to the country. It is therefore necessary, that it should take steps for an organization of physicists on a proper basis and try to impress upon the public, the importance of physical research for the future of national reconstruction. It should try to get endowments and establish research funds for the encouragement of younger physicists and for providing them with a berth in life. I hope that in the years to come, all this will happen and the Indian Physical Society will be as useful an institution as the much older Societies in Germany, England and America. [6]

Around 1936 or so, Saha took an interest in ionospheric research. His student G. R. Toshniwal, from Rajasthan, had extraordinary experimental skill. With the meagre resources, he set up a laboratory for ionospheric research. B. D. Pant and R. R. Bajpai were working under Toshniwal. They discovered the fourth condition of reflection of electromagnetic waves, which was extremely puzzling at that time.

Saha thoroughly examined Appleton's condition of reflection of electromagnetic waves from ionosphere. Along with his student R. N. Rai, he worked out the details of propagation of electromagnetic waves, through the atmosphere. They obtained four conditions of reflection:

$$(\alpha)\, p_0{}^2 = p^2 - pp_\mathrm{h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots x - \text{wave}$$

$$(\beta)\, p_0{}^2 = p^2\left(p^2 - p_\mathrm{L}{}^2\right)/\left(p^2 - p_\mathrm{h}{}^2\right) \ldots\ldots\ldots x - \text{wave}$$

$$(\lambda)\, p_0{}^2 = p^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots o - \text{wave}$$

$$(\delta)\, p_0{}^2 = p^2 + p_\mathrm{h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots x - \text{wave}$$

The condition (β) was new and was not given by the then assumed condition for reflection, that is, $\mu = 0$. The existence of reflection (β) was detected at Allahabad by Pant and Bajpai. For cases (α) to (δ), Bajpai and K. B. Mathur had calculated electron concentration required for the four modes of reflection, taking $p = 23.3$ kHz, $f = 23.3/2\pi = 3.70$ as, $0.88 \times 10^5/\text{cm}^3$, $1.40 \times 10^5/\text{cm}^3$, $1.52 \times 10^5/\text{cm}^3$ and $2.40 \times 10^5/\text{cm}^3$.

The question was how the same *x*-wave could get reflected from three different strata at one and the same time. When a wave was propagating vertically upward, it was split up into an *o*-wave and an *x*-wave, which propagated with different velocities in the ionosphere. On reaching the level where concentration was $0.88 \times 10^5/\text{cm}^3$, the wave got reflected. According to the ray treatment, the reflection should be completed, as the disappearance of group velocity meant that there was no further forward propagation of energy by the waves. But Pant and Bajpai in their laboratory noticed the reflection of the *x*-wave according to the condition (β), and Toshniwal observed a threefold splitting of the wave, presumably of the *x*-wave, one of which he interpreted as mode (β). The observation was later verified by Leiv Harang, and all the four conditions of reflection had been verified by R. Jouaust and his co-workers. Those cases showed that reflection according to (α) was incomplete, even when there was the requisite electron concentration, and the *x*-wave could sometimes leak through the layer and get reflected under certain conditions. Another problem was the existence of simultaneous reflection from layers at widely different heights. The best known example was sporadic E-layer reflection. Appleton concluded that 'either the recombination of ions was prevented or there was some ionizing agent present, which could influence the dark side of the earth'.

Saha and Rai explained it as a layer of electrical particles of abnormal density, but extreme thinness was formed at the height of the normal E-layer. That layer reflected partly the energy of the waves and part of the energy of the incident waves leaked through the layer and got reflected from the upper F_2-layer. The phenomenon could not be understood if $\mu = 0$ was taken as the condition of reflection, and then reflection from the lower layer would be completed.

Starting from Maxwell's equation, they derived equations for the propagation of electric and magnetic vectors, associated with the electromagnetic wave in the atmosphere, considering the effect of ion concentration and collision and the earth's magnetic field. Their calculations showed that the wave could penetrate some thickness of the ionized layer, without appreciable diminution in intensity. If the thickness of the layer was of the order of a kilometre, a part of the energy of the incident wave might be transmitted, though the value of μ was zero for the wave transmitted at the point, where it met the electron barrier.

Though Saha was involved with various organizational activities, he continued his research on ionosphere. Along with his students and collaborators, he continued research on electromagnetic wave propagation through the earth's atmosphere. The study was focused on the wave treatment of the problem of propagation, dealing with questions of polarization, reflection, oblique propagation and absorption of waves. In 1938, he showed that when the complex refractive index was treated as constant, the condition for reflection and polarization of the radio waves for vertical propagation was the same as obtained by Appleton.

At that time, there were two methods of attempting a theoretical explanation of the ionization of the upper atmosphere. First, the work of Pannekock, which was thermodynamical and based on Saha's theory of thermal ionization of atoms as extended by Milne and Woltjer to material systems, traversed by radiation from an external body at a higher temperature. The second method was that of Chapman, who considered the ionization produced by the absorption of a monochromatic beam of light in an atmosphere in which the density was assumed to vary exponentially. In the same year 1938, Saha showed that the two theories of upper air ionization were not essentially different from each other. In Chapman's theory, they gave the value $(1/h\nu)$ to the quantity, β, which was introduced as a proportionality factor for deducing the number of electrons from the radiation absorbed and extended it to continuous radiation, and they came to Pennekock's results. For absorption coefficient, a wave mechanical formula was used in the place of Kramer's expression. The rates of production of electrons from the O atoms, the recombination coefficient of ions and electrons and the equilibrium values of electron concentration were deduced for uni-component systems. From those expressions, Chapman's formula for variation of electron production with height was deduced as a special case, but the scope of the formula was found to be greater, as it was found to hold not only for monochromatic light, as in Chapman's, but also for continuous light. The actual values of electron production at noon, for the F-layer from the O atom, were given and compared with values given by Appleton.

It was further shown that the method was capable of giving formula for electron production by monochromatic light and yields results in terms of quantities, which were physically definable.

The paper was read before the Silver Jubilee Session of the Indian Science Congress in January 1938. But for some unavoidable reasons, it could not be sent for publication before April. Meanwhile E. O. Hulburt published some of the results deduced in Saha's paper in *Physical Review*, March 1939, obtained by a somewhat different procedure.

Saha had been advocating 'large-scale industrialization' as the only solution for India's problems of poverty and unemployment. The editor of the *Modern Review* invited him to restate his views on the subject. Saha wrote:

> To have a comprehensive idea of the New age, we should look at the kind of life pursued in a country like USA, England or Germany and the present system of industrial production in these countries, and contrast it with the course of human life and industry in the same countries two centuries ago…. The "Power Industry" is the key to the present system of industrial production, but even other industries cannot stand competition, in the face of constant improvement due to scientific research, but for state protection. But the best kind of protection is "Efficiency" and this is safeguarded by the organization of the National Council of Scientific and Industrial Research. The object of this body is the scientific study of the existing methods of production, and application of the latest scientific knowledge to the betterment of the method and the creation of new industries. In addition to this, every big company has its own research workers. …The task before India is, to organize her industrial life according to the neo-technical method of production. Unlike certain other countries, India taken as a whole, is one of the three countries (other being Russia and the USA) which possess all the resources in power, minerals, and agricultural land, which can enable her to pass to the neo-technical method of industrial production. Unless this is done, India can never solve her problems of poverty and unemployment, and can never be assured of a bright future. [7]

Fig. 8.6 Sir Arthur S. Eddington visited Allahabad University (1938). From *left to right*: Standing – Chandrikaprasad, A. N. Tandon, B. D. Nag Chaudhury, K. B. Mathur, B. N. Srivastava, P. K. Kichlu, K. Majumdar, R. N. Rai, G. R. Toshniwal. Sitting – Prof. V. V. Narlikar, Prof. N. R. Sen, M. Suleiman, Prof. M. N. Saha, Sir A. S. Eddington, Prof. A. C. Banerji, Prof. Tarachand, Mrs. Bibha Majumdar and Dr. R. C. Majumdar (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

In December 1937, Sir Arthur Eddington visited Allahabad University on Saha's invitation (see Fig. 8.6). The Indian Science Congress Association celebrated its Silver Jubilee at Calcutta in 1938. Lord Rutherford was to preside, but he died few months before the celebration. Sir James Jeans presided over the celebration.

The National Academy of Sciences held a symposium on *power supply* in 1938. Pandit Jawaharlal Nehru presided over the function. A large number of persons participated in the discussions, including B. C. Chatterjee, N. N. Godbole, G. R. Toshniwal, A. N. Tandon and B. P. Adarkar. Saha initiated the discussion saying:

> The total output of work per capita in India is only 90 units, of which the major part is from manual labor, and only 7 units are from electrical power derived from coal, or running water, while in the advanced countries of the west, the total output is nearly 1800 units, of which not more than 60 units are from manual labor, and the rest is all derived from the forces of Nature.

In summarizing the discussion, Nehru said:

> There can be no two opinions regarding the necessity of establishing a Power Research and Survey Institute with a view to ensuring cheap and abundant supply of power for the nation.

> The Congress is not blind to the urgency of the matter. But the condition under which the Congress government functions is not wholly understood. Democratic governments are greatly burdened by their ordinary routine work and complaints from innumerable persons who now have access to them. They must first do things which are demanded by hundreds of thousands, and have no time to listen to the counsels of a few dozen, however wise they may be. Further the Government is so tired of listening to trivial matters, that they are jaded, and have little time to discuss far-off schemes with experts and scientists.
>
> On the side of the Government, it can be said that the expert scientist is not always a helpful person. He does not realize that things which have to be put before the Government, must be definite and must be related to what is actually happening. The proposals must fit in with the realities of the situation.

In a vote of thanks to Pandit Nehru on behalf of the National Academy of Science, Saha said:

> It was in the fitness of things that Pandit Jawaharlal has agreed to preside over this annual gathering of scientists in India. His position in the country can be described by a phrase, which Americans use with respect to Abraham Lincoln: First in war, first in peace, and next to Mahatma Gandhi, he occupies the first place in the hearts of his three hundred and fifty million countrymen. The time has now come for him, to give a lead in peace-time work of reconstruction and consolidation of the country.
>
> Both war and peace had their own problems, but peace time problems were more exacting than war-time ones. For mistakes committed during war-time was to some extent inevitable and excusable, but peace-time blunders were of more serious consequences to the nation. The Congress having accepted office, had to confront peace-time problems. It seemed to him, that their work of national reconstruction was being handicapped by some fetishes, which they raised, probably as a war-time measure. But no progress could be made unless they got rid of those fetishes and attacked the problems from a realistic point of view. And science was not science, if it hesitated to call a fetish other than a fetish, of which there were too many in this country. They would probably agree that in the reconstruction of the nation, science was to play a very significant part. The Government would have to devise ways and means for the organization of work, for the production and distribution of the commodities needed for the sustenance of the nation and proper utilization and conservation of the nation's resources. The co-operation of scientists would be needed for that work. If scientific men and technicians did not exist for the development of any line of work, they had to be created out of the rising generations.
>
> The first attempt at the organization of scientific life in these provinces was barely 7 years old, when the National Academy of Sciences was started with the cooperation of the leading scientists of the province, and under the active and personal encouragement of the late Governor, Lord Hailey. It had not fulfilled all the ideals with which it started – in fact, but for the reading of original papers and their publication, it had discharged very few functions of the National Academy. If it was to discharge those functions, it should not be merely an association of scientists on a voluntary basis, but should be assigned a definite task, be invested with proper authority, and have a permanent home and a permanent secretariat. Even if this Academy had not been granted those rights and privileges, the national government would soon have to create another body with identical objects. [4]

By this time, Saha decided to make Allahabad a permanent home. He built a comfortable house also. He was highly respected in Allahabad and Uttar Pradesh. But around 1938, the University atmosphere started deteriorating with politics. It became impossible for Saha to work with dignity and honour. He started searching for a job elsewhere. He had two offers, one from Calcutta University as the Palit professor and the other from Royal Institute of Science, Bombay, as a principal. He preferred Calcutta University for obvious reasons. He had left Calcutta in 1923 and returned to his Alma matter in 1938.

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Chapter 9
Again in Calcutta

In 1938 Saha was about to leave Allahabad for good. But in spite of troubles at the workplace, he was working on magnetospheric research. In the pioneering work on the magneto-ionic theory, Appleton did not actually solve the relevant Maxwell equations, but expressions were obtained for the refractive index from a calculation of the dielectric constant of the medium, which was supposed to consist of a number of free electrons and ions. The displacement of these, under the magnetic field, which was limited by collisions with neutral particles and positive ions, constituted the displacement current, which was necessary to calculate the complex dielectric constant. Appleton's method was usually known as the ray theory of propagation of the electromagnetic waves. The refractive index comes out in general to be a complex quantity and had two different values, depending upon the state of polarization of the wave. Further, it was a function of the electron concentration and collision frequency, both of which were functions of height. Consequently, the wave equation became too complex for solution. From the analysis, it followed that the original wave split up into two, ordinary and extraordinary, which were propagated with different velocities, as in a doubly refracting medium. Saha supposed that in the case, when collision could be neglected, the wave was reflected from the layer where the refractive index became equal to zero. That enabled him to obtain the conditions of reflection involving the electron concentration and the frequency of the wave, which were well known and had received verification at least in the case of F-layer.

A number of other methods also had been proposed, namely, that of Försterling and Lassen, Saha, Rai and Mathur and Hartree, developed further by Booker. The work of those authors led to the same value of refractive index as that of Appleton.

S. N. Bose had tackled the same problem, by the method of characteristics, used for wave propagation by Hadamard, Debye and others. He confirmed, in general, the conclusions of the previous investigators when collisions can be neglected but gave new results when the collisions could not be neglected.

Saha examined Bose's method and results critically. Finally, he concluded that both real and imaginary parts of refractive index were essentially positive, and they could be zero, only in the ideal case when the collision frequency was zero. Hence

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it was not possible to put complex refractive index equal to zero and deduce any condition from it. In the same way he could not put refractive index equal to infinity when it was complex.

In July 1938, Saha joined as a Palit professor and head of the Physics Department in the University College of Science and Technology, Calcutta. He had left Calcutta in 1923, and at that time, he was just a promising researcher. Now he was a physicist of international reputation.

By this time India was restless. The struggle for freedom was gathering momentum. Mahatma Gandhi started the Civil Disobedience Movement in 1930 with his famous *Dandi March*. Gandhi together with chosen followers walked nearly 375 km from Sabarmati Ashram to Dandi, a village on the Gujarat seacoast. Newspapers reported his daily progress, his speeches and the impact on people. After reaching Dandi, he picked up a handful of salt and broke the salt law, as a symbol of the Indian people's refusal to live under British-made laws and therefore under British rule. He declared that the British rule in India had brought about moral, material, cultural and spiritual degradation of the great country. He regarded the rule as a curse. He was out to destroy the system of government. Sedition had become his religion. His was a non-violent battle. The movement spread rapidly, throughout India. Lakhs of Indians offered *Satyagraha*. There was mass boycott of foreign goods and refusal to pay taxes. Even women marched shoulder to shoulder with men in processions. The government's reply to the national struggle was the same as before – an effort to crush it, through ruthless repression, *lathi* charges and firing on unarmed crowds of men and women.

The movement gradually waned. The Congress withdrew it in 1934. The movement had not succeeded in winning freedom, but it had succeeded in further politicizing the people and in further deepening the social roots of the freedom struggle. The *Round Table Conference* passed the Government of India Act of 1935. The Congress contested elections in 1937, under the new act of 1935, and gained support of the majority.

Saha was critical of the Congress High Command and their support to both *cottage industry* and the *mixed economy* proposed in the Bombay Plan[1]. He was critical of Gandhi's policy of the *spinning wheel* and *Khadi*. The USSR planning was his role model for progress. Subhash Chandra Bose was not like other Congress leaders and was absolutely clear about post-independent problems.

In October 1938, Bose called a meeting of Ministers of Industry in the Congress-controlled provinces and other prominent men of India at Delhi. Bose invited Saha to attend this meeting. Saha arrived one day late and found that Sir M. Visvesvaraya

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[1] Bombay Plan – In pre-independent India eight leading Indian industrialists, namely, J. R. D. Tata, G. D. Birla, Sir Ardeshir Dalal, Sri Ram, Kasturbhai Lalbhai, A. D. Shroff, Purshottamdas Thakurdas and John Mathai, published a set of proposals for the development of the post-independence economy of India which was known as Bombay Plan. Its title was *A brief memorandum outlining a plan of economic development for India*. Though Pandit Jawaharlal Nehru, the first Prime Minister of India, did not officially accepted the plan, the Nehruvian era witnessed the implementation of the Bombay Plan. The economy could not grow without government intervention, and regulation was its key principle.

was requested to be the chairman of the *National Planning Committee*. Mr. Visvesvaraya was an eminent civil engineer, *Dewan* of Mysore State, advocate of National Planning and one of the authors of the Bombay Plan. Saha persuaded Visvesvaraya not to accept the position of chairman because unless a top-ranking member of the Congress was chairman, the Planning Committee would be regarded as academic and would have no value in the eyes of the Congress. To make sure that Nehru accepted the chairmanship of the National Planning Committee, Saha went to Shantiniketan and asked Rabindranath Tagore to write to Mahatma Gandhi to this effect.

Saha was a member of the core committee and chairman of two sub-committees – *Power and Fuel* and *Technical Education*. The committee started its work immediately and in 1939 submitted an interim report, consisting of 26 volumes to the President of the Indian National Congress, Dr. Pattabhi Sitaramayya. After submitting the report the committee was dissolved.

Meanwhile at the political front in 1939, Subhash Chandra Bose was reelected as President of the Congress against Gandhi's wishes. But Bose resigned later in the year, because effective functioning was not possible in Congress without Gandhi's support.

Saha returned to Calcutta after 15 years. Almost everything was changed. Sir Asutosh was no more. Now Shyama Prasad Mukherjee was Vice-Chancellor. Raman left for Bangalore. The people working in the Physics Department were S.K. Mitra as the Ghosh professor, B.B. Ray as the Khaira professor and S.K. Acharya, J.C. Mukherjee, B.N. Chuckerburti and D. Banerjee as lecturers. Saha's classmates, his earlier associates, were working at various posts: N.R. Sen in Applied Mathematics (as Ghosh professor and head); P.C. Mitter in Chemistry (as Palit professor and head); J.N. Mukherjee (as Ghosh professor), Priyadaranjan Ray (as Khaira professor) and P.N. Ghosh in Applied Physics (as Ghosh professor); B.C. Guha in Applied Chemistry (as Ghosh professor); and S. P. Agharkar in Botany (as Ghosh professor).

The Palit laboratory contained apparatus for research on the Raman effect. After Raman's departure, the Indian Association for the Cultivation of Science (IACS) donated it to the university. Saha himself was not working in that area, but he wished that the work should be continued. Mr. S.C. Sirkar was research assistant to the Palit professor and earlier had worked with Raman and acquired detailed knowledge of the topic and the required skill. Saha asked him to continue the work on the Raman effect. He carried out research with great vigour and efficiency. Sirkar later became Mahendralal Sircar professor in IACS. At Allahabad, Saha had initiated research on ionosphere and the upper atmosphere. At Calcutta, S. K. Mitra had set up an ionospheric research laboratory and his group made outstanding contributions. Now for Saha, working in the same area meant as if creating a rival school. He retained his interest in theoretical work.

In 1940 he was working on the structure of atomic nuclei. He compiled and presented the then existing knowledge of the known nuclei, stable as well as radioactive, in the form of a chart along with S. C. Sirkar and K. C. Mukherjee. The chart was drawn with the mass number, as abscissa; the isotope number which was defined, as the excess of the number of neutrons over protons as ordinate; and *Z*-lines, at 45° to the abscissa or ordinate. All nuclei, stable as well as radioactive, had been represented with their abundance for stable nuclei and half-lives. The chart enabled to form a complete picture of all nuclei, as well as of the nuclear processes. The rules for stability of odd nuclei were new. A large number of predictions had been made regarding the occurrence of rare stable nuclei and of radioactive nuclei. In the case of elements undiscovered at that time, Nos. 43, 61, 85 and 87, predictions had been made regarding the number of isotopes and of the most stable varieties.

While Saha and his coworkers were preparing the paper, Bohr and Wheeler's paper on the 'mechanism of nuclear fission' was published in *Physical Review*. They had explained it using I/A-diagram, where $I = N - Z$, N was the number of neutrons, Z was the number of protons and A was the mass number, which was nearly identical with Saha's idea. Saha argued that the bombarding U or Th nuclei with neutrons was probably resulting in a release of neutrons from 2 to 6 and splitting up the remaining nucleus into almost two equal halves, which leave each other with energy of about 200 MeV. The energy of splitting could be calculated from theoretical considerations of the energy formation of nuclei and was found to be in accordance with experimental observations. In some cases, the products of fission and the products of successive disintegration had been correctly identified. Then he summarized the results obtained by different observers, showing the successive series which had been observed.

The mass numbers of the U-fission product series, to which Abelson assigned the values 132, 134 and 136, had been shown to be untenable and correct mass numbers as 131, 133 and 135, respectively. Further, two series had been shown to possess the mass numbers 141 and 143, respectively.

As the Second World War progressed, India was forced into the war. British rulers realized that repression cannot be continued indefinitely, and it was becoming clear that India will recover its independence.

The general feeling among British was that science and technology had not been used to exploit India's natural resources, for betterment of her masses and towards war efforts. As the war continued, allied forces, of which British and hence British India was a part, had channelized maximum possible resources from all corners to overcome the Nazi threat.

In 1940, on the initiative of Sir Ramaswamy Mudaliar, a senior member of the Viceroy's Cabinet, a Board of Scientific and Industrial Research (BSIR) was formed with S. S. Bhatnagar as Director of Scientific and Industrial Research. The objective was to start cooperation of Indian scientists and industrialists in this direction. Saha and other scientists felt that the organization was not ideal, but hoped that in future, it may be shaped in the desired form and accepted the invitation to join.

In 1942, it was upgraded as the Council of Scientific and Industrial Research (CSIR). Initially, it was proposed that the governing body should contain only officials and industrialists and not any scientist. But all scientists opposed that idea and threatened to resign. Then the decision was reversed.

From the British side, it was an attempt to get India's willing cooperation in war efforts. The Indian side was represented by Sir Ramaswamy Mudaliar, Sir Azizul Haque, Sir Ardeshir Dalal and others. They decided to set up a chain of organizations to solve India's post-war problems using science and technology.

In February 1942, in the British Parliament, British physiologist, Nobel Laureate A.V. Hill, suggested close collaboration with Indian scientists, for the war efforts and for India's growth. The Secretary of State for the Government of India, L.S. Amery, invited Hill to tour Indian scientific institutions. Prof. Hill was secretary of the Royal Society. He had discussions with leading Indian scientists, H. J. Bhabha, S.S. Bhatnagar, J.C. Ghosh, J. N. Mukherjee and M. N. Saha and scientific bodies on science, medicine and technology.

In October 1944, on Prof. Hill's suggestion an Indian Scientific Mission, composed of some prominent scientists, was formed to visit the UK, the USA and Canada. The members of the mission were:

1. Dr. Nazir Ahmad – Technology and organization of agricultural research
2. Col. S. L. Bhatia – Medical education, research in medical sciences; medical services and public health
3. Dr. S. S. Bhatnagar – Scientific and industrial research and organization, activities of CSIR, coordination between India and British research organizations
4. Dr. J. C. Ghosh – Future status of the National Institute of Sciences and coordination between India and British scientific societies
5. Prof. J. N. Mukherjee – Agricultural research and organization
6. Prof. S. K. Mitra – Radio research and development, coordination between the British Association and Indian Science Congress Association
7. Prof. Meghnad Saha – Coordination between Indian Science Congress Association, National Institute of Sciences and similar British Societies; fundamental research in physics and of the upper atmosphere

The objective of the mission was to interact with wartime organizations in science and technology in those countries and to determine how scientific and technical research could be used to develop natural resources for economic betterment of the people and to recommend suitable plans for India.

The Mission studied the development of scientific research in the UK, the USA and Canada and made contacts with scientists of those countries.

The team visited London, with excursions to Slough (the Radio Research Station), Teddington (National Physical Laboratory) and universities of Oxford, Cambridge, Leeds, Sheffield, Manchester, Edinburgh, Glasgow and Aberdeen. They also visited Billingham and Huddersfield, the centres of production by the Imperial Chemical Industries (see Fig. 9.1). They had discussions with scientists, industrialists and important political leaders.

On an invitation from the British Institute of International Affairs and the British Association for the Advancement of Science (BAAS), Saha delivered a lecture on 10 November 1944. The topic was *Science in Social and International planning with special reference to India*. It was reproduced in *Nature.*

While describing the Indian condition, Saha said:

Fig. 9.1 Scientific mission to the UK and the USA where they visited Imperial Chemical Industries, Billimgham, Stockton-on-Tees, UK (1944). From *left to right*: front row – Dr. Nazir Ahmed, Sir. J. C. Ghosh, Prof. M. N. Saha, Dr. S. S. Bhatnagar, Dr. J. N. Mukherjee (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India)

> …He (Prof. Hill) has stated his findings publicly, and they are practically the same as mine. By whatever standards you measure, you find 90 per cent of India is still in the Middle Ages. The thin veneer of modernism, which travelers find in the great cities of Bombay, Calcutta and Delhi must not lead you astray. Ninety percent of India is still in the sixteenth century conditions of England. We have terrible child mortality, the conditions of public health are appalling, and 90 per cent of the people have to live in slums. They have scarcely any interest in life, and are on the brink of disaster, as Prof. Hill has told the British public repeatedly.
>
> The National Planning Committee of the Indian National Congress, had rightly concluded that India had been almost entirely untouched by modern scientific methods, and if she wanted to get past the present dreadful conditions, she must tackle seriously, the monumental task of applying modern scientific and industrial methods, for the development of her potential wealth, as has been done by the USSR with signal success within the past twenty-five years. According to a competent authority, India, like the United States of America, the USSR and China, is one of the few political countries of the world, which has enough potential resources in power, minerals, and forest and agricultural products, for a balanced development of industry and agriculture to produce *plenty* for her population. ……. Civilized life in India has, from time immemorial, grown in river-valleys, which have been used for navigation and irrigation. During the British regime, the development has been one-sided, namely, for irrigation only, and navigation has been allowed to decline. But both Soviet Russia and the United States of America have, within the last twenty-five years, set a new ideal for river development. …… It is regrettable that Indian leaders have so far paid attention, only to the question of political freedom. It is natural that everyone of us, should want our country to attain full nationhood and the people have full sovereignty, but the problem of survival for millions of Indians, cannot be postponed; in fact, we believe that the only way to achieve unity of thought and purpose in the political field, which is now wanting, is first to look at the problem of existence for India's millions. To solve this problem successfully there must be a national purpose behind all planning, and I do not see how any planning can be given effect without a National Government, or unless we have a Government which has popular support and is composed of leaders, in whom the people have confidence. [1]

In the USA, the team visited political centres like Washington; educational centres in New York, Chicago and Berkeley; Mt. Wilson and Palomar observatories; California Institute of Technology; Massachusetts Institute of Technology; offices of Tennessee Valley Authority; and so on.

Saha expressed his curiosity about atomic energy and research in this direction. He was unaware of the highly guarded Manhattan project. The bomb was yet to be dropped on Hiroshima and Nagasaki. He was grilled by the FBI when he visited the Carnegie Institution for Science in Washington. The team was under surveillance till it left the USA and Canada in February 1945.

In the Presidential address at the annual meeting of the Royal Asiatic Society of Bengal in 1946, Saha described his experience as a member of the Indian Scientific Mission. In his address, while highlighting the importance of fundamental research, he said:

> I have served for the past several years on the Board of Scientific and Industrial Research and on many other committees in the company of industrialists and government officers. It has always been difficult to bring home to my non-scientific colleagues, who are, unfortunately in favour of the growth of Indian science, too numerous in these bodies, the importance of fundamental research. With the industrialists, the profit motive has always been uppermost and whenever, any research scheme has been put forward, the question has been asked in what way will that benefit the industrialists of the country. The officials in general are not receptive and are unappreciative of the necessity of fundamental research.
>
> The great physicist Sir J. J. Thomson said, after the Boer War that “if fundamental research, were subjected to the orthodox government system of planning, they would have probably asked the scientific men to find out a rational way, of finding bullets located in the human body. The orthodox way would have been to make the human body a pin-cushion, but the X-rays could not have been discovered in that way. [2]

Saha developed an interest in the theory of electron capture by positive ions while passing through gases. In 1945 he published his studies with D. Basu. An alpha particle passing through a gaseous medium, as in a cloud chamber, produces a track consisting of ions formed around electrons liberated from the surrounding gas. It was noticed by Henderson and Rutherford that towards the end of the track, the phenomenon was more complex.

Saha calculated the probability that an alpha particle passing through hydrogen gas would capture an electron in its 2p orbit from the ground state of the H-atom. It had been shown that, contrary to the view of Brinkman and Kramers, the probability of capture in the 2p orbit was of considerable importance especially for the low velocity of the incident alpha particle. The knowledge of the cross-sections of the capture of electrons to higher excited states of the alpha particle was necessary to explain the origin of the H-lines in the spectrum of the chromosphere, following his earlier suggestion in 1942. The solar chromosphere-like visible lines of neutral helium were extremely strong while they were totally absent from the Fraunhofer spectrum, but the well-known line of ionized helium 4686 Å was found in lower layers; it was unexpected in view of the fact that it has an excitation potential of nearly 75.25 volt while the ordinary excitation in the chromosphere was 9–14 volts. Saha explained the origin of He^+ and He-lines, by assuming that high velocity alpha particles were generated in the solar body, due to some nuclear process, and as they move up, they get slowed down by losing energy through ionization. When they had sufficiently slowed down, they began to capture electrons in different orbits 1s, 2p, 3d, ms, mp and md. When an electron captured in 4f, d orbit jump to 3d, p orbit, the line of wavelength 4686 Å was emitted.

That discussion brought out the importance of calculating the cross-sections for the capture of electrons in orbits higher than 1s. The capture problem was expected to play an important role in explaining the spectrum of aurora borealis, which had been shown to be due to the injection of charged particles from the sun into the earth's atmosphere.

By this time Saha was heavily burdened with administrative as well as academic work, namely, his regular responsibilities as Palit professor and President of IACS and in planning of a separate institute for Nuclear Physics. Yet he was working on Nuclear Physics. In 1946, he discovered, along with A. K. Saha, regularities in the energy of the β^+, β^- and γ emissions and *K*-capture of different nuclei. They deduced from the Weizsäcker-Bethe formula expressions for energy release in the case of β-transitions and *K*-capture, which involve only the isotopic number term, the Coulomb interaction terms and spin-dependent terms in the mass-defect formula. They classified nuclei into groups having a definite value of I ($= N - Z$), and the theoretical results had been compared to the observed ones. In general, good concurrence had been obtained in the case of nuclei belonging to the seven groups, $I = -1$ to $I = 6$, whose properties were well determined. Many apparent anomalies from empirical rules of stability had been explained. A few important deductions arising out of their investigations were as follows:

1. Li^5 was expected to be a nucleus, having a long life of several years and decaying by *K*-capture to He^5, which should be stable.
2. A^{39} reported as β^--nucleus with a life of 4 min was a glaring anomaly: A^{39} was expected to be a long-lived nucleus decaying by *K*-capture to K^{39}.
3. Even-even nuclei might not always be stable, when the nucleus was a bit off the main line of stability. Thus Ti^{44}, Cr^{48}, etc., if they could be prepared, would be found like C^{14}, to be long-lived products, decaying in these cases by *K*-capture.
4. It was probable that Ca^{48}, stated by Nier to be a rare stable isotope of Ca with a frequency of 0.2 per cent, was illusory, like Co^{57}, which was once believed to be stable, but they predicted it as unstable. Irene Joliot-Curie had independently arrived at the conclusion that a stable Ca^{48} does not exist. That nucleus and Ti^{52}, Cr^{56} and Fe^{60}, if they could be produced, would be found unstable, decaying like C^{14} with the emission of slow β^--rays. The first stable nucleus in the group $I = 4$ should be Ni^{64}.
5. The radioactive nuclei V^{50}, Mn^{54} and Co^{58} should decay with both β^+ and β^- emissions and *K*-capture, but only β^+ emission and *K*-capture activity had been reported till that time. If they were found unable to emit β^--rays a fundamental difficulty would arise in the theory of β emission.
6. The spin-dependent part of the nuclear binding energy was found generally to be of the order of a few MeV, while according to classical theory, it should be $\approx (Zev/cr^2)\mu_k$, where Z was the number of charges in the nucleus, v was the velocity of a nucleon

> inside the nucleus and μ_k was the nuclear magnetic moment. Making plausible assumptions about the quantities, they found that it was of the order of about 10–20 keV. It showed that they had to apply some type of meson theory to find out the right order of value of the spin-dependent part of the nuclear binding energy.

Saha continued his research on radio waves also, where he put forward the conditions of the escape of radio-frequency energy from the sun and the stars. During the time of solar disturbances, there were large outbursts of radio frequency, 10–200 MHz, from the sun. It had been found that the sun had a magnetic field of the order of 50 G, but the spots had from 100 G to 4000 G, depending upon the size of the spot. According to the magneto-ionic theory of Appleton, an electromagnetic wave, generated anywhere on the earth's surface, could escape vertically from the earth only when the frequency of the waves exceed certain limits, depending upon the maximum electron concentration above. The validity of those conditions had been verified by innumerable experiments.

Saha calculated from those conditions, the concentration of electrons needed for the escape of waves. From the observed values of the concentration of electrons in the different layers of the sun, he concluded that O-radiations of radio-frequency range, obtained from the sun, could not have their origin either in the reversing layer or the chromosphere, but only in the corona and that also, progressively, in the outer layers as the wavelength was increased. But the corona had been shown to be a purely 'electron atmosphere', without any heavier atomic particles, excepting very small concentrations of heavily ionized Fe, Ni and Ca, which produced the coronal lines.

His calculations for E-waves showed the possibility of reception of the waves on the earth. At Allahabad, Toshniwal had detected those waves, and his findings were also confirmed by Leiv Harang.

He concluded that the large spots were just the regions where the E-waves of the frequency range 10–200 MHz can escape. He further added that those considerations apply equally well to the stars composing the Milky Way, from which waves in the metre range had been observed. They could not be emitted from the surface of the hotter stars, but from cooler stars of G, K and M-type, and probably the escape of the radiation was facilitated by the development of spots in those stars, analogous to the case of the sun.

While writing about the origin of radio waves from the sun and the stars, he pointed out that the atomic or rather nuclear processes stimulated by strong magnetic fields of the type, which were characteristics of an active sun, could give rise to the radio-wave emission by the sun and the stars. Rabi and his school had demonstrated that process of excitation of the energy levels of nuclei of atoms and molecules by a strong magnetic field. When the atoms were placed in a strong magnetic field which was being crossed at right angles by a much smaller, but rapidly varying field, its period being comparable to those of the emitted radiation, but not necessarily equal, under the action of the strong magnetic field, the atom took up various orientations. The varying field caused the orientations to change rapidly, and in the process radio-frequency waves were emitted. The energy values of the different orientations changed considerably with fields, but Rabi had calculated them from the extension of the theory of the Paschen-Back effect. From that calculation, Saha worked out wavelengths of radiations for Na^{23}, from few metres to few centimetres, and he predicted that the same theory can be applied to the nuclei H, Li^6, Li^7, B^{10}, B^{11}, N^{14}, Al^{27} and so on, giving rise to both metre and centimetre waves. He argued that the most important part in the sun and the stars would be played not by Na but by hydrogen because according to well-corroborated astrophysical arguments, 95% of the total number of atoms in the atmosphere of the sun and in the stars also, hydrogen is formed in the majority of cases, more than 90% of the atmosphere. Na was chosen simply to illustrate the phenomenon. In the spots, due to lower temperature, the hydrides CH, MgH and SiH (and possibly H_2) were formed in great abundance, and their spectra formed characteristic features of spots, but the greater proportion remained in the atomic state. From calculations Saha showed that both centimetre and metre waves could be emitted by the H-atom.

Rabi and his students had also shown that, in addition to waves arising from nuclear transitions, the rotational states of the molecules were capable of radio-frequency transitions in magnetic fields.

Amidst all the administrative responsibilities and social and political turmoil, Saha was working on the propagation of electromagnetic waves through the upper atmosphere. Along with B. K. Banerjea and U. C. Guha, he published his work on the problems of an ionized atmosphere traversed by a magnetic field like the earth's atmosphere. He deduced the expressions for electrical polarization and complex conductivity for such an atmosphere when traversed by radio waves in a tensor form, as first suggested by C. G. Darwin. The equations for propagation of radio waves through such a medium were obtained by the use of cardinal axes, and then the equations of vertical propagation were deduced. The expressions were obtained for refractive indices of ordinary and extraordinary waves, which matched with the expressions given by Appleton. The expressions were obtained for polarization, absorption, etc. of the radio waves travelling in the ionosphere. The curves were obtained for the polarization ratio and refractive indices of the two waves, as a function of the magnetic latitude of the place of observation.

There was an outburst of sunspot activity which started on 22 February 1946. The days of the greatest intensity of solar noise, that is, 27 and 28 February, occurred when the sunspot was near the central meridian passage, and at the time of intense sunspot activity, several solar flares were observed in addition to the most brilliant one on 28 February. The sunspot decreased in size after the 28th of February and at the same time solar noise subsided.

The observations showed that the solar radiation (solar radio noise) was closely connected with sunspots, appearing and disappearing with it. The radiation had the characteristics of random noise; the intensity of the spectrum was neither steady with time nor continuous in wavelength, nor monochromatic. The intensity of radio emission was extraordinarily high. It was 1000 times associated with black-body radiation from the sun disc as a whole. The intensity was subjected to sudden fluctuations, occurring generally with the onset of the flares or other disturbances. The simultaneous observations of the same sunspot groups showed that the senses of rotations of the polarized signals in the two hemispheres were opposite.

Saha discussed the conditions of escape of radio waves from the solar atmosphere, with the help of magneto-ionic theories of propagation of radio waves through an ionized atmosphere traversed by a magnetic field. It had been shown from those theories that the magnetic field of the spots actually enabled the E-component of the waves to escape from deeper layers of the solar atmosphere and thus provided an explanation of the observational fact that radio waves were actually emitted by the spot regions themselves. It was shown that the same theories gave a general and satisfactory explanation of all the facts observed, for example, the circular polarization and sudden intensification of emission with the onset of radio flares.

On returning from a tour of the UK, the USA and Canada, Saha began to explore the possibility of transforming a part of the University Department into a separate institute for Nuclear Physics. He had realized the importance of atomic energy for social causes. This tour had acquainted him with research in major centres throughout the UK, the USA and Canada.

He was aware of Bhatnagar's idea of creating a chain of research institutes separate from universities. H. J. Bhabha set up the Tata Institute of Fundamental Research (TIFR) in Mumbai in 1946.

Saha was also reorganizing IACS and planning a new building for it. He was a member of the planning committee and chairman of the Advisory Board of the Central Glass and Ceramic Research Institute. The Central Glass and Ceramic Research Institute was opened on 26 August 1950 (see Fig. 9.2).

Fig. 9.2 On the opening day of Central Glass and Ceramic Research Institute, Jadavpur, Calcutta (1950). From *left to right*:?, Dr. B. C. Roy, Justice C. C. Biswas, Dr. S. S. Bhatnagar, Pandit Jawaharlal Nehru,?,?, Prof. M. N. Saha, Dr. Atmaram (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India)

At this time he worked on primary cosmic radiation and theory of the solar corona. In 1945, he promoted a biophysics group by using grants from R.P. Saha (Rs. 45,000/−), B.C. Law (Rs. 7500/−) and G.D. Birla (Rs. 200,000/−). Mr. N.N. Dasgupta was sent to Stanford University to work with Marston on electron microscopy. After returning in 1948, he constructed the first electron microscope in India.

In independent India, when the planning commission was formed, Saha was excluded. Probably it was due to staunch opposition within the Congress to the recommendations of the National Planning Committee. The lobby was so powerful that even Nehru with his strong conviction could take no concrete steps till 1950. In 1953, the Planning Commission submitted its industrial programme which was substantially different from the original plan. There was no well-defined social theory and no care for the underprivileged class. On the contrary, interests of the privileged class were protected.

Visit to USSR

In the summer of 1945, Saha received an invitation from President Komarov to attend the 220th anniversary of the USSR Academy of Sciences. The celebration took place from 15 to 30 June. He thought it was a chance of obtaining first-hand knowledge of the strange land immediately after the termination of hostilities in Europe. In fact he had just returned in February, after a long tour of 5 months from the UK, the USA and Canada. Other invitees, Shyama Prasad Mukherjee and C. V. Raman did not join the tour, so Saha prepared for a solo journey.

On the way he met Joseph Needham and Sir William Dunn, Reader in Biochemistry in the University of Cambridge, who as head of the British Scientific Mission to China had been rendering excellent service to China during the last 3 years. Needham had just arrived from Chungking after an 11 h journey and was arranging his air passage to Moscow to attend the Jubilee session. He was invited to substantiate his scheme of international cooperation in science among the different nations of the world. That scheme was forwarded to the San Francisco Conference for adoption. Later on those efforts resulted in the birth of the UNESCO.

Starting from Calcutta ‘Dum Dum’ airport at 6 a.m. on 7 June 1945, they reached Karachi after short stops at Allahabad and Delhi. At Karachi, the formalities of getting an Iranian visa from the Iranian Consul were quickly gone through, due to the efforts of his former student Mr. Manindra Nath Chakravorti, who was officer-in-charge of Railway Transport for Karachi Harbour. Saha spent the night at his house.

In the morning they took off from Karachi and reached Basrah after successively calling at Jiwani in Baluchistan, Shaga in Oman and the Bahrain Islands. At Basrah they spent the night in the Hotel Shatt-al-Arab, a luxurious hotel on the bank of the Shatt-al-Arab River which was the name given to the united streams of the Tigris and the Euphrates rivers. The next morning they reached Baghdad after a short flight of 2 h. They stayed at Regent Palace Hotel. It was 9 June. They had to wait till 11 June, in Baghdad to reach Tehran, because of non-availability of a plane which was biweekly. They utilized that time in visiting the National Museum of Iraq and other places. The Museum contained the archaeological finds of that ancient land right from 4000 B.C.

They left Baghdad on 11 June, at 12 noon, and reached Tehran at 3 p.m. At Tehran, Saha stayed at Mr. F. S. Madan's house, he was an Indian businessman well settled in Tehran. While in Tehran, they visited the National Museum of Iran, which was one of the finest, as regards both the buildings and the arrangements for displaying antiquities. Since Saha was interested in ancient and archaeological studies, he evinced keen interest in visiting archaeological museums. They visited the university also.

At Tehran, the number of delegates increased by the arrival of the American batch of about 16 delegates and Iranian delegates. The Harvard astronomer Harlow Shapley was head of the American delegation. He was Saha's old friend. Saha had stayed with him at Harvard College Observatory for 2 months in 1936, as a visiting professor. They left Tehran on 14 June at 5.00 p.m. and landed at Baku at 7.45 a.m. Then starting from Baku at 9 a.m., they reached Moscow airport at 5.45 p.m.

They were state guests during their sojourn in Russia, and on that occasion, having been specially invited for the celebrations, they enjoyed special privileges. They had their programme schedule fixed beforehand by the Academy, which included visits to Academy meetings and research institutions, dinners and lunch parties, operas, ballet and concerts, and cars would be waiting for them at the hotel at the appointed hour. If any of them expressed a desire to visit a particular person or institute not included in the agenda, a special conveyance was provided in case the person was available and the institution was one which could be shown.

The Russians attended the session in large numbers. It was their first holiday after 4 years' continuous toil. They were very eager to learn from the foreign delegates all that had taken place in the world of science all these years. There were delegates from the constituent republics, which had academies of their own, or having branches of the Supreme Academy at Moscow. Some of them were the Azerbaijan National Academy of Sciences with headquarters at Baku, the Armenian National Academy of Sciences at Erivan, the Mongolian People's Republic at Ulan Bator and the Kazakhstan Academy at Alma Atta. Their programme in Moscow was like any other conference. The Academy of Sciences had arranged a number of interesting trips: an all-day visit to the Moscow-Volga canal; a two-day visit to the Yasnaya Polyana, home of Leo Tolstoy; and visits to a state farm and a collective farm, about 20 miles north of Moscow.

The Moscow-Volga trip took place on 21 June. It was selected by the largest number of scientists. They had to motor to the northern port of Moscow known as the Khimki station about 10 km from the Kremlin. They had to pass Moscow airport and drive some distance into the open country. They boarded the fine river steamer 'Gorki', having a displacement of 2000 tons. The boat was new, scrupulously clean, provided with fine cabins, dining halls and recreation rooms. Besides foreign scientists, the steamer was crowded with a large number of people from Moscow, of all ages, young men and women predominantly. They were mostly workers in factories and ex-soldiers who had come to enjoy their day off from work in the canal. They started at 10.30 a.m. passed through locks 6, 5, 4 and 3 to Dmitrieff and then retraced the path and returned at about 9 p.m. to their hotel. There was another three-day trip to Leningrad, the home of the Academy of 209 years before its transfer to Moscow in 1934. They boarded a train at 6 p.m. on 25 June and reached Leningrad at 11.30 a.m.

In 1926, a committee consisting of 200 scientists and engineers headed by Prof. Krzhizhanovsky was appointed for elaborating the plan of Governmental Commission for the Electrification of Russia (Goelro Plan). The Plan was projected for 10–15 years, and it was provided with a capital investment of 17 billion rubles (about 2300 crore rupees) and aimed at an industrial production rise of 180 to 200 percent of the pre-war level. It was Lenin's vision. Saha had an opportunity to discuss many things with Prof. Krzhizhanovsky. He was a senior citizen of 74 but quite hale and hearty. He was also interested in the progress of India.

Indian Association for the Cultivation of Science (IACS)

In 1876, a medical practitioner, Dr. Mahendralal Sircar, founded the Indian Association for the Cultivation of Science (IACS). His objective was:

> …We want an Institution, which will combine the character, the scope and objects of the Royal Institution of London and of the British Association for the Advancement of Science. We want an Institution, which shall be for the instruction of the masses, where lectures on scientific subjects will be systematically delivered and not only illustrative experiments, performed by the lecturers, but the audience should be invited and taught to perform them, themselves. And we wish that the Institution be entirely under native management and control….. (August 1869, *Calcutta Journal of Medicine*)

This indicates his far-sightedness. He was aware of the importance of the role of science in the near and distant future. In the nineteenth century, this was unusual for India because the researches carried out at that time were by the Government of India for its own needs, namely, trigonometric survey, geological survey and meteorological survey, etc.

Mahendralal Sircar was a private medical practitioner with good income, but not enough to sustain the running of the institute. The funds collected were also not enough for a 'single professorship'. Today, looking back, one realizes that he was far ahead of his time and unfortunately his countrymen (also) could not understand him.

The activities of IACS were limited to popular lectures in different scientific topics. Father Lafont (rector of St. Xavier's College), Jagdish Chandra Bose, B. L. Chowdhury, Girish Chandra Bose and Ashutosh Mukherjee helped Sircar in these activities. For some time, classes were conducted to prepare intermediate students in science, in botany, chemistry and physics. A few scholars and honorary workers carried on research in physics, chemistry and botany.

In 1908, there was a sudden and unexpected turn of events. C. V. Raman, who was working in the Indian Finance Services, was transferred to Calcutta. Raman had carried research in acoustics when he was a M. Sc. student at Madras Presidency College in 1906. He did not get a good job in the field of education and joined the

Indian Finance Services. Even in the field as dull as administration, he retained his interests in research in physics. He found IACS as a convenient place for research. Dr. Amrita Lal Sircar, son of Dr. Mahendralal Sircar, was secretary of IACS, welcomed Raman and provided all available laboratory facilities for his research. The IACS became an active and leading research institution, which was the dream of its founder.

In 1917, Ashutosh Mukherjee invited C.V. Raman to join Calcutta University as Palit professor of physics. But the College of Science had yet no laboratory, so Asutosh, a man of vision, permitted Raman to continue his research at IACS and allowed him to use the apparatus purchased with the grants of the university to set up the laboratories at IACS. It was a fortunate thing for Indian Science that far-sighted people, like Asutosh, took sound decisions.

Raman worked with combined facilities of Palit laboratory and IACS laboratory. Some Palit research scholars carried out their research at IACS, so that Raman could supervise their work more effectively. The grandson of Raja Peary Mohan Mukherjee (one of the ex-presidents of IACS), Mr. Kumar Sri Panchanan Mukherjee, donated generously to IACS, from which two research scholars were appointed to assist Raman in his research. Due to increased resources and facilities, Raman extended his research in the fields of optics, X-rays and magnetism.

In 1928, his research in light scattering discovered a new effect, now known as the *Raman effect*. It was first published in the *Indian Journal of Physics* in 1928. Raman was awarded (full) Nobel Prize in Physics in 1930 for his discovery.

Raman was offered Directorship of the Indian Institute of Science at Bangalore and he moved to Bangalore in 1932. His coworker in the discovery of Raman effect, K.S. Krishnan, then reader in physics at Dhaka University, was appointed as Mahendralal Sircar professor in physics. This professorship was created from an endowment from Rai Behari Lal Mitra of Calcutta.

Prof. Raman, as a president of the Committee of Management of IACS, had proposed complete change in the constitution of IACS. There was violent opposition to these changes. In the meeting for confirmation of changes, the proposals were rejected and a new governing body was formed with Nilratan Sarkar as president of the Committee of Management and J.N. Mukherjee as secretary. K.S. Krishnan was allowed to carry on his research with all facilities of IACS. He set up a laboratory for research in crystal magnetism and did notable work along with his students; S. Banerjee, B.C. Guha, A. Bose and A. Mukherjee. K.S. Krishnan was elected as a Fellow of the Royal Society (London) in 1941. He left IACS in 1942 to become professor of physics at Allahabad University.

Saha was a life member of IACS from 1926, but had not taken active part in its management. After returning to Calcutta, he began to take more interest in the works of IACS. After the death of Nilratan Sarkar in 1942, U.N. Brahmachari was elected as president of IACS; he was Saha's very good friend.

Saha became secretary and later vice-president in 1944 and in 1946, after Brahmachari's death, was elected as president. The Managing Committee, under the leadership of Saha, reorganized research as well as the administrative activities of IACS. With the help of his friends, he secured funds from the Government of India and State Government of Bengal for purchase of 10 acres of land at Jadavpur. At Bowbazar Street there was no scope for expansion. Saha persuaded the Government of India to raise the annual grant from Rs. 20,000/− per year to Rs. 350,000/−. A new building at Jadavpur was constructed under his supervision, and IACS moved to its new place in 1951. According to new rules, no president was permitted to hold office for more than 3 years at a time. Saha left it and J.C. Ghosh was elected as the new president.

In 1952, with the initiative of S.S. Bhatnagar, secretary to the Government of India in the Ministry of Natural Resources and Scientific Research and a member of the Council of the IACS, it was proposed that IACS should have a full-time director. The selection committee advised the Council to offer the post to Saha. Bhatnagar persuaded Saha to accept this post. Saha became its director. He drafted a 5-year plan of activities for IACS.

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Chapter 10
Saha Institute of Nuclear Physics (SINP)

In 1936, Saha attended an International Conference at Copenhagen (see Fig. 10.1) and also visited Lawrence's laboratory at Berkeley, where cyclotron was built and research in Nuclear Physics was carried out. He was attracted towards Nuclear Physics and realized the great potential of the subject. Hann and Strassman discovered nuclear fission in 1939. European and American scientists concentrated on nuclear fission and its applications. Later, the USA worked on a (Manhattan) project of making an atom bomb, which was dropped on Japan (Hiroshima and Nagasaki) resulting in the end of Second World War.

Saha decided to work in Nuclear Physics. He included it in the M. Sc. syllabus also. By this time, the days of working individually in any field of physics with minimal equipment or on low-cost projects were over. Research in physics was carried out on large projects with a huge capital, as well as recurring grants supplied by the government. The atmosphere in pre-independent India, was not conductive to the kind of research Saha had aimed. Yet he determined to set up a cyclotron for Nuclear Physics research. It was a core facility for experimental work. Establishing a Nuclear Physics laboratory was not an easy task. The cost of constructing a cyclotron and its recurring expenditure, was beyond the budgetary provision of any university. So Saha had to look for funds from elsewhere. It was the period of the Second World War. Both financial as well as political circumstances were not favourable. He knew that it was an expensive proposition and asking grants from University or private bodies would have scared them. He followed a middle path. But later on, this path put him in trouble. He started with a small amount of money which was inadequate. People wanted quick results and were disappointed when results were not forthcoming. Serious doubts were cast about his abilities and were used against him. But in spite of all problems, the Institute of Nuclear Physics was created and made remarkable progress.

Saha worked on the National Planning Committee and frequently met Jawaharlal Nehru. He convinced Nehru of the importance and possibilities of nuclear energy. Nehru persuaded the Tata Trust to provide funds. The first funds Saha received for cyclotron laboratory were as follows:

P.V. Naik, *Meghnad Saha*, Springer Biographies,
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Fig. 10.1 International Conference on Nuclear Physics, Copenhagen, Denmark (1936). Prof. M. N. Saha is (sitting) discussing with Prof. M. Oliphant in the second row, third from left (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India.)

1. Rs. 60,000 – Sir Dorab Tata Trusts (1941)
2. Rs. 60,000 – University of Calcutta (1942)
3. Rs. 12,000 – G. D. Birla (Krishnarpan Charity Trust Fund)/recurring 5 years (1943)
4. Rs. 6000 – Sir Dorab Tata Trusts)/recurring 5 years (1944)

Saha had sent his student B.D. Nagchaudhari to Lawrence for a Ph.D. in 1938. He returned to India after 3 years in California. He was given the responsibility of purchasing a 50 ton magnet and other parts for the new cyclotron. The parcel reached India, but due to the war, it was impossible to procure other parts such as high-frequency power supply and high-performance vacuum pumps. The university workshop could not produce the required high-vacuum pumps and the work came to a halt in 1944.

In 1945, Saha started work on a separate Institute of Nuclear Physics. In 1947, he managed to raise funds for a total of Rs. 620,000: Rs. 70,000 as a capital grant through Nehru, Rs. 350,000 as operating costs from the Central Government and Rs. 200,000 for the new building by University of Calcutta. Saha was aware that no individual donations or University resources can support such research. Only the Government could afford it. Saha's hopes were bright as Jawaharlal Nehru was heading the new National Government. The funds collected were inadequate but sufficient as a start. He thought it was time to start.

Fig. 10.2 Foundation stone laying ceremony at 92 Upper Circular Road, Calcutta (1948). From *right to left*: Dr. Shyma Prasad Mukherjee, Dr. B. C. Roy, Mr. Ram Prasad Mukherjee, Mr. P. N. Banerjee, Prof. M. N. Saha and Justice C. C. Biswas (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India.)

On 21 April 1948, the Institute of Nuclear Physics (INP) was born. Mr. Shyama Prasad Mukherjee, the then Minister of Supplies and Industries in the Government of India, laid the foundation stone of the Institute of Nuclear Physics (see Fig. 10.2). P. N. Banerjee the then Vice-Chancellor of Calcutta University presided over the function. In his address Saha thanked the generous donors, Messrs. Tata Sons Ltd., Birla Brothers., Dalmia Jain Ltd., Raj Bahadur R. P. Saha, Dr. B. C. Law and Mr. M. K. Sur, for their donations with which they had helped the project. He also thanked the engineering firm of Jessop and Company for help in setting up the heavy cyclotron magnet for a nominal charge and the Council of Scientific and Industrial Research for grants, which enabled them to maintain scholars and purchase apparatus.

While stating the aims and objectives of the institute, he said [1] that the institute was dedicated to fundamental researches in Nuclear Physics, Nuclear Chemistry and Biophysics or in short ‘Atomic Energy Research’. The spectacular results of application of the principles and results of pure research often lead people to forget the sources from which they were derived or to underplay their importance; but the scientists of the USA, who had given sincere thought to the subject of Atomic Energy Research, had never undermined the importance of fundamental research.

Then he described different types of Institutions in the USA and the UK working on Nuclear Energy Research and their contributions to the field. Though the donations received in India were very negligent compared to American and British centres of nuclear research, he thought that he must convey a brief account of the work done.

Saha along with his students and collaborators had finished the assembling of cyclotron. The magnet, the power installation and the ion source had been working very satisfactorily, and they had been getting beams of several microamperes. In Fig. 10.3, Meghnad Saha is seen in front of the cyclotron at the Institute of Physics. Unfortunately, the vacuum pump system which was ordered from America was lost in Singapore in 1942, and in spite of their best efforts, they were unable to find one to suit their purpose. The Council for Scientific and Industrial Research gave them a grant for the manufacture of pumps during war, and they were able to produce samples up to a certain standard of performance, but their suction capacity was not sufficient for their purpose. The fact that America had banned exports of scientific equipment, particularly vacuum equipment which could be used for atomic research, made the situation still worse. But they hoped to overcome their difficulties soon.

N. N. Dasgupta installed the electron microscope for which he was deputed to Stanford University in 1946. That was the first electron microscope in India and would enable a huge magnification of 10^5. They hoped to attack a number of biophysical problems with its help. They had received their radium plant, as well as the radium,

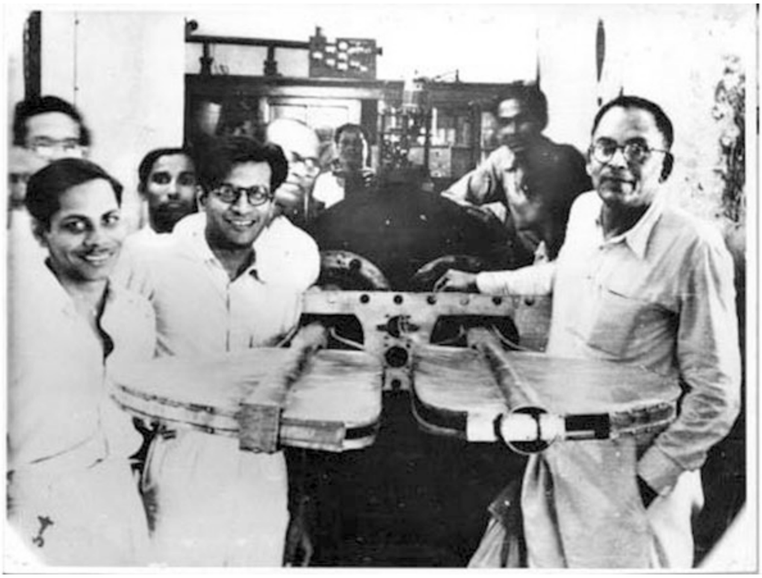

Fig. 10.3 In front of the magnet of the cyclotron at the Institute of Nuclear Physics (1948–1949 (?)). From *left to right*: Front row – Dr. A. P. Patro, Dr. B. D. Nagchaudhari, Mr. B. M. Banerjee (only part of his face is visible) and Prof. M. N. Saha (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India.)

and hoped to set it up and make the radium and its products available for physical and medical purposes soon after the new building was ready. In their workshop, they had elaborated the technique of GM counters for the study of cosmic rays, beta rays, gamma rays and neutrons. The group had also constructed and operated successfully a Wilson cloud chamber of a large size. No Nuclear Physics research was possible, without a regular supply of efficient instruments for detection of nuclear projectiles, for example, GM counters, Wilson cloud chambers, ionization chambers, beta-ray spectrograph, etc. In that field, they had thoroughly mastered the technique. Their scholars had constructed a number of beta-ray spectrographs and measured the beta-spectra of nuclei and had made important contributions. The thesis submitted by one of their scholars, A. K. Saha, for doctorate degree evoked the warmest appreciation from the examiners, Madam Irene Joliot-Curie and Profs. Ellis and Born. The technicians of the cyclotron under the guidance of B. M. Banerjee had worked out electronic devices for the various parts, which they considered ingenious for the purpose.

Theoretical methods had been evolved in the location of beta-ray spectra of radioactive nuclei, which had succeeded in bringing a certain amount of order in the nebulous field of beta-activity. The methods of estimating the age of rocks containing thorium and uranium had been developed in their laboratory. The alpha-activity method, due to B. D. Nagchaudhuri, was entirely original in conception. Saha himself had worked in 1942 on a theory of the solar corona, on the hypothesis of tri- and quadri-fission of uranium and other nuclei, which was found probable on theoretical grounds. Those had been verified in 1947 by a Chinese couple working in the laboratory of Irene Curie-Joliot in College de France in Paris. N. N. Dasgupta and P. C. Bhattacharyya had made fundamental contributions by measuring the life of meson at rest in 1940.

It was 7 years since they started new work amidst war, communal strife and political unrest. They had seen during the past 2 years people murdered within sight of them on many occasions and refugees from the neighbouring areas rushing in and taking shelter for months within their laboratory rooms. It was the period of partition for India and sudden break of communal riots. After independence however, the work had become regular.

Saha thanked Pandit Jawaharlal Nehru for a grant of Rs. 70,000 for renewal of their equipment and purchase of new equipment for the efficient running of the cyclotron.

In 1949, the Atomic Energy Commission came into existence with the following objectives:

1. To survey the country for raw materials
2. To take steps to develop those materials industrially
3. To set up a nuclear reactor within 5 years
4. To promote fundamental research in its laboratories

The Commission did not include ‘training of personnel’ as one of its objectives, and this created difficulties in procuring funds from the Central Government. Another problem was that the administration of the institute was with the University Syndicate, and it was a very sluggish body.

Saha took tremendous efforts to overcome these difficulties. After various negotiations and personal intervention by the Prime Minister, the Institute of Nuclear Physics was raised to the status of an autonomous all-India body.

The governing body had nine members: four were nominated by Calcutta University, four by the Government of India and one by the Inter-University Board. The Vice-Chancellor of Calcutta University was the Chairman, ex officio, and Saha was a life member of the governing body and Honorary Director and in that capacity Vice-Chairman of the governing body. In the resolution before the senate for the adoption of the new constitution, Saha declared that scientists have discovered methods of unlocking the tremendous amount of energy hidden in the nucleus and its use for the benefit of mankind. It might bring about a greater technological revolution than the discovery of fire or steam engine, as

1. It placed in the hands of man a source of power limitless in quantity, transportable to every region of the world and usable for every need of mankind.
2. It placed in the hands of man new weapons for control and treatment of diseases.

In general, a long time elapsed between a scientific discovery and its practical use by mankind. To shorten this time-lag, the governments of most countries have formed organizations in the form of the Atomic Energy Commissions with considerable finance and scientific personnel, to evolve methods for practical utilization of atomic power. A large fraction of the budget of the Atomic Energy Commissions was set apart for the training of personnel and the financing of fundamental research in universities, because it was felt that knowledge of the laws of the nucleus was still extremely insufficient and it can be extended only by patient and painstaking researches. Secondly, that knowledge of the fundamental laws of the nucleus might lead to a great simplification in the present practices for the utilization of atomic energy, which were based on existing knowledge.

The need for the training of personnel was far greater in India. It was a matter of extreme gratification that the Calcutta University had taken very early steps for teaching and research in Nuclear Physics. It organized a course of elementary and special training for the M. Sc. degree in Nuclear Physics as early as 1940 and it had trained quite a number of brilliant young men in the methods of nuclear research. Its early efforts have culminated in the establishment of the Institute of Nuclear Physics.

The institute was formally opened on 11 January 1950 by Irene Joliot-Curie. Other members present were Frederic Joliot, Robert Robinson, J.D. Bernal and Justice C.C. Biswas, the Vice-Chancellor. In his address, Saha said [1] that many physicists and chemists of India had been silent spectators of the great discoveries in nuclear science in Europe and America since 1921, but they were unable to make any notable contribution in that field, as their laboratories did not afford the slightest facility for any work on that line. He narrated one occasion about a discovery of neutron-induced nuclear reaction. While at Allahabad, in 1932, he and one of his students D. S. Kothari were discussing Chadwick's discovery of the neutron. They came to the conclusion that neutrons could be smuggled more easily into the nucleus of the atom than the proton or the alpha-particle, and thus it would be possible to induce nuclear reactions in all atoms. They needed a small quantity of radium for the work they planned. While they were trying to find some prospective donor for a gift of 1 g of radium, the work of Fermi on neutron-induced reactions, which he carried out with the help of about a gram of radium lent to him by the Italian government, came to be known.

He further said that in scientific research, skill and inspiration were not sufficient for success, but equipment and technical help were mandatory. They had no hopes of getting sufficient help for scientific research during the 1930s and 1940s on account of the national struggle for freedom, the consequent unrest and the Second World War from which Calcutta, of all cities in India, had been the worst sufferer. But in spite of these difficulties, they had been making preparations, which had culminated in setting up the Institute of Nuclear Physics.

Saha thanked all donors and the Government of India for recurring grants. He also thanked Prime Minister Pandit Jawaharlal Nehru and S. S. Bhatnagar, the secretary of the Department of Scientific Research, for their personal interest in the work of the Institute of Physics.

Then he commented that though the renowned Atomic Energy Establishments, which had come into existence, had mostly for their specific purpose the solution of problems for the utilization of atomic energy, they were rendering meritorious service to research workers in physics, biology, chemistry and medicine by supplying isotopes made in the pile and in the cyclotron by the manufacture of delicate and expensive apparatus needed for research and by undertaking large-scale developmental experiments which were beyond the reach of ordinary university laboratories. The Atomic Energy Commissions had recognized the importance of fundamental work by giving subsidies for research work and helping in other ways. Work on the nucleus was expensive; even a rich country like Great Britain had found it necessary to confine its patronage for Nuclear Physics work only to six universities, and many universities in the USA had been combined to run common laboratories.

Saha hoped that the Indian Government would evolve a similar policy for development of atomic energy because it promised to solve a good deal of India's problems, and one day India must tackle the problem seriously; but the greatest need of the hour in India was the training of students in methods of study and research in Nuclear Physics and providing facilities for fundamental research so that knowledge in that field may grow and India might develop sufficient technical skill to undertake work along the lines of Atomic Energy Commissions of other countries. The Institute of Nuclear Physics had started with the modest programme of training of students and of carrying out fundamental research on different topics. Compared to facilities offered by reputed European and American universities, their accommodation was just sufficient after the completion of new buildings. The programme was therefore extremely limited. They were in need of funds, both capital and recurring, to carry out their objective, and contributions would be gratefully accepted.

At the end of the speech, Saha said that atomic energy put in the hands of man is an unlimited source of power which could be distributed over all regions of the earth – deserts, mountains and other inhospitable regions. If properly developed and distributed, it would relieve mankind of the curse of drudgery, to which the sons of

Adam had been doomed, according to the Bible, for their original sin. It gave tracer elements which were powerful tools of research for the investigation of the problems of life, of medicine and of the process of agricultural production. But used unwisely, it might lead to the decline of civilization.

In spite of various administrative responsibilities, Saha never lost interest in his research. In 1951, he thought about the occurrence of stripped nuclei of neon in primary cosmic rays. In the analysis of the primary cosmic radiation observed in the out-of-the-atmosphere observations with plate technique, Bradt and Peters had given the completely stripped nucleus of neon as one of the main components of the heavier cosmic particles. The relative abundance was almost the same as that of oxygen-16. Saha argued that Bradt and Peters' identification constituted a very strong argument against the hypothesis that the sun was the source of cosmic particles received on the earth. To have stripped nuclei of neon from the sun, it should be first demonstrated that neon existed on the sun and it was at least once ionized on the photosphere or the chromosphere. But the evidence was absolutely negative, in spite of the fact that strong lines of Ne and Ne^+ occur within the solar range of wavelengths 3000–10,000 Å. The fundamental lines of Ne and Ne^+ occur in the far ultraviolet, and the lines which occur in the solar range belong to the transitions:

$1s^2.2s^2$ ($2p^5.3$ s – $2p^5.3p$) or higher transitions for Ne
$1s^2.2s^2$ ($2p^4.3$ s – $2p^4.3p$) or higher transitions for Ne^+

But the physical conditions on the sun were such that if the neon existed at even moderate strengths the lines of Ne, Ne^+ belonging to the above-mentioned combinations could not escape detection, at least in the flash spectrum of the sun. The analogous case was He and He^+, which had their fundamental lines in the extreme ultraviolet; but of the higher transition lines, only $\lambda = 10830.38$ Å, 1 s.$2p^3S_1$ – 1 s.$2p^3P_1$ was found as an absorption line in the Fraunhofer infrared spectrum; and none of the other lines of He, 1 s.(2 $s^{1,3}S$ – $np^{1,3}P$ – nd), was found ordinarily in the Fraunhofer spectrum except when the solar atmosphere was disturbed. But the lines 1 s.$2p^{1,3}P$ – 1 s.$nd^{1,3}D$, which include the well-known D_3 and other higher transition lines of helium, were found in great strength in the solar chromosphere, thus proving that though helium existed in great strength in the higher solar atmosphere, it was difficult to observe in the Fraunhofer spectrum, owing to the large excitation potential of its excited levels, which could give rise to Fraunhofer lines by absorption. But determinations of the abundance of helium to hydrogen in the chromosphere could be obtained on certain plausible assumptions and were variously given as 1:14, 1:33, etc.

The presence of ionized helium in the flash spectrum was indicated through the line $\lambda = 4685.91$ Å, $\nu = 4N[(1/3^2) - (1/4^2)]$. That was unexpected, on account of the high ionization potential of helium, 24.465 V, and the extra excitation required raising normal He^+ to the 4-quantum levels. Saha argued that if the neon was present in some strength in the sun, one could expect, from analogy with helium, that lines of both Ne and Ne^+ would be present in the flash spectrum of the sun. But not a single coincidence was found in the observations of the flash spectrum of the sun, published by Menzel or Mitchell. Therefore Saha concluded that both Ne and Ne^+ were

Fig. 10.4 Prof. M. N. Saha is addressing at the Institute of Nuclear Physics on the occasion of a foundation stone laying ceremony of students' hostel (1956) (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India.)

absent from the atmosphere of the sun and it was a strong point against the hypothesis of the solar origin of local primary cosmic ray particles.

The Department of Atomic Energy (DAE) had sanctioned a 5-year plan for the Institute of Nuclear Physics in 1954. Now INP was in better condition, compared to earlier phases of collecting money, apparatus, etc.

On 19 January 1956 (see Fig. 10.4), as an Honorary Director of the INP, on the occasion of a foundation stone laying ceremony of the students' hostel of the institute, Saha said [1] that the institute had decided to concentrate on the following lines:

(a) Particle accelerator – They had already a cyclotron. They wished to install an electron synchrotron, for which plans were under preparation.
(b) Nuclear physics – Proper dealing with alpha, beta and gamma spectroscopy, nuclear induction technique and microwave spectroscopy.
(c) Electronics and radio – Instrumentation.
(d) Nuclear chemistry.
(e) Theoretical nuclear science.
(f) Neutron physics.
(g) The post-M.Sc. teaching section.

The Institute of Nuclear Physics had a section of Biophysics, and it was hoped to diversify into a separate institute. The Professor of Biophysics N. N. Dasgupta was enabled through the generosity of His Excellency, the ambassador of the West

German Government and the Government of India, to undertake a study tour the previous year in Europe. He studied 17 famous biophysical centres in England, France and Germany. He had drawn up plans for an Institute of Medical Physics based on his studies. The plans had been submitted to the Biophysical Committee of the Council of Scientific and Industrial Research. They hoped that the new institute would materialize, leaving the Institute of Nuclear Physics the space it occupied which was needed for its own expansion.

Saha further said that nuclear science was a very expensive affair, even when they confine themselves to only science and did not indulge in technology. Their activities had been much hampered in the past due to financial difficulties, which were fortunately over due to the personal interest of the Honourable Prime Minister. Some of their work had received appreciation from the international world. The accelerator division, under B. D. Nagchaudhuri, installed a 40″ cyclotron and had devised a neutron spectrometer on a new principle, which separated neutrons of a particular energy by using delayed coincidence techniques. However, due to lack of facilities, the same work had been developed by the Americans, although it occurred to American contemporaries at a much later date. With greater technical development in the country, they could have been far ahead of others in that particular development. The work was being pursued in connection with neutron capture reaction studies. Another technique developed in the accelerator section was the attainment of large direct or impulse voltages by the radio frequency methods. That was a conventional technique, but could be a useful method for injecting large current impulses in accelerators and for the large current low energy accelerators for certain types of studies. That department had also taken an interest in mass spectrometer and had been designing one on the principles, similar to double focusing beta-ray spectrometers for mass analysis of high masses and for separation of small amounts of isotopes at low masses.

The Nuclear Physics Division under A. K. Saha had undertaken studies on beta and gamma spectroscopy, on nuclear induction and microwave spectroscopy with the collaboration of G. N. Sarkar. One of the lecturers, T. P. Das, who worked on nuclear induction, submitted a thesis for his doctorate degree. One of his examiners was a renowned American investigator, who in recommending him for the doctorate degree, said that his thesis represented work which was almost equivalent to three Ph.D. theses in the USA. Not only was it voluminous but it was a well-planned, fine piece of work. This scholar had never been outside the laboratory and had done all his work in the laboratory there.

The Electronic and Radio Instrumentation Section under B. M. Banerjee acted as general adviser to all the other sections in devising electronic and radio equipment for their use, besides taking part in teaching and research. Mr. Banerjee had devised a new kind of ionospheric recorder, with ten times the resolving power of ordinary recorders. It had received unsolicited spontaneous praise from such a great authority as Sir Edward Appleton. With the help of that apparatus, R. N. Ray and J. K. Das Verma had photographed polarization ellipses of signals, reflected from the ionosphere and had deduced a new method of obtaining the collision frequency and electron density in the ionosphere.

The sections on Nuclear Chemistry and theoretical nuclear science had not been developed to the extent they wished due to dearth of space and personnel.

Their programme was unfortunately deficient in one respect. Neutron physics was a very important branch of nuclear science. It provided the fundamental physical basis of nuclear energy development. In the USA and Soviet Russia, it was recognized that research and teaching laboratories should be provided with research reactors yielding fairly intense supply of neutrons. Saha quoted a passage from the November 1955 issue of *Nucleonics* which said, 'Every country interested in nuclear power as its ultimate objective, will go through the research reactor stage. This is already what is happening in the more advanced countries. Because of the nuclear educational void, other places need small-reactor experience'. The institute had a good nucleus staff for such a reactor. S. N. Ghoshal was trained under Prof. Segre at the University of California and had been lecturing on Reactor Physics for 2 years in the institute.

Mr. A. P. Patro, one of the research scholars, was awarded a research scholarship by the Norwegian Government and conducted research on neutron physics at the Joint Dutch-Norwegian reactor projector at Kjeller near Oslo. Mr. M. K. Banerjee, one of their younger lecturers, had been given a scholarship by the Government of West Bengal to study Reactor Physics under Prof. Wigner at the Palmer Physical Laboratory. Prof. Wigner was the first Director of the Oak Ridge National Laboratory and was responsible for many new ideas in that line and was regarded as one of the greatest experts on reactor technology. They had other people who were also working on Reactor Physics. The institute negotiated with the Government of India for the installation of a research reactor, without which their research and teaching work could not be completed.

The post-M.Sc. Associateship course in nuclear science had been designed to give further training in nuclear science to students who had taken an M. Sc. degree in physics, mathematics or chemistry so that they would be able to undertake research and technical work in that ever-expanding field. They had felt the need for such a course nearly 5 years ago, but were able to persuade Government to agree to start such a course only in 1953. That section was under Santimoy Chatterjee. Saha further added that it was gratifying to find that the need for such a course had been felt in the USA and in the UK, which was clearly indicated in the addresses by Prof. Massey and Prof. Blackett before the Physical Society of London. Moscow University had also instituted a course in nuclear science, and Saha had the pleasure of visiting that laboratory in early July.

At the concluding part of the speech, Saha added a few remarks on what was not possible for them to attempt in that field. The objective of an institute like theirs was to comprehend the laws of nuclear science, which was an entirely new world. Nuclear scientists were grappling with that problem, just in the same way as astronomers did with the problem of the motion of planets before the discovery of dynamics and Newton's law of universal gravitation. It was felt that the study of the physical properties of unstable particles, π-, μ- and θ-mesons and hyperons, would be very helpful in the discovery of those laws. But these were produced by collisions of billion-volt protons and α-particles, which compose primary cosmic rays with the molecules in the earth's atmosphere. For that purpose billion-volt generators were being constructed. The earliest was the Cosmotron at the Brookhaven National Laboratory, which accelerated protons to 2.3 BeV. With the help of those particles, they had been able to obtain all unstable particles.

The Radiation Laboratory, California, had built up a bevatron, and it was accelerating protons up to 6 BeV. With the help of that machine, which had cost 45 crores of rupees, they had been able to produce anti-protons and thus confirmed partly Dirac's theory of antimatter, in which the nucleus had a negative charge and surrounding electrons had a positive charge. It would be interesting to see how the protons and anti-protons behave when they come together. Dr. Topsuiyev, Secretary of the Academy of Sciences, USSR, who had come to India, told Saha that the Soviets were building up a 10 billion-volt bevatron which would be ready by 1956. Saha said that the construction of such an apparatus was beyond the capacity of India, but even with the meagre resources, it was possible to solve a number of problems of great interest in nuclear science.

After Saha's death the INP, his crowning achievement in spite of all difficulties, was renamed the Saha Institute of Nuclear Physics (SINP) in 1956.

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Chapter 11
National Problems and Social Concerns

Science and Culture

At Allahabad, around 1930 or so, Saha was deeply concerned about various national and social problems. He became restless and impatient. He was eager to exchange ideas with leading intellectuals and scientists of the country. The Indian Science Congress platform was not enough because it met only once in a year. With tremendous efforts, he founded the U. P. Academy of Sciences along with his colleagues which later became the National Academy of Sciences of India. He felt the need for a journal to air his and other experts' views for social causes. In collaboration with his friends at Calcutta, he founded a monthly journal *Science and Culture* in 1935 and then the Indian Science News Association.

Science and Culture was modelled on *Nature*. He wrote:

> The call that brings *Science and Culture* into existence is truly the call of the times. Nor it is obvious to every thinking man, that India is now passing through a critical stage in her history, when over the cultural foundations of her ancient and variegated civilization structures of a modern design are being built. It is necessary that at such a juncture, the possible effects of the increasing application of discoveries in science to our national and social life, should receive very careful attention; for if the present is a child of the past, it may with equal emphasis be asserted, that the future will be a child of the present. The present generation by its policy and action, will shape the course of the future.

He discussed in brief the history of Indian civilization and stressed the applications of science.

> If the discoveries of science are properly and intensively applied, they will offer far better solutions to our bewildering economic, social and even political problems…..Its (*Science and Culture*) object is dissemination of scientific knowledge among the public and advocacy of its application to all walks of life as far as practicable. The need of such a journal has long been felt, for, though India can now boast of a large member of workers in different branches of science some of whom have, by their contributions won international positions, their labours are mostly confined to their technical subjects. …. It will publish articles written in popular language by experts about the recent contributions to knowledge in various branches of science. It will publish articles discussing Government policy in technical

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> matters like rural reconstruction, transport, power development, industrial policy and such others which have their basis on science. Besides these, considerable space will be reserved for correspondence which will be open to all scientists…..An additional feature will be review of books and reports of activities of government research and technical departments. [1]

The very first editorial of *Science and Culture* showed how deeply Saha thought about society, national problems, science and its applications, or, in short, overall human progress with special reference to India. One can guess the amount of time he had spent and efforts he had put in thinking and reading numerous books and articles, related to various aspects of life. He himself wrote many editorials and articles related to organizations and institutions, scientific research, humanism and science, archaeology and history and personalities. *Science and Culture* was published from Allahabad, for the first few years, and then from Calcutta. In the first year he contributed 13 articles. Till his untimely death in 1956, he contributed 136 in total.

Saha wrote extensively on various national issues from 1922 to 1956. In the history of Indian science, no scientist is seen writing on such a scale with wide ranging subjects. All his articles or editorials were not mere descriptions or casual remarks. He studied all reports, papers, etc. related to that topic, in a meticulous manner, and applied his analytical and rational mind to these problems and many a time suggested practical solutions also. One may not totally agree with his thoughts, but his sincerity about the subjects was beyond dispute.

Saha was concerned with almost all national problems and studied these problems in details. The remarkable thing was that he investigated the root causes of the problems, finding out how that problem was tackled somewhere else, be it in Europe or America or anywhere else. What were their findings, problems in execution and how should we (India) learn from it; how certain things were best in Indian context, etc. In each problem, the analytical mind of the scientist or rather physicist was visible. At the same time he was aware of cultural, historical, social, economic as well as political contexts also. His articles and editorials in *Science and Culture* was conclusive evidence of it. He wrote on:

1. The need for a hydraulic research laboratory
2. Irrigation research in India
3. Planning for the Damodar Valley
4. The Damodar Valley reclamation scheme
5. Multipurpose development of Indian rivers
6. Public supply of electricity in India
7. National fuel policy
8. Oil and invisible imperialism
9. Fuel in India
10. Some constitutional hindrance to the development of India’s national resources
11. Development of resources and Indian constitution
12. Mineral sources and mineral policy
13. The problem of industrial development in India

14. Automobile industry in India
15. Industrial research and the Indian industry
16. The industrial policy of the Planning Commission
17. Scientific research in national planning
18. Principles of regional planning
19. Problems of independent India
20. National Planning Commission
21. The 5-year plan and so on

These topics and subtopics showed his wide ranging interest, study and concern.

Saha wrote extensively on the subjects of education, research, river management and calendar reform. While emphasizing the importance of educational trusts, he gave the example of the *Carnegie Educational Trusts*. Before the First World War, America's contribution to science, though noteworthy, was not remarkable. She was far behind countries with older traditions like England, France and Germany. But during the post-war period, in many subjects, she was forging ahead of other countries. Some of her greatest contributions were recognized by Nobel Prizes, for example, Millikan, Michelson, Compton, Morgan, Langmuir, Urey and others. The remarkable growth of intellectual and scientific life in the USA was due to a group of charitable foundations for educational purposes, endowed by American millionaires, notably Andrew Carnegie, J. D. Rockefeller, Guggenheim, Like, Bartol and others. The capital of the Carnegie Trusts alone was about a hundred crore of rupees. The income from these huge trusts was spent in financing a large number of research institutions, helping research schemes and providing for research workers. A German professor of astrophysics once remarked to Saha that they had in mind all the great work in the way of the physical and trigonometrical survey of the heavens, which the Americans were carrying out with such great success, but they had no funds which the Americans commanded. Another British professor, who had earlier won a great name in astrophysics, did not look through his telescope for years because, he said, his instrument was a mere toy compared to the giant American ones and used to spend his time more profitably in other fields.

Saha described in his article a short biography of Carnegie and the work of his trusts and commented on India's need for further research endowments. Without suitable libraries, laboratories and research grants, even the most acute brains were unable to achieve anything. The universities were turning out a large number of young men, equipped with the latest scientific ideas and fired with the ambition to do scientific work, but it was a sad tale that they found no place to work and no future to sustain their efforts and with a sad heart had to return to ordinary vocations merely to keep the wolf from the door.

At the end he wrote:

> In India evil is very rampant but the greater evil is the medieval mentality, which our people have still to outgrow. They have still to be convinced that, if poverty is to be successfully combated it can be done only by the greater diffusion of scientific knowledge, and by the adoption of scientific methods to agriculture and industry. And this cannot be done solely

> by the government. India's rich men must scale the moral height of Andrew Carnegie who held that "To die rich is to die dishonored", and we may add that to leave millions for your children or successors, which they have not earned themselves is not only to spoil their future but is in most cases, actually to push them along the road to perdition! [2]

Saha was aware of events going on in the world, as well as our current and future status! He had studied the history of India thoroughly and world history as well. In his article *Industries and Scientific Research*, he explained in detail the organization of scientific research in the United Kingdom in aid of British industries. All the arts and crafts which were at the bottom of modern industries had their origin in scientific discoveries made within the last 2 or 300 years. Subjects like metallurgy; electrical communication; various chemical, medical, food and transport industries; and countless other modern arts and crafts had revolutionized modern life not only in its industrial but also in intellectual, economic and social relationships. All those had their foundations in pure researches carried out in laboratories within the last 2 or 300 years. Those who were responsible for the planning and the management of these concerns must have a thorough and sound grasp of the fundamentals of the science out of which they had evolved. Science had not only created to all these modern arts and crafts but also continued to develop them. Every day, as a result of an obscure discovery made by some academically inclined person and its clever use by practical people, the old established methods of manufacture were being discarded or radically altered. There was no room in the modern world for any industry which continued to rely on old, time-honoured methods. When these facts were clearly realized, there would be no difficulty in finding out the nature of the actual duty of the universities to the community. The scientific staff of the universities would be doing a great disservice to the country, if they gave up doing research on fundamental and basic problems of science and training the students under their care in the latest advancement in their particular subject. If they had to undertake any industrial work, it could be only supplementary to their fundamental duties.

Industries should supplement university finance by giving subsidiary grants, which would be spent for industrial research work under competent professors by a staff of research fellows and students, who had the requisite knowledge and training in their respective sciences. All universities were churning out surplus science graduates, who had proved somewhat embarrassing to the Government and the public. The best solution was to employ them in industrial research, which would be beneficial to the country.

Then Saha described in detail the example of Messrs. Steel Brothers of London, who were interested in the extraction of petroleum in the Punjab area, secured the cooperation of Prof. S. S. Bhatnagar, Head of the Chemistry Department of Punjab University, and gave him financial support by making grants for a period of 5 years at the first instance. That enabled him to carry on his research work on petroleum, with the help of a staff of research assistants, paid out of these grants. Later on, Messrs. Steel Brothers had increased and extended those grants for another period of 5 years.

At the end of the article, he wrote that every industrial organization of India ought to realize that it was high time that a close cooperation between science and industry should exist. Scientific industrial research very rarely received all encouragement which it deserved, and the country must wake up to its call without further delay [3].

In the late 1930s, Saha was thinking about a central organization for the promotion of scientific research in all aspects, on a planned and coordinated basis. He had a model of the Russian Academy of Sciences in front of him. On similar lines he had proposed a National Research Council for India [4]. He discussed its need and role in scientific activities of the country. In 1917, a National Research Council was first appointed by the National Academy of Sciences, at the request of the President of the USA. The council included the most prominent researchers in the USA and all departments of research were fully represented. Its objective was to coordinate the scientific research work of the country, in order to secure efficiency in the solution of the problems of war and peace, and that council had rendered possible the nationalization of research in the country. Selection and training of researchers had also been given special attention to, and it had been found that the success achieved in many of the laboratories in the USA, where, with suitable organization, important investigations both directly connected with industry and pure science and had been successfully dealt with by men of no more than average ability working under competent direction. The National Research Councils in almost all countries, where they had been constituted, were not specifically concerned with the promotion and coordination of industrial research alone but were principally designed with a view to organizing, promoting and collating research in pure, as also in applied sciences, calculated to promote an all-round economic development of the countries concerned and general advancement and diffusion of scientific knowledge.

Saha suggested that the council should be composed of representatives of scientific departments under the Central Government and representatives of scientific bodies like the Indian Science Congress Association, the National Institute of Sciences of India, the Royal Asiatic Society of Bengal, the National Academy of Sciences of Allahabad, the Indian Academy of Sciences, Bangalore, etc. The council should have standing committees for specific subjects, just as the Department of Scientific and Industrial Research of Great Britain and the National Research Council of Canada had established.

River Management

Bengal was the gift of the *Ganges* and the *Brahmaputra* rivers. But curses came along with the gifts. During 1922 to 1932, two catastrophic and many minor floods visited Bengal, which caused widespread havoc and distress among the rural population. Though the flood was natural, the hindrance generated due to improper planning, in subsidence of floodwater, was man-made. The damage to human lives, cattle and crop, erosion of soil and breaking out of cholera and malaria in an epidemic form could have been reduced to a certain extent by planning with scientific analysis of the causes of the catastrophic floods and related evils.

Saha's concern about rivers and floods went back to his childhood days. Flooding of rivers was part of his village life. In his school days, he worked for flood victims. In 1922, floods created havoc in Bengal. Meghnad Saha and Subhash Chandra Bose were involved in relief work organized by P. C. Ray. Saha was in charge of publicity. He wrote an article *The great flood in northern Bengal* in *Modern Review* in 1922 and pointed out many things.

For the residents of the area, normal floods were like rituals. In general it was a source of blessings rather than misery. For example, it fertilized the soil by precipitation of river-borne silt and often even irrigation was not necessary. People in that area adapted to a mode of living in such a way that normal floods did not affect them. But the newly constructed railway line created problems. Mr. J. C. Roy of the *Social Service League* observed in a letter to the *Amrita Bazar* that at the time of the reconstruction of the new broad-gauge line, many openings on the original line were either closed or shortened in width. As a result, water could not pass easily; the flood got blocked by the railway line. Almost all correspondents had recorded the same opinion.

A worker of the *Bengal Relief Committee* who visited the area described the area as an open sea, dotted here and there with tops of trees and patches of high land, on which all classes of people were huddled together, waiting for the water to subside. The water took a long time in subsiding due to railway embankments.

In the past years there had been very serious floods in the region but that of 1922 had an unusual feature, and it was that the holding up of the floodwater by the railway embankments for an unusual length of time resulted in total destruction of crops. The District Gazetteer of *Rajshahi* showed that the flood of 1871 was highest on record but the damage to the crop was less. The water rose and then subsided. But in 1922, railway embankments held the water for a long time.

The official version of the flood threw all the blame on the fury of nature. If the railway engineers who constructed the *Sara-Santahar* and *Sara-Serajgunge* railway were conversant with this episode and cared to learn their lesson from it, the people of *Rajshahi* and *Pabna* would have been spared much of the misery.

The Director of Public Health, Dr. Bentley said:

> unfortunately, the engineers who are responsible for the construction of District Board Roads and Railway lines in this region, did not trouble their heads about the natural drainage of the country. The roads and railway lines are insufficiently provided with culverts and waterways. The water itself is not an evil, but it must be quickly drained off.

Khan Bahadur Emdaduddin Ahmed, Chairman, Rajshahi District Board said: '… the railway lines are the chief causes of the flood…… The waterways of this line are very insufficient. When this line was being constructed, we prayed and petitioned for a larger number of waterways in the line, but failed to influence the railway authorities'.

Saha wrote in his article:

> I do not for a moment, suggest that the railway engineers have purposely done the mischief. But it is clear that they failed to do good or did not care to study the interest of the people living in the regions through the heart of which the line was constructed. It is difficult for an

> engineer trained in England to realize the immense importance of unobstructed flow of water to the peasant here. The peasant of Bengal has no railway shares or debentures to live upon. The few acres of land which he possesses and tills, supplied food and clothing for himself and his family and enabled him to pay the rent, to the *Zamindar*. There is no industrial concern in the area where he can earn his bread as a labourer. He lives and dies with his paddy fields.

As a publicity officer of Acharya P. C. Ray's Flood Relief Committee of 1922, Saha proved that *the misery brought by flood was mostly man made, knowingly or unknowingly*.

A decade later, while writing on the same topic of catastrophic floods in Bengal in *Modern Review*, he described the problem of Bengal. The flatness of the country and comparative shortness of the rivers was such that normal floods had to be discharged by a large number of channels or branches. It resulted in delta-building activities on a large scale causing widespread topographical changes, within comparatively short intervals of time, creating serious problems in agriculture, sanitation and distribution in population. That could be easily seen from the position of the present and the distant past.

Before 1787, the river system of Bengal was such that floodwater was equally distributed over the whole province, and the problems of malaria and erosion were not on a large scale. Professor P. C. Mahalanobis studied this problem in a scientific spirit and based his conclusions on a large amount of data, about rainfall and an extensive study of the topographical features of the area. He concluded that the catastrophic floods were results of a number of circumstances, such as very heavy rain fall, simultaneous high levels of the *Ganges* and the *Brahmaputra* rivers, which hold back the rainwater and prevent their quick discharge into sea.

Saha suggested that both temporary and permanent remedies lay in restoring the river system, as much as possible to the state which it had before 1787. For that, engineering operations needed were almost on an unparalleled scale.

He further said that the Bengal Government maintained an irrigation department, but irrigation was not the problem of Bengal; it did not suffer from shortage of water but from excess and unequal distribution of water. Bengal did not want an irrigation department but a river-training (control of river waters) organization.

At the end, he suggested the creation of a hydraulic research laboratory for research in river training in Bengal, creation of a statistical department for continuing Professor Mahalanobis' studies and an up-to-date hydrographic survey of the river systems of Bengal.

Planning for the Damodar Valley

Saha was not merely a critic of planning. Whenever an occasion arrived, he actively participated in work. His most outstanding contribution could be seen in the *Damodar River Planning*. In August 1943 there was a disastrous flood in the Damodar River. Calcutta was cut off from the rest of Upper India for about 3 months. The period was crucial because the eastern region was threatened by the Japanese Army. Saha's writing in the daily press was one of the major reasons which compelled the Bengal Government to appoint the *Damodar Flood Enquiry Committee*. The Maharajadhiraj of Burdwan was chairman, N. K. Bose secretary and Saha one of the members.

The P. S. Rao Committee, appointed to report on the administration of the Damodar Valley Corporation (DVC), remarked on the work of the Damodar Flood Enquiry Committee:

> A moderate flood – about half the size of the 1913 flood – breached the left embankment in July 1943, and submerged the adjoining area to a depth of six to seven feet, devastating many villages, causing serious breaches of the railway line, necessitating diversion of traffic, by severing all communication, by road and rail, between General Headquarters and the 14th Army for some weeks, throwing out of gear defence arrangements, during a critical period of the Second World War, isolating Calcutta from the rest of India and dislocating normal life. That brought the problem of the control of the Damodar floods, once, more into the forefront. One of the first to draw public attention to it and insist on a comprehensive solution, was the eminent scientist, Dr. M. N. Saha. The Government of Bengal constituted a Committee, known as the Damodar Flood Enquiry Committee, under the chairmanship of the Maharajadhiraj of Burdwan with Dr. Saha, as one of the members to advise on permanent measures to control floods in the Damodar River and in particular to consider the utility of the earlier scheme of constructing flood-regulating reservoirs prepared in 1920. The Committee, recommended the construction of concrete dams on the Damodar and its tributaries, so as to hold 1.5 million acre feet of water, at a cost of about Rs. 6 crores, of irrigation and flushing schemes on both the banks, costing Rs. 3.5 crores and afforestation and other measures to prevent soil erosion, costing another Rs. 30 lakhs. It also recommended that in addition to flood retention, definite storage capacities, might be allotted for generation of hydroelectric power and for irrigation purposes. The Committee expressed the view, that it would be an advantage from the point of view of flood control and soil conservation, if forests and rivers of India, were made the concern of the Central Government. The Government of Bengal accepted the Committee's report and appointed a Superintending Engineer, to carry out further investigations and work out detailed measures. [5]

Saha demonstrated that the river system could be handled for multipurpose scheme, like Tennessee Valley Authority (TVA), USA, using the Tennessee River system. But the war halted further work. During 1943–1944 Saha published a number of articles and editorials, to create public opinion and to shape government policy. He also discussed the matter with B. R. Ambedkar, member-in-charge of Power and Works in the Viceroy's Cabinet, and his secretary D. L. Majumdar (ICS). Subsequently, the Government of India adopted a resolution to set Damodar Valley Corporation (DVC) the same way as TVA in the USA.

Saha wrote:

> The Labour Department of the Government of India is to be congratulated in undertaking seriously such a project, which is the first of its kind in India. …Readers of *Science and Culture* may recall the article on *The Planning of the Damodar Valley* by M. N. Saha and K. Ray. It is surprising, how closely the specific recommendations of the TVA experts, agree with those given in his article, though a matter of government prestige, has probably stood in the way of any acknowledgment being made. In fact, none has been made, but that does not matter. The people of Bihar and Bengal are vitally interested in the problem, and a good recommendation made with the prestige of a TVA expert is sure to evoke their good will and applause. [5]

Saha submitted a note to the Government of India regarding the selection of members of Damodar Valley Corporation, which reads as:

> … provided a competent Chief Engineer and adequate technical staff under him are available, the members of the Corporation should have between themselves, the totality of the following abilities:
>
> (a) Ability to get in close touch with the people of the area and evoke their enthusiasm so as to make them partners in this effort for the promotion of their general well-being.
> (b) Ability to gain the confidence of, and deal tactfully with (i) the officers of the local government and (ii) leaders of industry in the area, so as to secure their cooperation in the smooth working of the project.
> (c) Ability to select and handle employees and wage-earners of the Corporation, so as to make them a contented but efficient instrument for service and productive work.
> (d) Ability to negotiate contracts for award of works, on terms favourable to government.
> (e) Ability to supervise purchase of equipment and stores and put them to efficient use.
> (f) Ability to supervise the operation of settlement and revenue officials, in the areas newly brought under irrigation.
> (g) Ability to guide the development of the great industrial resources of the area, with maximum enterprise, intelligence and vision.
> (h) Ability to present major problems confronting the Corporation, in a clear, comprehensive and accurate manner, at high level conferences and discuss them with a purely objective outlook, what is called, a scientific bent of mind.
> (i) Ability to execute work and implement policies, which are approved in such high-level conferences with optimum economy of time and money.

The Corporation should have, besides the Chief Engineer, an able Secretary to handle matters, requiring policy decisions and a Director of Administration, with considerable legal knowledge and experience. [5]

These details indicated that he thought deeply about the problem in a comprehensive manner.

Freedom Movement

Saha had sympathy for freedom fighters, but he kept aloof from all political movements, because he had decided to devote his life completely to science. He had great regard for workers and leaders of the freedom movement. He also offered monetary help to political victims. Acharya P. C. Ray was fond of quoting to his pupils the example of the Italian chemist Cannizzaro who, on the call of Garibaldi, closed his laboratory, shouldered a gun and joined Garibaldi's young men on his Sicilian campaign. That produced a very disturbing effect on many young minds, but Saha felt that his work strictly lay in the laboratory and in the training of students. Though he had great regard for freedom workers and leaders, he never appreciated the *back-to-village* or *traditional-type cottage industries*. He thought people were misled by such slogans and they did not understand the blessings of the industrial revolution. It was impossible to fight poverty, disease and malnutrition without the massive use of modern science and technology.

Saha's Question and Netaji's Reply

Saha had known Netaji Subhash Chandra Bose, who was younger than Saha from his student days at Presidency College. He admired Netaji's fight for the country's freedom, his independence of thought, action and vision about nation building. Saha sent him the first copy of *Science and Culture*. Netaji wrote:

> The appearance of *Science and Culture*, is to be warmly welcomed not only by those who are interested in the abstract sciences, but also by those who are concerned with nation building in practice. Whatever might have been the views of our older "Nation Builders" we younger folks approach the task of nation-building, in a thoroughly scientific spirit and we desire to be armed with all the knowledge, which modern science and culture can afford us. It is not possible, however, for political workers with their unending preoccupations to glean that knowledge themselves; it is, therefore, for scientists and scientific investigators to come to their rescue.

In August 1938, the Indian Science News Association invited Netaji Subhash Chandra Bose to preside over the third general meeting of the association. Bose was elected President of the Indian National Congress in 1938. Saha posed a question to the Congress President: 'May I put some questions to Mr. Bose?' said Prof. Saha in conclusion. 'May I enquire whether the India of future is going to revive the philosophy of village life, of bullock cart, thereby perpetuating servitude, or is she going to be a modern industrialized nation which, having developed all her natural resources will solve the problem of poverty, ignorance and defence and will take an honoured placed in the comity of nations and begin a new cycle in civilization?'

'If the Congress High Command', said he further, 'decides on a policy of industrialization, are they going to set up a rationalized scheme of industrialization and establish a National Research Council and mobilize the scientific intelligentsia of the country? I put the question, because the Congress has come into power in several provinces and because there is great confusion of ideas, regarding the future industrialization of India'.

Netaji replied:

> The movement for Indian emancipation has reached a stage when *Swaraj* (Independence) is no longer a dream – no longer an ideal to be attained in the distant future. On the contrary, we are within sight of power; seven out of eleven provinces of British India are now under Congress Ministries. Limited though the powers of those governments are, they have yet to handle the problems of reconstruction, within their respective domain. How are we to solve these problems? We want, first and foremost, the aid of science in this task.
>
> The Congress and the task of National Reconstruction – I have always held the view and I said so in my presidential speech at the *Haripura* Congress, that the party that fights for freedom, cannot liquidate itself when power is won. That party should face the tasks of post-war reconstruction as well. Hence, Congressmen of today have not only to strive for liberty, but they have also to devote a portion of their thought and energy to problems of national reconstruction. And national reconstruction will be possible only with the aid of science and our scientists.

Bose was wholeheartedly in favour of large-scale industrialization. He put forth some of his ideas on the problems of national reconstruction.

> … India is still in the pre-industrial stage of evolution. No industrial advancement is possible until we first pass through the throes of an industrial revolution. Whether we like it or not, we have to reconcile ourselves to the fact that the present epoch is the industrial epoch in modern history. There is no escape from the industrial revolution. We can at best determine whether this revolution, that is, industrialization, will be a comparatively gradual one, as in Great Britain, or a forced march as in Soviet Russia. I am afraid that *it has to be a forced march in this country*.

Netaji emphasized the need of a National Planning Commission for the whole country. The Congress ministries in the seven provinces had already been feeling the need of a uniform industrial policy and programme. The Congress Working Committee had passed a resolution, immediately after the Congress Ministries came into existence to the effect, that it was necessary to appoint a committee of experts, to advise the Congress governments on industrial matters. The Congress Premier's Conference, which was held under the chairmanship of Subhash Chandra Bose in May 1938 in Bombay, had also confirmed this view. In July of the same year, the Congress Working Committee decided that Bose should convene a conference of the Industries Ministries of the seven Congress-administered provinces. Bose gratefully recognized the efforts of *Science and Culture* to direct intelligent thoughts towards the problems of industrialization and said that the articles in *Science and Culture* on Electric Power Supply, Food Control, River Physics, the need of establishing the National Research Council, etc. had been highly illuminating and instructive. He outlined the Principles of National Planning as:

1. Though from the industrial point of view the world is one unit, we would nevertheless aim at national autonomy, especially in the field of principle needs and requirements.
2. We should adopt a policy, aiming at the growth and development of the mother industries, viz. power-supply, metal production, machine and tools manufacture, manufacture of essential chemicals, transport and communication industries etc.
3. We should also tackle the problem of technical education and technical research. So far as technical education is concerned, as in the case of Japanese students, our students should be sent abroad for training in accordance with a clear and definite plan, so that as soon as they return home, they may proceed straightway to build new industries. So far as technical research is concerned, we shall all agree that it should be free from governmental control of every kind. It is unfortunately only in this country, that government servants are entrusted with scientific research on receipt of princely salaries and we know very well what results have been obtained therefore.
4. There should be a permanent National Research Council.
5. Lastly, as a preliminary step towards national planning, there should be an economic survey of the present industrial position, with a view to securing the necessary data for the National Planning Commission.

These are, in brief, some of my ideas on the problems of industrialization and national reconstruction and I believe they are held in consensus by scientific men and women in this country. We, who are practical politicians, need help you, who are scientists, in the shape of ideas. We can, in our turn, help to propagate these ideas and when the citadel of power is finally captured, can help to translate these ideas into reality. What is wanted is far-reaching co-operation between science and politics. [5]

In his address, Saha tried to ascertain the attitude of Congress towards the problems of industrialization. Bose said that all Congressmen do not hold the same view on this question. But the rising generations are in favour of industrialization. Industrialization is necessary for solving the problem of unemployment, to compete with foreign industries and for improving the standard of living of the people at large.

All these thoughts indicate that Bose was very clear about post-independence problems and future plans, in contrast to other political leaders. Unfortunately, Bose resigned as President of Congress in 1939, which had far-reaching consequences on Indian history.

Calendar Reform

Knowingly or unknowingly, Saha developed a lifelong interest in astronomy and cultural heritage due to his two teachers, P. C. Sengupta and P. C. Ray. Sengupta introduced him to the world of astronomy, both ancient and modern, and Acharya P. C. Ray made him aware of our heritage and involved him in social work.

Saha's absorbing interest in ancient Indian history and love for astronomy could be seen culminating in the reform of the Indian calendar. He studied this subject for a long time. In 1939, while writing on the 'Need of calendar reform' he said:

> the calendar is an indispensable requisite of modern civilized life…. But calendars are almost as numerous as nations. At present almost the whole of Europe, uses the Gregorian calendar for economic as well as for religious purposes, and in other parts of the world, the Gregorian calendar has spread along with European dominations. But most of the Eastern countries excepting Japan and China retain, at least for religious purpose, indigenous system of calendar, which very often clash with the official calendar and produce serious dislocation of public work. …. The Hindu calendar, which regulates the life of 99% of the Hindus, is a most bewildering production of the human mind, and incorporates all the superstitions and half-truths of medieval times…. The Hindu calendar describes April 15, as the day of the vernal equinox, but as is well known, this event actually falls on March 21. If the error is allowed to continue, the months will be described as a complete cycle round the year in about 23,000 years. Further, as the festivals are connected to the moon, the seasons and the stars, the dates have to be adjusted periodically by an intricate system of intercalation. In spite of these errors, very few have the courage to talk of reform. We are content to allow religious life to be regulated, by the encyclopedia of 'errors and superstitions' which is called the Hindu almanac, and to regard it as scripture. [6]

The Council of Scientific and Industrial Research (CSIR) of the Government of India appointed the Calendar Reform Committee in November 1952: 'To examine all the existing calendars, which are being followed in the country, at present and after a scientific study of the subject, submit proposals for an accurate and uniform calendar for the whole of India'.

The committee consisted of M. N. Saha as chairman and L. L. Lahiri as secretary. The other members were A. C. Banerji (Allahabad, Uttar Pradesh), K.L. Daftari (Nagpur, Maharashtra), J. S. Karandikar (Poona, Maharashtra), Gorakh Prasad (Allahabad, Uttar Pradesh) and R. V. Vaidya (Ujjain, Madhya Pradesh).

In a message to the committee, Prime Minister Jawaharlal Nehru said:

> 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 attend 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.

As per the terms of reference, the committee examined scientifically all the calendars prevalent in India, namely, the Gregorian calendar which was used for civil and administrative purposes all over the world. The Islamic calendar was used for fixing the dates of Islamic festivals, and Indian calendars or *Panchangas* were used for fixing dates and moments of Hindu, Buddhist and Jain festivals in different states of India and in many cases civil purposes also. There were about 30 Indian calendars.

It was evident from his articles in *Science and Culture* that Saha was deeply preoccupied about calendar, calendar reform and world calendar.

The committee pointed out that the Gregorian calendar, which was used all over the world for civil and administrative purposes, was very unscientific and inconvenient.

Time Measurement

The flux of time is cut periodically by several natural phenomena, namely, recurring alternation of day and night, recurrence of the moon's phases and recurrence of seasons. These recurring phenomena are used to measure time. These phenomena have great importance for man because they determine human and animal life. Organized social life was started in the valleys of the Indus and Ganges (India), the Nile (Egypt), the Tigris and the Euphrates (Mesopotamia) and the Huang Ho (China) rivers, several millennia before Christ. These early societies were founded on agriculture and agricultural practices and depend on seasonal weather conditions.

People wanted to know in advance the night of the new moon or the full moon to celebrate festivals; the onset of the season for preparing ground, sowing and harvesting; etc. The prediction of these events is found in the *Calendar*.

The Day

In the three natural recurring events – alternation of day and night, the moon's phases and seasons – the day is the smallest unit. It is taken as the fundamental unit of time, and the length of month, the year and seasons are expressed in terms of day as the unit.

Earlier, people defined day as the time period between sunrise to sunrise or sunset to sunset. But soon it was realized, that the sun does not rise or set at the same time in different seasons of the year, except when it is at the equator. Then the idea of mean solar day came, which is now taken as the fundamental unit of time. The *mean solar day* is the average interval between the two successive passages of the sun, over the meridian of a place, derived from a very large number of observations of such meridian passages. In addition to the mean solar day, the astronomers define a *sidereal day* also. It is the time period between two successive transits of fixed stars. It measures the time of rotation of the earth round its axis. The mean solar day is larger than the sidereal day, because by the time the earth completes a rotation around its axis, the sun slips nearly a degree to the east, due to the motion of the earth in its orbits, and it takes a little more time, for the sun to come to the meridian of the place. Thus:

1. Rotation of the earth = 23 h 56 m 4.100 s
2. Sidereal day = 23 h 56 m 4.019 s
3. Mean solar day = 24 h 3 m 56.555 s

The actual sidereal day, which measures the period of rotation of the earth, is generally taken as constant. The variable part of the solar day comes from the obliquity of the sun's path to the equator and unequal motion of the sun in different parts of the year.

The Month

The word month is really 'moonth' or period of the moon. The month is a lunar phenomenon and it is the time period from completion of new moon to the next new moon. The length of the month varies from 29.246 to 29.817 days, due to the eccentricity of the moon's orbit and other causes. The month or lunation used in astronomy is the mean synodic period, which is the number of days comprised within a large number of lunations divided by the number of lunations. Its value is 1 lunation = $29.^{d}5305882–0.^{d}0000002$ T, where T = number of centuries after 1900 A.D.

The Year

In the earliest mythology of most nations, the length of year was 360 days, consisting of 12 months, each of 30 days. The Egyptians found from the recurrence of the Nile floods that the year had a length of 365 days. Later they found that the true length was 365.25 days.

But even 365.25 days is not an accurate measure of the length of the year. About 400 B.C. a Babylonian astronomer Kidinnu discovered that equinoctial points, that is, the points where the sun's path cuts the equator are not fixed. This point is very important, because when the sun reaches this point, day and night become equal throughout the whole world, and many nations used this point as the beginning of the year. Kidinnu found that this point has a slow westward motion along the sun's path, that is, precession of the equinoxes.

The year should be defined not as the period in which the sun goes through its orbit, that is, returns to its conjunction with a certain fixed star, but with the time of its return from vernal equinox to vernal equinox. This is known as *tropical year* and modern data shows its length is nearly 365.2422 days. But the other year, the period of the return of the sun to the same point is also used, and it is known as the *sidereal year*. It is little longer than the tropical year, that is, 365.2563 days.

The Calendar Reform Committee studied the history of the calendar through ages along with various misconceptions and confusions throughout the world. It described the problems of the calendar – whatever may be the correct lengths of the month and the year, for the application of human life, the following points have to be observed in framing a civil calendar:

1. The civil year and the month must have an integral number of days.
2. The starting day of the year and of the month should be suitably defined. The dates must correspond strictly to seasons.
3. For purposes of continuous dating, an era should be used and it should be properly defined.
4. The civil day, as distinguished from the astronomical day, should be defined for use in the calendar.
5. If the lunar months have to be kept, there should be convenient devices for luni-solar adjustment.

A sound and satisfactory solution for these problems was not available. The early calendars were based on insufficient knowledge of the length of time cycles – day, month and year – and led to gross deviations from facts, which had to be rectified from time to time by the interventions of dictators like Julius Caesar, Pope Gregory XIII or a founder of a religion like Mohammed or Akbar the Great Indian Emperor.

The Gregorian Calendar

The Julian year was of 365.25 days and the true year was of 365.2422 days. The difference was of 0.0078 days. Therefore, the winter solstice, which fell on December 21 in 323 A.D., fell back by 10 days in 1582 A.D., and the Christmas day was losing all connections with the winter solstice. The discrepancy was also noticed in connection with the observance of *Easter*. The Council of Trent, which assembled in 1545, authorized the Pope to deal with the matter. In 1582, Pope Gregory XIII published the revised calendar and ordained that Friday, October 5 of that year, was to be counted as Friday, October 15. The centurial years that were not divisible by 400 were not to be counted as leap years. In consequence, the number of leap years in 400 years was reduced from 100 to 97 and the year length became 365.2425 days; the error was only 1 day in 3300 years.

The calendar was adopted by the Catholic states of Europe immediately, but elsewhere it was adopted later. Great Britain adopted it in 1752. But by that time the error was of 11 days. September 3 was designated as September 14. Some countries adopted it comparatively recently: China and Albania in 1912, Bulgaria in 1916, Soviet Russia in 1918, Rumania and Greece in 1924 and Turkey in 1927.

Though this Christian or Gregorian calendar is widely used, it is an inconvenient system of time reckoning. The objections to this calendar are as follows: the days of the months vary from 28 to 31, quarters consist of 90 to 92 days and two half-years contain 181 or 184 days. The weekdays wander about the month from year to year. The number of working days per month varies, from 24 to 27, which creates confusion and uncertainty in economic dealings and in the preparation and analysis of statistics and accounts.

People were aware of these difficulties and even tried to resolve it. In 1834, the Italian padre Abbe Mastrofini proposed a 13-month calendar. It was also strongly advocated by philosopher Auguste Comte. But no attention was paid to it and it was thus abandoned.

The proposed world calendar was a simple device. The year was divided into four quarters, each of 3 months of 31, 30 and 30 days' duration. January, April, July and October would each have 31 days and start on Sunday; February, May, August and November would each have 30 days and start on Wednesday; and March, June, September and December would each have 30 days and start on Friday.

In this improved world calendar,

1. Every year was the same.
2. The quarters were equal and each quarter had exactly 91 days, 13 weeks or 3 months.
3. Each month had 26 weekdays, plus Sundays.
4. Each year began on Sunday and ended on Saturday.
5. The calendar was stabilized and perpetual by ending the year with a 365th day that followed December 30 each year called *World Day* or December 31, a year-end *World Holiday*. Leap-year day was similarly added at the end of the second quarter, called *Leap-year Day* or June 31, another *World Holiday* in leap years.

Due to the request from the Government of India, at the eighteenth session of the Economic and Social Council of the United Nations held at Geneva during June–July 1954, the proposal of the World Calendar Reform was discussed. Saha as a chairman of Calendar Reform Committee attended this meeting to explain the desirability of the proposed reform.

Several Jewish organizations raised objections to the World Calendar, stating that it interferes with the unbroken seven-day week, by introducing World Day and Leap-year Day without any weekday denomination. This will interfere with their religious life.

Saha said that the religious sanction for the seven-day cycle was either non-existent, or slight, among communities other than the Jews, and even among them, it dates only from the first century A.D. The claims of certain Jewish rabbis to prove that the seven-day week cycle has been ordained by God Almighty from the moment of Creation which event, according to these Jewish rabbis, took place on the day of the autumnal equinox, also a new-moon day, was an extraordinary conception of medieval scholars, which no sane man can entertain in these days of Darwin and Einstein.

The Week

The day, the month and the year are related to astronomical phenomena, but the cycle of seven days called the *week* is an entirely artificial cycle. According to the ancient Babylonian superstition, the number seven had some magical meaning as it corresponded to the number of heavenly bodies which are in motion, namely, the sun, the moon and the five planets, Mercury, Mars, Jupiter, Venus and Saturn. About 1800 B.C. the Babylonians invented the cycle of 7 days, each day after a planetary God. The seventh day was originally considered as an unholy day. But when the Jews took up the Chaldean calendar about 600 B.C., they called it the Lord's day and invented the myth that God rested after His Labour of Creation on the seventh day, the *Sabbath*. According to Jewish scriptures, all work was prohibited on the seventh day.

Many ancient nations, including the Hindus, had originally no such cycle as the week. It appears to have come into vogue in India with the Macedonian Greeks, who got it from Babylon in the first century A.D. From 325 A.D. the use of the week became common throughout the Roman Empire. The seven-day cycle has no foundation on any natural phenomenon. It is related to the human system as regards endurance, efficiency and the need for rest. History shows that the seven-day week is an artificial man-made cycle. It arouse out of the psychological need of mankind for having a day of rest and religious service, after protracted labour extending over days.

The continuous seven-day week was unknown to the classical Greeks, the Romans, the Hindus and early Christians. Roman Emperor Constantine I introduced it into the Christian world around 323 A.D. Weekdays are not found in earlier Hindu scriptures like the *Vedas* or the classics like the great epic *Mahabharata*. Even today, they have no importance in religious observances of Hindus, which are determined by the moon's phases.

From a detailed study of history of the calendar through ages, Saha concluded that the continuous seven-day week was not a part of religious life of any ancient nation, and it is not, even now, part of the religious life of many modern nations. It is man-made and introduced on psychological grounds and therefore can be and should be modified, if it improves and simplifies human life.

Calendar Reform Committee studied the history of calendar making in all countries from the earliest times, particularly the history of calendar making in India, and drew its conclusions. Its recommendations were entirely in agreement with the precepts laid down by the *Siddhantic* astronomers, as given in the *Surya-Siddhanta* and other standard treatises. The committee had also compiled a list of all religious festivals observed in the different parts of India and listed them under the headings *lunar* and *solar* with their criteria, for fixing the dates of their observances.

The committee had suggested a system of calculations, for the religious calendar also, based on most up-to-date elements of the motion of the sun and the moon.

The committee's report was submitted to CSIR in 1955 and the Government of India, in accepting the recommendations of the committee, decided that 'a unified national calendar' – the *Saka* calendar – be adopted for use with effect from 21 March 1956 A.D., that is, 1 *Chaitra* 1878 *Saka*.

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Chapter 12
River Physics and Flood Control

In Sir P. C. Ray's 70th Birthday Commemoration volume [1] while insisting on the need for a hydraulic research laboratory, Saha said that such a need had been long emphasized by an expert, Sir F. Spring, C.I.E., chief engineer to the Government of India in 1903. He was responsible for the design of a large number of railway bridges, the most well-known being the Sarah Bridge (Bengal) over the Ganges, mentioned in his book 'River Training and Control'. It was rather strange, that when science was being applied to every walk of life for ensuring human comfort, the problem of river control had never been scientifically studied in India. He mentioned the list of hydraulic research laboratories in Germany, Austria, Czechoslovakia, Hungary, Soviet Russia, Sweden, Norway, France, Italy, Holland and the USA and briefly described the work of major hydraulic laboratories in the world and described the problem of Bengal.

Bengal is the land of rivers and her prosperity and well-being depend on her great rivers and their tributaries. The past showed that the change of river courses either by men or providence had been dealt with dire consequences. In the fifteenth century, the city of Gaur[1] was the capital of Bengal for over a thousand years and possessed a population of over two million. It was completely destroyed by a terrible marsh fever, caused by the diversion of the courses of the Ganges and the springing up of an unhealthy marsh in the vicinity of the city. The whole area had been ravaged by malaria and black fever.

Saha pointed out that there was a lack of any organization for recording experience or original research in connection with the physics of great rivers. He suggested the appointment of a river commission not merely for Indus but for the organized study of the physics of great alluvial rivers. There was a need for a thoroughly scientific location and for the automatic reading of gauges at hundreds of places for several years. Suitable lengths had to be selected with care and knowledge

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[1] *Gaur* is a ruined city on the present India-Bangladesh border. Its major part is in *Malda* district of West Bengal, India, and smaller part is in *Nawabganj* district of Bangladesh. The current course of the Ganges is away from the ruins.

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of several of the great Indian rivers. Systemization of the surveys was to be undertaken on these rivers, and fresh surveys had to be carried out.

He discussed the work done in river physics laboratories and their applications in America, Germany, Italy and so on. While writing about the problems of Bengal, he pointed out that the Ganges, though a much shorter river than the Mississippi, discharged more water at Sarah than the Mississippi near the head of its delta. No reliable estimate of the discharge of the Brahmaputra was available, but its discharge was supposed to be much larger than that of the Ganges. Those massive discharges, which were timed at certain intervals, took place over an area, which was smaller compared to the Mississippi River Basin. He suggested that the discharges of all these rivers, their periodic variations, the amount of silt brought by them, the distribution of the water in the country and study of the precipitation data for each basin – all these factors – must be accurately studied before any great engineering project, such as river training, railway bridges and bunds, excavation of old channels, flood control, canalization for irrigation and navigation, was undertaken. The plans must be tested in the laboratory, with the aid of models repeatedly, and advantage should be taken of the accumulated experience of western countries that had not been done in the past or in the present; and unfortunately great engineering schemes were being launched without proper study.

Eastern Bengal was then prosperous and mostly free from malaria because every year she was washed by floods, which deposited fertilizing silt on her soil and carried away the germs of malaria. But history has proved that the rivers of Bengal, either due to slow earth movement or delta-building activities, periodically oscillate between wide limits and if one overlooked an old channel and scooped out a new one, the old basin becomes the hub of malaria and black fever.

Saha warned that a big river like the Dhaleshwari keeps depositing silt in the countryside around populous villages and raises its level. After some time the level of the villages becomes lower than that of the fields and stagnant pools are formed within the villages. Then suddenly malaria breaks out with unprecedented violence on an unsuspecting population. If the river was not controlled and people were not taught how to live in such areas and keep their pools clean, he warned that eastern Bengal may be subjected to the same devastating epidemics which had ruined western Bengal. The need for scientific study of the physics of rivers was a universal problem which could not be undertaken piecemeal.

Some people argued that the training of rivers was the work of such stupendous magnitude and that it was futile to make any attempt in interfering with them. He quoted Sir John Benton, former chief engineer to the Government of India, who remarked that the greatest change which took place in the river systems of Bengal was the diversion of the Brahmaputra from the east of Dhaka to the west. That began with a catastrophic flood in the headwaters of the Teesta River in 1736, but it took about half a century to be completed. That catastrophic change, which was responsible for many evils, could have been easily prevented if it was attended to promptly.

The other great change which had taken place since 1776 was the gradual silting of the headwaters of the rivers Bhagirathi, Jelanghi and Mathabhanga, which used to provide water to central Bengal. It rendered central Bengal a land of stagnant rivers and subjected it to devastating outbreaks of malaria. It was the most prosperous part of Bengal during the Moghul period, far richer than eastern Bengal, but to date its productivity of soil had fallen off by about 45%.

To endorse his suggestions about research on river physics, Saha cited the opinions of Sir W. Willcocks, the eminent engineer from Egypt, who said that the rivers in central Bengal could be revived and the prosperity of the country could be restored by clearing off the headwaters of the Mathabhanga and subsequently, when the country became rich, by erecting an Egyptian barrage across the Ganges, 11 miles downstream of the Baral head. The barrage would hold up the waters of the Ganges by about 7 ft. for a hundred miles upstream and allow it to send a large volume of its excess water down the rivers of Central Board. Another advantage was that less water would flow through the over-congested Padma River, which had caused widespread havoc by its erosion. Already half of the Vikrampur area was washed away. The waters of the Brahmaputra alone were more than sufficient for eastern Bengal.

Saha suggested that such a scheme must be studied for years in the laboratory with the help of successive laboratory models and other data, before it was launched. Not only central Bengal, but it would also rid eastern Bengal of the periodic catastrophic floods which were due to the blocking of the Brahmaputra waters by a simultaneous rise in the Ganges. He further pointed out that the expenditure on river physics laboratory would be 0.5% of the damage caused by flood of 1931 alone to the poor people of eastern Bengal.

Finally, he proposed that a hydraulic research laboratory should be established for the study of problems of river training, flood, irrigation, navigation and hydraulic power development. It should be a purely research institute, after the model of the Wasserbau Laboratory of Berlin-Charlottenburg or Vienna. The objective should be the study of physics of great rivers, preparation of plans in cooperation with the department and testing of the plan by means of laboratory model. As the problems require thorough knowledge of physics and mathematics, and demand much originality for their solutions, the laboratory should foster a research environment. It should be placed under a distinguished physicist who was also well-versed in mathematics. He should be provided with a well-qualified staff, consisting of experts in allied subjects, and a well-equipped laboratory. Such a laboratory should be attached to the university, as engineering colleges in India had not then developed any research atmosphere. In addition to this, there should be a Department of Field Service, which would undertake a hydrographic survey of the rivers of Bengal, including relevant topics in topography, collection of precipitation data and other geophysical factors likely to be of use, in the preparation of a great constructive project.

Saha was constantly preoccupied with the subjects like flood, irrigation, navigation through channels, cheap electric power production and so on. Apart from writing in *Science and Culture*, he expressed his thoughts at various platforms. In 1938, for the presidential address to the annual meeting of the National Institute of Science (India), he selected the topic *The problem of Indian rivers*. While discussing it, he remarked that the riparian area of India consisted of the lower reaches of the rivers where they begin to form deltas. The physical condition of these areas and the life of the rivers were quite different from those in the upper sections. Up to Rajmahal (now in Jharkhand state), the Ganges receive only tributaries, but below it the river flows through soft soil and divides itself into a labyrinth of channels. The land was low and subject to inundations during the monsoon season. There was a great difference of opinion, as to whether the ancient rulers made any attempt to prevent these rivers from leaving their beds, finding out new channels and eroding villages and cities.

From the position of the rivers in Punjab, about 2000 years ago, he showed that the rivers had a tendency to change their course and that they generally move west. There was a tussle between the desert and the river valleys. The desert was constantly encroaching on the rivers and pushing them to the northwest, either it was due to some deep-seated tectonic action, whose influence was accumulative or there had been a change in the course of the monsoon tracks of rain clouds. Besides Harappa and Mohenjodaro, a large number of cities, were buried under the sands of Sindh and Rajputana.[2] These cities could not have existed unless there was ample supply of water in those regions 5000 years ago than now. The north-western monsoon formerly had a more southerly course and passed over Sindh and Rajputana. The rivers of eastern Punjab used to unite in a powerful course and flow in a separate channel, parallel to the Indus, to the sea, thus giving Sindh all the advantages of a land between the two rivers, the Indus on the west and the Saraswati on the east. The lower course of the Saraswati ran dry during the Vedic times. The other rivers had moved away from their courses generally to the west. According to geologists, the changes in the courses of the rivers were due to crustal movements. These changes caused great hardship to the population which was mainly dependent on agriculture.

Throughout historical periods, constant changes had taken place on the lower courses of Ganges and Brahmaputra. These changes had exerted a far-reaching influence on the economic and political condition of the countries through which they passed. The peak discharge of Ganges during the monsoon period exceeded that of the Mississippi and was seven times that of the Nile. The discharge of the Brahmaputra was about one and a half times greater than that of Ganges. These circumstances, combined with the fact that they flow over a comparatively small region – Ganges, 1500 miles, whole of India, and Brahmaputra, 1800 miles of which 800 miles of India – had made these rivers as unique objects of interest. During the past 150 years, the courses of the Ganges and the Brahmaputra rivers over the lower reaches had changed considerably. Some of the ancient watercourses had entirely disappeared, and new systems which did not exist 200 years ago had come into existence. The Ganges and Brahmaputra 200 years ago used to discharge their waters by two separate courses which were about 150 miles apart from each other. There was a third system of watercourse between these two which, flowing

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[2] Between 2600 B.C. and 1900 B.C., more than a thousand settlements of the Indus civilization, including at least five cities, covered at least 800,000 square kilometres. Only 10% of sites have been excavated [2].

through northern Bengal, used to discharge its water independently into the sea or into one of these two rivers. But great changes occurred between 1787 and 1818, and after that the main streams of the Ganges and the Brahmaputra unite 200 miles inland. That had brought about widespread changes in the topography and the economic life of those regions. Those wide changes were characteristic of all the rivers in the whole of Bengal and in Assam and to a much lesser extent of the deltas of the Mahanadi River of Odisha. Those changes had caused great dislocation of human life – old cities had been eroded, prosperous rural-areas had been washed away, swamps had been formed and regions once populous had been ravaged by malaria. The question was could those changes be controlled at all. Besides causing widespread changes in rural areas, the deltaic rivers had played havoc with the ancient cities that were results of centuries of patient and concentrated labour by ancient rulers and communities. Most of the ancient cities in the country playing a great part in its political history grew on their banks or on the banks of their tributaries. No full and consistent account of the causes leading to the rise and growth of these cities or the phenomena of the growth and decay of states connected with them caused by the action of the rivers was available to the public.

Saha discussed some of the ruined cities in deltaic areas. Ancient Patliputra was the capital city in India from sixth century B.C. to about fifth century A.D. – for the span of nearly a thousand years. It was an important trade centre at the junction of five rivers, the Ganges, the Son, the Ghaghara, the Gandaki and the Punpun, at a time when rivers were the main channels of communication. It now lies buried under the present city of Patna in Bihar, at a depth of 17 ft. below the ground level. Its destruction was due to devastating floods. In the deltaic regions, the level of a city gradually plummets while that of the surrounding country rises, so protective bunds had to be constructed to keep the floodwater out. But sometimes, when the city was located between two rivers, like Patliputra, and there were simultaneous floods in both rivers, those bunds gave way, causing inundation and depositing of thick layers of silt. The excavation had shown that ancient Patliputra used to be very often ravaged by floods and ultimately disappeared under the silt deposit. It was quite probable that the disappearance of the Magadhan supremacy after sixth century A.D. in Indian politics may be due to the destructive action of rivers on the chief cities of Magadha which the rulers were unable to gauge and control.

Many prosperous cities in the lower Indus Valley had been abandoned, because they used to be very often visited by floods or the rivers changed their courses and deserted cities. The whole Indus Valley is full of dead sand-buried cities along the old course of the Indus.

Another menace to great cities on river banks was the possibility of the formation of unhealthy swamps in the neighbourhood, which might gave rise to catastrophic epidemics. The city of Gaur was the capital of eastern India from fifth century A.D. to 1576 A.D. It was situated between two branches of the Ganges River, and another large tributary, the Mahananda, flowed nearby. A deadly swamp grew in its rear on account of changes in the river courses and possibly due to the lowering of the city level, the drains in the cities could not discharge the sewerage to the rivers properly. The result was the outbreak of an epidemic which swept away the majority of the population about the year 1575 and the vast city, which was estimated by the Portuguese merchants of the sixteenth century to contain a population of over two million, now remained buried under an overgrowth of jungle.

Saha reiterated the point again and again, of forming many river physics laboratories. Considering the vast size of the country and the diversity of the problems in the different regions, the number of river physics laboratories, one in Punjab and the other in Maharashtra, was extremely small and the equipment of these laboratories which had been constructed were not sufficient.

He had studied the training of the Tennessee River (USA) in detail and wrote an article about it [3]. He was of the opinion that, of all the river basins in the world, the Damodar Valley had the closest parallel to the Tennessee Valley, though at a smaller scale. The radical solution of the problems of the Damodar Valley lay, therefore, in the adoption of similar procedure as had been done by the US Government through the Tennessee Valley Authority (TVA) with necessary modifications.

While writing on Planning for the Damodar Valley [4], Saha said that though it was only the people of Bihar and Bengal who were directly concerned with that problem, the studies were of interest to the whole of India. Since time immemorial, human life in India had developed in the valleys of the great rivers which had served as natural highways, as arteries for supply of water essential for agriculture and other essential human activities. But for ages past, rivers had been interfered with in unscientific way by different parties, producing very injurious effects on agriculture, public health and river communications. But modern scientific developments had enabled the advanced countries of the west and America, not only to retard such evil effects but to develop the rivers to the fullest extent for the above purposes and also to generate hydroelectric power, wherever possible, and thus enhance the nation's industrial capacity.

In those studies, along with his colleagues, students and friends, Saha had tried to prove that it was possible to treat the Damodar River basin to full measures of planned reclamation and thus convert a destructive river system into a beneficial agency, producing a large amount of electrical power, ensuring water for irrigation and flushing of the river basins throughout the year, eradicating the eternal menace to rail and road communication and guaranteeing public health. The source of trouble was the unequal distribution of water – the rainfall coming in abrupt surges and lasting only for a short period in the year during the monsoon months. The solution of the problem lay in scientific storage and adequate management and distribution of water resources of the basin, combined with land reclamation measures.

Saha had studied the works of Lt. Garnault, Mr. Horn, Mr. B. L. Sabharwal, Mr. Addams-Williams, Mr. E. L. Glass, etc. who were appointed on various occasions since 1863 to recommend fuller remedial measures, after a scientific study of the problem. Their reports contained summaries and discussions on the subjects of construction of dams on the Damodar River and its tributaries like the Barakar, Usri and others. He partook that knowledge and used his own discretion to offer solutions.

Whether for flood control, water control or power production, the core of the constructive work lay in the erection of a series of dams in the upper Damodar and Barakar regions and a series of barrages in the lower reaches for distribution of water for irrigation and flushing. He formulated his plan for the multipurpose dams. He described all dam sites on Damodar and Barakar rivers in detail, such as catchment area, storage capacity of proposed reservoirs, flood control, power generation, irrigation, effect of rainfall, reduction of flood crests, groundwater, problem of silting of reservoirs and so on.

In his article on *Multipurpose development of Indian rivers* [5], he recommended the following steps in any scheme of development:

1. Survey of the inherent characters of the land and the natural resources – water, minerals, soil and vegetation.
2. Planning on a multipurpose basis so that power, navigation, irrigation, land use and flood prevention were integrated in an efficient way.
3. Design.
4. Construction – systematic researches should be constantly taken for a sound construction of the plan.
5. Utilization – an optimum utilization could be assured only on the basis of a balanced development of the entire valley.

While emphasizing the importance of each of the above steps, he discussed in detail the case of the Tennessee River and the measures taken by Tennessee Valley Authority.

Though he studied in detail the cases of the rivers in Bengal, due to the availability of delta formation and changes in their courses, the points he raised were applicable to all Indian rivers.

Even today, his reflections on widespread havoc caused by floods and its scientific solution are relevant. Those were not baseless but genuine fears.[3]

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[3] One example is enough. On 26 July 2005, there were massive floods in Mumbai, the financial capital of India and a megacity of international importance. It caused damage to lives and property. The lack of scientific studies and mismanagement of flood control was one of the reasons.

Chapter 13
Saha and Bhabha

In the early period of development of science and technology in India, Mahalanobis, Saha, Bhatnagar and Bhabha played a dominant role in building scientific institutions in India. Bhabha's contribution to the Indian Atomic Energy Programme was monumental.

Homi Bhabha was born in 1909, in a highly cultured and accomplished *Parsee* family in Bombay. His father was a barrister from London with an M.A. from Oxford. He was a legal adviser to the House of Tatas and served on the Board of Directors of many Tata companies. His mother Meherbai (nee Panday) was the granddaughter of the famous philanthropist Sir Dinshaw Petit. Homi's paternal aunt was the wife of Sir Dorabji Tata, who was the elder son of J. N. Tata, the founder of the Tata Industrial Empire. The Tatas had good relations with British rulers as well as national leaders of the Indian independence movement. Mahatma Gandhi, Sardar Vallabhbhai Patel, Motilal Nehru, Jawaharlal Nehru and many other leaders of the National Congress were regular visitors to the Tata House when they were in Bombay. The Tata and the Bhabha families had friendly relations with Nehru's family. In his boyhood, Bhabha got an opportunity to see national leaders very closely and even listen to their conversations and discussions.

After preliminary education in Bombay, Bhabha left for England in 1927 for higher education. It was a period of revolution in physics. Rapid developments were taking place in quantum mechanics after the breakthrough of Heisenberg, Schrödinger, Born, Pauli, de Broglie, Dirac and many others. The atmosphere in Cambridge around the Physics Department was highly charged and exciting. Bhabha plunged into research in physics. In 1941, he was elected Fellow of the Royal Society (FRS), London.

In 1939, Bhabha was on vacation in India when Second World War broke out. It was the turning point in Bhabha's life as well as Indian science. He stayed permanently in India. The foundation of the Tata Institute of Fundamental Research (TIFR) and later on the Atomic Energy Establishment were his major contributions

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to Indian science. He worked in physics at Cambridge University for more than a decade. He also visited Europe and worked and interacted with world leaders in physics like Dirac, Bohr, Pauli, Fermi, Kramers and Rutherford.

Atomic Energy

In 1939, nuclear fission was discovered and scientists immediately anticipated its potential applications. Both the controlled and uncontrolled chain reactions were thoroughly investigated. Fermi was successful in developing a controlled chain reaction, and it opened a new era. The dream of producing cheap and plentiful electrical power was within reach. The closely guarded Manhattan Project succeeded in making the atom bomb, which was dropped on Hiroshima and Nagasaki ending the Second World War. The fundamental discoveries in nuclear physics were made mainly in Germany, England, France and other European countries. But immediate practical war application was developed by USA and Canada. Historically, this splendid state effort with huge resources was mainly carried out and directed by refugee scientists and scientists from friendly countries. The research work carried out on this project in the war period of 5 years, which would have taken at least 50 years under normal circumstances. The major work was focused on atomic pile and production of fissionable material like U^{235} and Pu^{239} for making bombs. The use of the atom bomb in the Second World War changed the course of human history. There might not be use of an atom bomb in the future, but danger was persistently looming over mankind in the form of war, storage of nuclear material and threat from terrorist activities.

The systematic development of atomic energy in the direction of peaceful uses started around a year or so after the end of the war. USA tried to keep knowledge about nuclear physics under secrecy and monopoly. But soon other countries acquired that knowledge and carried out research on their own.

After independence, when Jawaharlal Nehru became Prime Minister, there were many expectations from him at the national level. The atom bomb ended the Second World War and atomic energy became the new hope and sensation throughout the world. Obviously, India wanted to develop an atomic energy programme.

It was impossible for India to start an atomic programme on the scale compared to that of USA, UK or USSR due to the lack of industrial power, trained personnel and resources.

In 1947, Saha was invited as India's delegate to the International Rutherford Memorial Meeting in Paris. He could gather information about the development of atomic energy in various European countries. In France, before the Second World War, people like Irene Joliot-Curie, Perrin and others were working on atomic energy, that is, the construction of a nuclear reactor. During the war due to defeat of France in 1942, all workers were scattered. Though the French group participated in the Manhattan Project, after the war they had problems in their own atomic energy programme, namely, dearth of raw material like uranium, thorium, graphite and beryllium, instruments and trained personnel, because USA restricted the export of raw material and instruments needed for nuclear processes. According to the McMahon Act of 1947 passed by the US senate, very strict restrictions were imposed. Yet the French Alternative Energies and Atomic Energy Commission made a 15-year plan to attain atomic autonomy. Saha found a similarity between France and India as far as an atomic energy programme was concerned. He advocated the French model of an Atomic Energy Programme.

The CSIR established an Atomic Research Committee (ARC) with Bhatnagar, Bhabha, Saha and many other scientists as members.

Saha opposed the formation of the Atomic Energy Commission (AEC) on the grounds that India lacked an industrial base and had no trained manpower available. According to him before launching a full-fledged atomic energy programme, the industry should be built up first and nuclear physics-oriented courses must be introduced in the universities, to train the required manpower.

Bhabha was the most influential member of the ARC, who identified himself with the atomic energy programme with clear conceptualization of an indigenous atomic energy programme. He had the experience with establishment of TIFR, plus had informal discussions with scientists from the UK, Canada and France about the possible help for the Indian Atomic Energy Programme. He was confident about future plans.

In April 1948, he wrote a note to the Prime Minister about the organization of atomic research in India. Jawaharlal Nehru accepted his note with all major suggestions. In August 1948, the Government of India passed the Atomic Energy Act. According to that act, the Atomic Energy Commission (AEC) was established in 1949 with Bhabha as the chairman, Bhatnagar as member secretary and K. S. Krishnan as the third member. Bureaucrats, ministers and departments were bypassed, and Bhabha was answerable directly to the Prime Minister. That became possible only due to the close rapport between Bhabha and Nehru. Thus, Bhabha was empowered to go ahead in the Atomic Energy Programme without any hurdle. That had deep and long-ranging consequences on Indian Science and Technology.[1]

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[1] For example, 'The Institute of Nuclear Physics' (INP) team was confident after the working of cyclotron and it wrote an ambitious plan in December 1954. They proposed the establishment of an Institute of Medical Physics around the already existing Biophysics Section. The plan also made a very clear reference to the future establishment of a 'hot chemical laboratory' and a research reactor facility. The buildings were to be expanded; and a scaling up of activities was projected such that, in the next 5 years, the Institute would be able to 'train personnel in subjects such as nuclear science and technology'. Continuing research on established and new lines was to be directed at 'assisting the Atomic Energy organization of India in developing atomic energy for peaceful purposes in India'. The accelerator division had begun work, on a Cockcroft-Walton generator of 1 MeV. Furthermore, they claimed, a group was constituted to build a linear accelerator patterned on the Harwell facility, as well as an electron synchrotron. The Department of Atomic Energy (DAE) discussed the plan immediately. Bhabha had recently been appointed Secretary of the DAE and thus occupied the highest bureaucratic position for atomic energy-related organizations in the country. In his response he first clarified bureaucratic matters: 'all reactors and all plants required for the generation of atomic energy are the exclusive responsibility of the State'. As a university laboratory, the Institute of Physics was restricted to research activity; the production

Saha lost the advantage of all his earlier associations with Nehru while Bhabha went miles ahead. It was a bitter disappointment for Saha which resulted in many critical remarks by Saha on the Atomic Energy Commission.

D. M. Bose said: ‘The decision of the Prime Minister to locate the Department of Atomic Energy and the Atomic Energy Commission with Bhabha as secretary of the former and the Chairman of the latter must have caused some disappointment to Saha. Since 1935 Nehru and Saha had cooperated in many fields of common interests, including the formation in 1938 by Subhash Chandra Bose of the Planning Committee of the Indian National Congress with Nehru as Chairman and Saha as an important member. A growing estrangement with the Prime Minister on some of his later decisions may have been one of the factors which induced Saha to enter politics in 1952. There can be no doubt, however, as events shaped subsequently, that Prime Minister Nehru was undoubtedly right in entrusting Bhabha, with the development of India’s plan for utilization of Atomic Energy. Bhabha identified himself completely with the development of Atomic Energy in India. Saha’s interests were many and varied’ [2].

Though there were differences of opinion between Saha and Bhabha, in 1954 Bhabha had a meeting with Saha and INP was offered Rs. 50 lakh for a second 5-year plan through DAE. By keeping aside personal differences for the betterment of research at INP, Saha accepted the offer and INP came under the mighty wings of DAE.

In 1966, while going to Vienna, Bhabha died in a plane crash in the Alps.

References

1. J. Phalkey, *Atomic State: Big Science in Twentieth-Century India* (Permanent Black, Ranikhet, 2013) p. 205
2. D. M. Bose, *Meghnad Saha Memorial Lecture* in Proceedings of the National Institute of Science of India, 33A (No. 3 and 4), 1967

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of isotopes or electronic apparatus was not within its mandate. The Atomic Energy Commission of India would arrange for the import and production of materials needed. On the other hand, the plan for building an electron synchrotron was in principle possible, given the experience of the Calcutta group with the cyclotron. However, ‘techniques of other accelerators are not within the experience and knowledge of the group you have’. With these revised directives, Bhabha suggested that the Institute of Physics rewrite its proposal; upon this a discussion of representatives of the Institute, DAE and the Ministry of Finance could take place [1].

Chapter 14
Saha in Parliament

With his friends and colleagues and in public, Saha promoted national planning and economic development plans. He was a constant critic of Gandhi's views and mentioned that to his friends and colleagues also. Saha's impression was that the 'Planning Committee was endorsing Gandhi's plan of cottage industry and excluding large-scale industrialization. Congress leaders had permitted foreign investment and foreign management to control industrial sector'.

Nehru read Saha's letter to Kripalani, in which Saha had criticized him. Nehru wrote to Kripalani: 'He (Saha) has referred to me repeatedly and made various statements regarding me, which are bound to convey an entirely wrong impression of what I said in the Planning Committee…. (The charges about Congress leaders being puppets in the hands of industrialists) are really extraordinary, and shows Professor Saha is not conversant, with what has been happening in India. …(It is) amazing, and displays a lack of appreciation of the whole political, social and economic events in the recent history of India. It is unfortunate, that Professor Saha's letter has been written in a spirit which is far from scientific or dispassionate'. [1]

Nehru did not support Gandhi's view points to a large extent. He knew the importance of large-scale industrialization. For him there was no conflict between the two. Nehru found that Saha was too rough and too critical. This was the first sign of Nehru and Saha going their separate ways. Later on, that gap widened.

'Perhaps Saha could have stayed away from politics and still be of service to the nation, had the events taken the course he so desired. He felt that the river projects were not being managed properly and that there was general confusion in planning. It was no longer possible to limit his protests to the fiery editorials of *Science & Culture*. The only way to voice his protest and be heard was from the floor of Parliament. That was the only way to inform the public and make the Government rectify its mistakes'. [2]

Sarat Chandra Bose, the elder brother of Subhash Chandra Bose, first suggested to Saha the thought of entering Parliament. Sarat Chandra was a member of the First Interim Cabinet in 1946. Sarat Chandra and other friends thought that Saha had devoted much time and thought for national planning, river valley developments

P.V. Naik, *Meghnad Saha*, Springer Biographies,
DOI 10.1007/978-3-319-62102-9_14

and industrialization; therefore, his presence in Parliament would be of great help to the nation. It was true. Many editorials and articles in *Science & Culture* addresses at various meetings, speeches, formal and informal discussions, personal communications and so on were full of national problems, social concerns and their probable solutions.

He was a staunch opponent of *spinning wheel*, *Khadi* and *handloom*. It was obvious that he could not get Congress nomination though he was approached by a prominent Congress Leader. He was asked to change his views but he refused. The nation's future was more important for him than mere slogans.

In 1952 elections Sarat Chandra Bose was no more, but his wife, Bivabati Bose, asked Saha to contest. Saha made up his mind. It was not an easy task for a scientist to contest for Parliament. It needed enormous resources, in terms of money, manpower and its effective and optimum management. Today, even after six decades of independence, no scientist would think of contesting for Parliament. But once Saha made up his mind, nothing could deter him. He contested from Calcutta North-West constituency, as an independent candidate supported by leftist parties. Saha was inclined towards 'left' but was never a member of any leftist parties.

A large number of students and teachers joined Saha's campaign. He won with a thumping majority. The Congress candidate, who was a prominent businessman, P. Himmatsingka, visited Saha at his home to congratulate and pay his respects. He was very sorry that circumstances had forced him to contest a person he had great respect for.

During the last 60 years, no one of such a formidable stature, except Saha, was ever elected as a representative of people! His work in Parliament from 1952 to 1956 (till his sudden death) proved that the choice of the people of Calcutta North-West constituency was correct. Figure 14.1 shows M. N. Saha being felicitated after being elected member of the Parliament.

In India, in the beginning of parliamentary democracy, one scientist who was an FRS at an early age and was contesting against a giant political party was something unusual. In England and America, the situation was different. For example, in England, P. M. S. Blackett (1948 Physics Nobel Laureate) and A. V. Hill (1922 Physiology/Medicine Nobel Laureate) were both elected to the House of Commons and in the USA, Glen Seaborg (1951 Chemistry Nobel Laureate) was a senator.

Saha raised pertinent questions and initiated debates on many important subjects. Many a time, he lashed out at the poor performance of the government. His charges were well founded and often put the government in an embarrassing situation. When no convincing reply could be given, the Congress members made personal attacks on Saha. In Saha's own words: 'The other day, in reply to a very embarrassing interpolation from me, in Parliament with respect to increase of tramway fares at Calcutta, Dr. Katju, the Home Minister, asked me to confine myself to 'the Physical Laboratory'. I was not allowed to say, that I was elected by a sweeping majority from one fourth of the population of the largest city of India who preferred me over lawyers, businessman, doctors and professional politicians, some backed by Congress. But I may say here, why I chose to offer myself for election. Scientists are often accused of living in an ivory tower and not troubling their mind with reali-

Fig. 14.1 Professor M. N. Saha being felicitated after being elected member of the Parliament (1952). From left to right: Sitting –?, Ms. Sanghmitra Saha, Prof. M. N. Saha and Dr. Santimay Chatterjee. Standing – Dr. Dharmabrata Das, Ms. Samhita Das (on Dr. Das' lap), Mr. Prasenjit Saha and Dr. Ajit Kumar Saha,?,? (This photograph is provided by the Saha Institute of Nuclear Physics, Calcutta, India.) ? means unidentified person as per original photo source caption

ties and apart from my association with political movements in my early years. I had lived in the ivory tower up to 1930. But science and technology are very important for administration now-a-days at least as much as law and order. I have gradually glided in to politics because I wanted to be of some use to the country in my humble way and may disclose to the public, how I did it and how the Hon'ble Dr. Katju was the indirect cause of it. For a while Industries Minister in the first Congress Government in 1938 in the United Provinces, Dr. Katju was invited in 1938 to open a match factory, somewhere in the United Provinces; where he delivered a very eloquent speech, saying that a great step was taken by the opening of the match factory towards large-scale industrialization. The speech gave me a rude shock, for it disclosed that a top-ranking Congress Leader, entrusted with the important tasks of reorganizing, improving, and initiating industries of his province, had revealed by his speech that he had no idea of what large-scale industrialization was. I found this to be the case with most elderly Congressmen, who were de facto potential ministers and could foresee that when in power, they could be like landsman who have never seen large sheets of water and still asked to pilot ships in the ocean. It was these considerations which led me to apply my mind to the problem'. [3]

Saha took his oath as a member of the Parliament on 13 May 1952. His students had observed that Parliament sessions had a great effect on him. He used to come back with great zeal and zest for work. He was very impressed by the excellent Parliament Library. His only regret was that the excellent facility was not properly utilized by members.

Saha made his first major speech in the Parliament on education, while participating in the debate, on the motion on address by the President on 20 May 1952.

Saha said that at the end of the motion, the following be added: 'but regret to note in the address absence, of any reference to the problems of educational reform particularly in the sphere of University and Professional education'.

He expressed his concern about education and said that the presidential address generally gave a statement of the policy to be pursued by the government during the coming year; but there was no reference in the presidential address to the state of education and to educational reform in India. The percentage of literacy was only 15 as per the government report. No democracy can act properly if 90% of the electorate was illiterate. Many years ago, when democracy was first established in England, John Stuart Mill said that universal suffrage without universal education would be a curse to the state. The working of democracy in a different part of the world had proved the correctness of Mill's prophecy. The rule of democracy in America during the early days was really the rule of Tammany Hall – party bosses ruling – because the electorate did not know for whom to vote. Something like that has also happened during the last elections, when votes were cast not on the merits of the candidates, not even on the programme, but on the sacred bull.[1]

He reminded the House that the problem of illiteracy and education had been studied thoroughly by different committees – even by the National Planning committee as early as 1939. Since independence, a large number of committees appointed by the Ministry of Education had pondered over it, and several measures had been proposed in order to deal with illiteracy.

He referred particularly to the report of the *Kher Committee*. Mr. B. G. Kher, Chief Minister of Bombay, was asked to preside over a committee for dealing with illiteracy. He recommended quite a number of salutary measures. One of those was that State Governments should spend 20% of their budgetary allocation on education and the Central Government 10% of the central budget. It was not a very large percentage. In the USA, in certain States nearly 30% and in the state of New York 40% of the state's budget was spent on education. Saha found that only Mr. Kher had tried to implement those recommendations. In other States, it was very much lower, except Mysore, where it was 25%. The Government of India had accepted the recommendations, but no efforts had been made to give effect to them. Therefore, the problem of illiteracy was not going to be solved in near future.

He said that he expected that the President[2] in his address would have given some direction to the different States for dealing with that problem, but such an important topic was omitted from his speech.

Saha in his address, while speaking about higher education, said that higher education in India was in very dismal state. The whole conception of higher education was wrong because when the British were ruling India, they wanted to produce simply clerks and assistants. In higher technical education and vocational educa-

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[1] The ruling Congress Party's election symbol was the 'bull'.

[2] Rajendra Prasad (1884–1963) was the first president of India during 1950 to 1962. The surprising thing was that for a couple of years he was a teacher and later a university professor.

tion, the situation was much worse. The objective of engineering colleges was to produce engineers who can operate a machine but not such as could design or plan anything. Independent India has to rebuild the country and for that we require scientists and technicians, a better type of engineer, not only lawyers who can earn fabulous sums of money but also such as would be competent to frame laws in accordance with the needs of a changing society. India also required linguists – people who would be able to serve the country in their spheres effectively. The government was aware that the whole education system needed complete overhauling and therefore in 1948 appointed a University Commission under the chairmanship of S. Radhakrishnan, who was a philosopher and educationist. He was assisted by a number of eminent educationists of India, England and America. Meghnad Saha was one of the members of the Commission. The University Commission made a tour of all the universities in India and other institutes. The Commission was shocked to find low standards which were prevalent throughout the country. Saha and many of his noted colleagues had the advantage of having had first-hand knowledge of the high standard prevailing in the universities in other countries of the world – in England, America, Europe and even in Russia. But they found that the standard of Indian universities had deteriorated to an extremely low level. They could not find a single Indian university, which was functioning satisfactorily. Most of them were suffering from an acute lack of funds. The grants to the universities had not been increased in spite of the fact that the cost of living had gone four times up and the cost of equipment nearly five to six times. Teachers were unpaid. In some places – for example, in Nagpur – teachers in some private colleges were being paid less than unskilled labourers in a neighbouring mill. Everywhere, teachers were underpaid; their salary could not make both ends meet. They could not devote their serious attention to their work.

The Commission found that in professional institutes, for example in medical colleges, no research work was being done. The teachers said that all their time was spent in teaching and professional work, which they had to do as they were not sufficiently paid. So they could not devote time for research work. In engineering colleges, the engineers that the colleges turned out were only operation and maintenance engineers; none of them was an engineer of a higher type who could undertake work of designing except in civil engineering – say of the Damodar Valley or other river valley projects which India had undertaken. There was no place where any research work was being done on the production of machinery or other articles, which India very badly need for the reconstruction of the country.

India had undertaken many schemes of reconstruction and had to import experts from foreign countries on fabulous salaries. An expert had been obtained for work at ‘Nangal’ Dam with a salary, which was higher than the salary of the President – several times higher.

The University Commission therefore recommended that the responsibility of running the universities could not be left entirely to the provinces. The Central Government should take upon itself half the responsibility for university education in the sphere of post-graduate and professional training. Therefore, the Commission recommended the creation of an autonomous University Grants Commission, which should have a budget of Rs. 5 or 6 crores, increasing to Rs. 10 crores, which would be distributed among the different universities and professional institutes according to their needs and demands. Even after 2 years, there was no indication that the Government of India intended to implement any of the recommendations of the University Commission.

He further said that education at that time in India was in a much neglected state. India could neither educate the electorate nor produce the right type of men who can build the country. Therefore the country was running into disaster. It would not be difficult to find the funds if people were really serious enough about it. But while expenses in all other sectors were increasing, the educational budget of the Central Government had remained static at 1% of the total budget for a number of years.

At the end, he said that it was proper that the Parliament should be informed of the sad state of affairs in regard to education so that the House can ask the government to provide more liberally for education in the future.

The partition of India in 1947 was an unbearable tragedy for Saha. His links with his native village – *Seoratali* – in Dhakka district (now in Bangladesh) were very strong. He was emotionally upset by the influx of millions of people uprooted from the erstwhile East Pakistan. As President of the East Bengal Refugee Relief Committee, he toured the refugee camps extensively throughout West Bengal. He had first-hand knowledge of the rural conditions of East Bengal before and after the partition.

He found that there was no precise Government policy and in fact, there was total confusion. The relief measures were totally inadequate, and the treatment needed urgently was absent. He raised his voice against this in public meetings, in newspapers and on the floor of Parliament.

On 23 May 1952 while taking part in the debate on the ‘Displaced Persons (Claims) Amendment Bill’, he said that Government of India had spent crores of rupees and done its best in its power to give relief to these people, but the measures taken were absolutely inadequate. The matter should have been dealt with on the basis of emergency, and if the work was done for the same amount of money which Government had spent, much relief could have been given. Most of the revenue had not gone to the refugees but to greedy Zamindars, officers and others.

In the same budget session of 1952–1953, Saha made another major speech in Parliament on 13 June 1952 on *Education* during the debate on demands for grants from the Union Ministry of Education.

He said that the main object, in moving his cut motions was to focus the attention of the House on certain recommendations of the University Education Commission, which were lying before the government for the previous 3 years without action on them.

First was that the university education should be on the concurrent list. At that time university education was a state subject. The Commission found that being a State subject, it lead to a deterioration of university education standards and to many other unpleasant things. Second, the President of the Republic should be a visitor to all the universities of India. Third, it should be the concern of the Central Government to provide ample resources for the development of universities. And fourth, the money so provided should be spent through an autonomous University Grants Commission, which should be properly constituted.

Even the Planning Commission had also stated that it should be a concurrent subject, as the university provides the best brains of the country.

It was observed, that almost in all provinces, the universities were functioning in different directions; there was no unity of purpose. Sometimes they followed policies which were highly provincial and detrimental to the cause of unity. Many of the universities were being made tools of State politics. Education should be free from all taints of provincialism. Universities should train a number of high class workers, brilliant workers, in the interests of the country as a whole. Therefore, it was thought that it should be a central subject and if not wholly a central subject, at least a concurrent subject.

The reconstruction of the country on a vast scale needed good workers, lawyers, doctors, engineers, technical men and scientific men of all types. In the Russian Five Year Plan, a very good part of the plan was devoted to the training of personnel, without which one cannot reconstruct the country. The Commission recommended that undergraduate education should be financed by the state Government and post-graduate research work and higher professional education, like medical, engineering and technical related expenditure, should be shared half and half between the State Government and the Central Government.

He gave examples of other countries also. In England, it was found at the end of the Second World War that universities were grossly underfinanced. The British Government appointed a University Grants Committee. It was given a magnificent sum of £ 30 million, a little over 0.01th part of their national budget, in order that these universities may be financed properly for the Herculean task of post-war reconstruction. He made another example of University Division of Russia. The country was devastated and blasted by the Second World War to a degree once unknown in history. But they had courageously undertaken the reconstruction of the universities. Moscow University received an amount equivalent to about Rs. 100 crores. Other universities also had been reconstructed. Dr. Radhakrishnan, an eminent educationist, was present at the opening of the new University of Moscow. He said to Saha: ‘I wish it was possible for me to witness similar occasions more frequently in my own country’. Unfortunately in India, universities were allowed to go to rack and ruin.

The Kher Committee, which was appointed by the Ministry of Education, had recommended that at least 10% budget of the centre should be spent on education. It should be done through the medium of a University Grants Commission, which would be an autonomous body, having the status of a Federal Public Service Commission. The task of distributing the grant would be vested in a full-time chairman and a number of full-time workers who would be assisted by a panel of experts on the model of the University Grants Committee of Great Britain. It should make periodic surveys of the work of all the universities, and wherever it found that any university required assistance, it would provide funds and ensure that the money was being spent properly. It would also initiate new chairs or new departments wherever necessary.

These recommendations laid long before the government and nothing was done. There had been a University Grants Committee since 1948. It was simply a subordinate section of the Ministry of Education. But it died a natural death. Saha thought he was still a member but on enquiry found that the committee was defunct. From the British systems, India had taken only the name and not the spirit, not only for University Grants Commission but for many other institutions. Saha pointed out that the British University Grants Committee was not a committee of the Ministry of Education. It was a committee of the treasury, which meant a lot. As far as the distribution of money for the universities was concerned, the Ministry of Education had no say in the matter. They received the money separately from the Treasury and distributed it according to their own findings and judgement.

Saha wished that the Indian University Grants Commission should be an autonomous body, getting a fixed amount of money from the Treasury and distributing that money according to their judgement, findings and survey.

There were certain developments, certainly to the credit of the government, for example, national laboratories. Due to the Prime Minister's interest and initiative, national laboratories came into existence. The country could expect a good deal from them.

While stressing the need for the University Grants Commission and its appropriate budget, Saha quoted S. S. Bhatnagar, the Secretary of the Ministry of Education and chief architect of a chain of national laboratories; from his writing about the relation between the national laboratories and the universities: 'While national laboratories and research institutes will play an ever increasing part in furthering the application of science to industry, it is clear that, ultimately we have to depend on the universities for steady and constant flow of scientific workers and leaders imbued with zeal and zest for research. Universities have been rightly recognized, as the fountain-heads of knowledge and it is in their free atmosphere, that we should look forward to a vigorous pursuit of fundamental research. Fundamental research is the source, from which extraordinary applications are likely to emerge and unless we keep ourselves in the forefront, contribution to applied research will also stop'.

In a report to the Royal Society in 1946, Bhatnagar also said: 'Those familiar with the facilities provided by the modern laboratories in America and Britain, would find it hard to understand the handicaps that beset the scientific worker in India at every step. Lack of equipment, lack of accommodation, long hours of routine work, due to insufficient teaching staff and finally the eternal want of funds, are some of the problems, that handicap science teaching and scientific research in Indian universities. These circumstances should not be lost sight of when assessing the work done in India. The Government of India has no machinery for making grants to universities and research bodies for scientific research'.

Saha further said that he had the experience of training nearly two generations of students. In addition, he had the experience of students and teachers of American, British, Russian and other European universities. Compared to others, Indian students were more enthusiastic and thirsty for knowledge and education.

At the end, Saha concluded that the contribution of India in science during the British period particularly after the First World War had been glorious. Many Indian scientists with very meagre means had attained international recognition. The coming generations should encourage greater scientists and it was the duty of the country to provide them with facilities, laboratories and libraries, where they could get their training and serve their country and conduct research work, which the country expected from them. He appealed to the Ministry of Education to form a University Grants Commission with ample funds, so that it can undertake the enormous task of reconstruction of the universities.

The University Grants Commission came into existence in November 1953, and a comprehensive University Grants Commission Bill was placed in Parliament in November 1955.

While taking part in the debate on the University Grants Commission Bill in Parliament on 23, 25 and 28 November 1955, Saha said that it was rather a pity that for 6 years no action was taken on the recommendations of the University Education Commission. However, he welcomed the Bill, which was open for discussion. He pointed out that the bill alone was not adequate. It should be made effective. In the Bill, almost the entire authority rested in the hands of the chairman. Though it was recommended that the chairman should be a full-time member, the joint committee omitted that provision. The work of studying the condition of education in the universities, under each division, arts, science, engineering, technology and medicine, would devolve on the officers alone and not on any responsible member of the Commission. It was a very undesirable state of affairs. Therefore, Saha moved an amendment that the Commission should consist of, first, an executive committee, consisting of a full-time chairman and four full-time experts. These experts should be specifically chosen for their knowledge of science, humanities, medicine, engineering and technology. They should be appointed full-time and should study their subjects thoroughly. For example, a man of medicine would evaluate the standard of teaching of medicine in every one of the universities and would present reports to the Grants Commission and suggest necessary measures. Without that, most of the funds which the government might be giving to the Commission would be misspent.

Saha proposed that in addition to the executive committee, there should be an advisory council, which would consist of not less than nine members and not more than 15 members, who should be appointed as mentioned. That policy-making body would meet once in 3 months or 6 months and would take decisions on the recommendations, which have been put forward before them by the members of the executive committee. If that amendment was accepted, it would meet the recommendations made by the Commission. Therefore, Saha requested the Hon. Minister to accept that amendment.

He described the workings of the University Grants Commission in England. At first, they started with only one chairman, a full-time chairman, but they found that this was inadequate and they had to appoint four or five more men, who were full-time workers and who studied the courses of scientific education in the different universities.

Saha suggested that the chairman should have his own staff and must devote his whole attention to that and then prepare the agenda. He would study the requirements of each university and what new courses have to be introduced, whether any department had to be strengthened, and so on.

In the Bill there was no provision for such conditions. They had nine men and one of them would be the vice-chancellor of the Bombay University. He would be a very busy man and he could give only part of his time to the work. Probably he would note the agenda prepared by the office when he was in the train. Somebody would come from Madras or Calcutta and somebody would do some other work. Saha thought in those respects, the Bill was very defective. The government had recommended that there should be some vice-chancellors of universities and these vice-chancellors would naturally try to get as much funds for their universities as possible. Men were not infallible and they have had their priorities.

Some members of Parliament thought the University Grants Commission would disturb the autonomy of the universities. But Saha pointed out the example of England. No autonomy of universities was jeopardized. The discussion continued for two more days. Many members of Parliament suggested a number of amendments, and they were accepted by the ministry.

Saha again stressed his point that mere allotment of funds was not sufficient. It must have a body of experts who could examine from day to day how that money had been spent. Otherwise, the funds would be wasted; it may be given to places which did not deserve it, and the whole objective of the University Grants Commission would be defeated.

Saha had studied in detail subjects like river physics, multiple river schemes and river valley projects right from the beginning of his career. His interest in those subjects was related to his childhood memories. His native village, Seoratali, in the district of Dhakka, now in Bangladesh, in the Brahmaputra delta region, remained virtually submerged under floodwater for a period of 4–5 months from June almost every year. Therefore, he used to remark that children in his native region learnt swimming even before walking.

His scientific interest rose in 1913 when he was a student of the M.Sc. class and participated as a volunteer in relief work for catastrophic floods in the Damodar Valley. He got first-hand experience of flood relief, as well as causes of flood. That event was the beginning of his interest and concern with the Damodar River, floods and taming of the river. Again in 1922, there was a devastating flood in North Bengal. Saha undertook relief work along with Subhash Chandra Bose and others under the leadership of his teacher – P. C. Ray. He had studied major river valley projects throughout the world.

On 20 June 1952, he moved three cut motions when demand for a capital outlay on multipurpose river schemes was placed in the Lok Sabha (Parliament) by the Union Minister for Planning, Irrigation and Power, and in support of his cut motions, he made an impassioned speech. He insisted on discussing the desirability of overhauling the entire administrative machinery of the river valley projects.

He said that these river valley projects had been discussed, even before the Congress Government came into power, and a good deal of spade work had been done. He wholeheartedly agreed with the government about the priority given to the Damodar Valley Project.

If the Damodar Valley Project was taken as one unit, the Mahanadi River Valley Project (Hirakud Dam) was six times larger and the Ganges River and all its tributaries were a hundred times larger. When a task of such stupendous dimension, was undertaken, it was very necessary that one should have proper administrative experience of taking up a small project. That was one of the reasons. There were some other reasons, namely, that in order to execute a river valley project, certain data was required: the amount of water flowing through the river, the topography, the minerals, the geographical formation and so on. A lot of preparatory work had been done, and an expert from the Tennessee Valley had been brought to make a preliminary draft. On the basis of that plan the government launched the Damodar Valley Project.

To review the work of the Damodar Valley Corporation, the Parliament appointed an Estimate Committee which had submitted its report. Before the Parliament voted for additional sums for the project, it was necessary to draw the attention of the House to the gross irregularities, which had been perpetuated by the Damodar Valley Corporation. He said that out of the 12 dams which were proposed, it was said that only four would be taken up, and after 4 years of work, it was found that only one dam had been completed and it was the smallest dam in the whole valley. It was little better than a pond. It was said that the Damodar Valley Project was tackling a thermal power station at Bokaro. That thermal power station was regarded as a standby; when the other dams would be completed, it would be taken up. But on the insistence of the World Bank, it was undertaken. It was near completion, but for that, no credit need be given to the Damodar Valley Corporation, because the consultants were all foreigners. It had been put in charge of a foreign company, and there were very gross irregularities in the way that company was doing its work. All that the Damodar Valley Corporation did was simply to pay the bills, and that too was done without proper scrutiny. Gross irregularities had also been noticed in the work of rehabilitation.

The report showed that it was a frightful state of affairs. The whole administrative machinery needed to be overhauled. The corporation was built on the model of the Tennessee Valley, but they failed to catch the spirit of the Tennessee Valley. Dr. Arthur Morgan, one of the outstanding engineers of the world, was head of the Tennessee Valley Authority (TVA). He created quite a record in engineering by constructing a dam within a span of 5 years. Dr. Morgan was a member of the University Education Commission. At Saha's request, he was invited to the Damodar Valley, and he detected very gross irregularities in the method of work and the matter still lay before the government. If the government had taken notice of it in time and implemented his recommendations, then so many crores of rupees which had flown down the valley of the Damodar River would have been saved for the nation.

Then Saha discussed the Hirakud Dam Project (Mahanadi Valley Reclamation Project). The project was undertaken very hastily. There was insufficient data about the flow through the main river and its tributaries. The Geological Survey Map showed that most of the areas of the Mahanadi River had never been visited by a geologist prior to 1945. In spite of that, a decision was taken to construct a dam there for flood control and hydroelectric power development. First of all, the British Governor, Sir Louis Hawthorn, laid the foundation stone in 1945. When the Congress

Government came to power, a second foundation ceremony was laid by Jawaharlal Nehru. Some people, including Saha, protested and said that the project should not be allowed to be launched without proper survey. The results were startlingly grave.

Saha assessed the quotation from the report of the Estimate Committee. It said that the whole work of the enunciation of proposals, planning, policy-making and execution was done by a single organization or authority or even an individual in different capacities, that is, one individual in his capacity as secretary to the government. He was also a consultant as well as the executor. Such gross irregularities could not be permitted by any government. The Estimate Committee justly pointed out that the arrangement was not only inappropriate but replete with dangers, drawbacks and imperfections which may cause a severe blow to the entire programme of the development of river valley schemes, on which the prosperity of the country as a whole was dependent.

One of the irregularities Saha mentioned was that a French mission was asked to advise on the possibility of rendering the Mahanadi River below Hirakud navigable, on the necessity of having a diversion canal so that the river water may be diverted when the construction work on the main river was being undertaken. The French engineers, who had their own considerable experience, because they had done reclamation of their own Rhone Valley, gave their verdict definitely against it. In spite of their objection, the bridge was constructed at a cost of Rs. 1.3 crores, and the tragedy was that no water could flow under this bridge for 7 years. The bridge was inaugurated by the then Minister with the usual flourish and fanfare. Saha said that funds should not be sanctioned until the administrative machinery was completely overhauled. He found that in Five Year Plan, an additional sum of Rs. 104 crores had been assigned for river valley projects. He alerted the House by saying that if the same state of affairs continued, not even Rs. 500 crores would enable them to complete those projects. Though the work done was below expectations, he did not suggest the abandoning of projects. Russians and even Americans also committed the same mistakes, but they quickly learned from them and overhauled their whole administrative machinery by which the work went on smoothly. He gave an example of the Volga River, which created all kinds of difficulties in Russia: it was tamed and harnessed to provide irrigation facilities for tens of millions of acres of land. It also generated power on an unprecedented scale. Saha hoped that the Ganges River also should be harnessed in a similar manner to derive optimum benefits. He urged the government to take up other projects also, namely, the Godavari Valley Project, the Koyana River Project and so on.

While taking part in the debate on ‘Indian Companies – Amendment Bill; Oil Exploration’ on 17 July 1952, Saha declared that without economic freedom, the political freedom of country was a mere farce. The Bills passed in Parliament were diverting the country away from the goal of economic freedom. In giving suitable opportunities to various companies through a number of subsidiary companies, India was putting herself more and more into the clutches of big American capital. Saha reminded the House and Finance Minister about the report submitted by a team of scientists, of which Saha was one of the members, who were sent to America, Europe and Canada on a goodwill mission during the period of the Second

World War in 1945. The report stated that the technique of oil exploration had gone beyond all measures and India should organize a Central Geophysical Laboratory where the country should train her young professionals in the methods of oil exploration, oil refinery and so forth. The report remained unnoticed in the archives of the Government of India, and now the country was asking all these different companies – the Standard Vacuum Oil Company, Burma-Shell and all their subsidiaries – to undertake a great philanthropic work for India. Saha pointed out the danger in it. He said that whatever issues those companies found, they would not reveal them to the Indian public and utilize them for their own use, and when the company would start functioning, all the well-known experts would be from America and would comment that Indians could not be trained for this kind of knowledge.

Saha said that as a scientist, he completely differed from that view. India had sent students to America, and many of them had been trained in methods of geophysical exploration. Therefore, he urged the government to set up a Central Geophysical Institute and equip it with up-to-date apparatus and machinery. The trained young scientists, in cooperation with geologists, would locate pockets of oil in the different parts of the country. Saha requested Parliament to listen to his plea that education in India must be placed on a new level and India should spend more on education, more for the training of the country’s own people, so that all that exploration work can be done on her own. India can train her own specialists and free herself from dependence on foreigners. It was felt that only Americans could perform the great work of oil exploration. But Saha requested the Finance Minister to refer to the reports on oil discovery in Germany during the war. They developed the technique of oil exploration. The German technicians were far cheaper than the American technicians. It was possible to secure the services of a large number of Germans for oil exploration to make the work cheaper. The course which India was taking would lead to the same kind of oil imperialism which the Americans had imposed on Mexico, and it was for that reason that, for about half a century, Mexico was merely a colony of America, and Mexicans there could not expect a better job than that of a peon. Every expert used to be brought from America, even clerks and others, and it happened in most of the European firms in India. Before independence, European companies in India had European employees, much fewer in number, and pay was also less. But in the post-independent era, the situation was exactly opposite; the number of employees was greater, as well as the pay scale. For the same kind of work, European employees were paid four to five times more than Indians. By way of profit and a substantial part of funds by way of high salaries, capital was transferred to foreign countries. Saha suggested that economic policy required a complete reorientation. Eventually, the Finance Minister agreed to draw the attention of the Ministry concerned towards the formation of the Central Geophysical Institute to train Indians for oil exploration and oil refinery work.

Saha had studied many problems related to industry and Government policies. On 13 November 1952, while taking part in the debate on Indian Tariff, he pointed out many lapses of the Tariff Commission. He expressed doubts regarding many of the recommendations of the Tariff Commission. While there was immunity for many things, there was discrimination between British manufacturers and manufacturers of non-British origin. For example, jute baling hoops, protective duty; on goods of British manufacture 30%; on goods of non-British manufacturer 40%; cotton baling hoops; 30% and 40% and so on. The result was that though many scientific instruments and other substances could be obtained cheaply from centres like Germany and the USA, as there was preferential duty on goods of British manufacturers, people were compelled to buy them from the British market. Saha wondered why there was rampant discrimination even after independence.

He drew the attention of the Union Minister for Commerce and Industry to the other aspects of protective duty. In the case of 30 out of 42 industries, revenue duty had been converted into a protective duty. The conversion of revenue duty into protective duty was justified when it increased production of the material, which had the effect of lowering the prices. Everywhere, protective duty had been imposed on the basis of cost of production. It had very seldom taken into account the price which was borne by the consumer. Saha found that in many cases, the consumer had to pay 30 or 40% more. In one or two cases, for example, the chocolate industry had to pay 100% more. The consumer was entirely at the mercy of the manufacturer. Taking advantage of protective duty, the producer claimed a very high price from the consumer. There was no protection for the consumer.

Saha illustrated the ineffectiveness of the tariff protection in one particular case of glass industry. It flourished during the war period because the import of foreign glass was stopped. They not only manufactured all the glass, which was needed in the country, but also exported some of the glass to other countries. But after that, the glass industry was almost in a state of collapse. According to the report of the Planning Commission, the installed capacity for the manufacture of sheet glass was 12,000 tons, whereas the actual production was only 5000 tons, about one third. It was the same with respect to hollow glass and bangles. The glass industry required three basic things: sand, limestone and soda ash. Sand and limestone were obtained at the same price in India as in Europe. But soda ash was in a very peculiar position. The soda ash was sold in Europe and England at about Rs. 120 per ton. In India it was sold at about Rs. 380 per ton. There were two chemical companies, those who manufactured soda ash, and they stated that they could not manufacture it for anything less than Rs. 360 per ton. Very little soda ash was being manufactured in India. The requirements were 170,000 tons and production was only 44,000 tons. That too was mostly of a light variety and not of a heavy variety, which was used for the manufacture of glass. There was something wrong somewhere. When the manufacturers were asked why they could not make it at competitive rates, they gave vague explanations which did not convince even the Tariff Board. The Tariff Board, which was the predecessor of the Tariff Commission, said in their 1949 report that they were not convinced as to why the price of soda ash was so high. They recommended that there should be a government factory at ‘Sindri’ for the manufacture of soda ash at competitive prices. The Tariff Board looked at the figures supplied to them by the two chemical firms and they concluded that soda ash could not be manufactured in India at less than Rs. 360 a ton, whereas in Europe it could be manufactured economically at less than Rs. 120 per ton. Thus, it was a vicious circle, and one had to find out why it was so. Many of the heavy industries were only manufacturers in name. They were really subsidiaries of the chemical and aluminium empires of foreign firms – of the Imperial Chemical Industries, which had gotten a chemical empire for the whole of the British Dominions, or, in USA, the DuPont de Nemours Co. – and other firms. It was in the interests of those companies to see that those industries would not flourish in other countries. A vicious circle had been created. Many so-called manufacturers, who were also distributors, found it cheaper, and they made more revenue by entering into some kind of clandestine contract with the empires to which they were subsidiaries. They bought it at a concessional price from them and dumped it at the protected price in India and made money. That was the reason why no soda ash was being made at a competitive price in India. Saha felt that from that vicious circle India should rescue herself. There was no meaning in freedom unless there was economic freedom, and in India there were sufficient raw materials and talent to enable to achieve economic freedom, provided India once for all got rid of the idea that every foreigner was an acknowledged genius and there were none in India.

Due to the vicious circle of soda ash – as per the report of the Tariff Commission – the landing price of sheet glass was six *annas* (around Rs. 0.37) per square foot, whereas the market price was about four times. The production of sheet glass by Indian companies was one third of their capacities. It was because many of those distributors had vested interests in the sheet glass industry, and they made sure that no sheet glass was produced, so that they could bring foreign sheet glass at a very cheap price, at six annas per square foot, and sell it at more than one rupee and pocket all the money. So the Tariff Policy, instead of increasing the production in the country and helping in the development of a new industry, was being utilized by capitalists for their private needs to which the country should pay serious attention. In his speech, Saha further pointed out that the Tariff Board, as mentioned in its report, had extended protection to the starch industry without giving any reason.

There were many other topics where the Tariff Commission and the Planning Commission had come to an agreement. One of the things was that many of the heavy chemicals, which were key materials for the promotion of industries in the country, should be left to the private sector. One of the materials was sulphur. It was an important key material, and it was not produced in the country. India had to buy it from the USA, Italy or Japan, and all those three countries were under US domination. So in the event of a probable world war, without development of any sulphur industry in India, half of sugar and other chemical factories would come to a standstill. Since 1942, India had been talking of manufacturing sulphur. The country had no sulphur but had pyrites. There was a similar position in Germany, but they had developed methods for the manufacture of sulphur out of pyrites, and it competed successfully with the price of sulphur imported from USA and other countries. Saha expressed surprise as to why it was not possible in India. The Tariff Commission said that they had consulted some of the factories, and they had carried out experiments. Their experiments showed that it could not be manufactured in India at competitive prices.

Saha was not satisfied with that kind of answer because many of those chemical firms were really subsidiaries of foreign companies. He suggested that India should not depend on any of those private chemical firms for data, and the National Chemical Laboratory – one of the national laboratories set up by the initiative of Prime Minister – should be authorized to find out a process for the manufacture of sulphur from Indian pyrites, and Saha thought if they could solve the problem, all the money which had been spent on them would be well spent.

Then Saha mentioned the problem of aluminium production. As per the government estimate, the country needed 15,000 tons of aluminium. It was only for making utensils. But the greatest use of aluminium was in the aviation industry, and if India manufactured aeroplanes, the need for aluminium would be around 50,000 tons. The metal aluminium was used not only for making utensils but also for parts of ships and in replacing iron. Therefore, India should pay serious attention to production of aluminium. It was found that instead of producing 15,000 tons, India was producing only 4000 tons, and the cost of production was much higher than the cost of production in other countries. One of the reasons was that the cost of electricity was higher. But why India could not produce cheap electricity was a pertinent question. Saha said that the Tariff Commission had neither the means nor the time to go into the question. They were simply playing into the hands of the manufacturers, who were taking advantage of the ignorance of the government and their indifference for their own interests. As long as India left the manufacture of aluminium, sulphur, etc. to private sectors, as had been proposed by the Planning Commission, India would never have any industry at all, in spite of the fact that she had plenty of resources that could be used as raw materials. The planners had to go deep into the 29 industries that had been sought to be protected and see whether they actually need protection and whether by giving protection to them, the country was not encouraging inefficiency and cheap methods of making money, etc. The functions of the Tariff Commission were much wider that those of the Tariff board.

One of the functions of the Commission was 'inquiry and report on the grant of protection for the encouragement of an industry'. Saha thought that they were entirely guided by industrialists. He said not only industrialists but scientists working in various national laboratories such as the National Chemical Laboratory, the Glass and Ceramic Research Institute, the National Metallurgical Laboratory, etc., could give sound advice not only on scientific matters but even on cost of production, etc. The Tariff Commission entirely guided by the industrialists seemed to hinder the country's industrialization.

Another item entrusted to them was the variation in the customs or other duties for the purpose of protecting industries. The most important item was inquiry and report on the effects of protection, on cost of production and on fixation of prices. The fixation of prices was a very important and major item in the economy of a country. It could promote an industry or demote an industry and also generate sufficient money, if managed properly, for the state exchequer, for the development of the country. The report of the Planning Commission mentioned that they have planned a number of industries, mostly agricultural, but left other industries entirely to the private sector. The chapter on finances in the report indicated that the financing was on traditional lines, just having some taxation, some deficit financing, etc. But the most important source of financing was the turnover tax which was the main item of taxation, with the help of which Russia had developed her Five Year Plan on a very wide scale, and that had been dismissed by the Planning Commission in one short sentence. The Planning Commission probably had no idea that Russia had developed all their industries from nothing; the main source of their income was the turnover tax. The turnover tax was nothing but a fixation of price and taking the surplus for the interests of the country. Instead of the money going to the pockets of private industrialists, it should go to the state exchequer, so that the state may invest those funds in schemes for the promotion of industries. The Tariff Commission had a very important function to perform in the fixation of prices for the industrial development of the country. Finally, Saha advised the Commission to consult not only industrialists but scientists and technicians and representatives of the consumers also.

While replying to the criticisms of Saha, the Union Minister for Commerce and Industry agreed to hear evidence of others and said it was certainly open to anybody who was interested, not only the industrialist but also the consumers, to give evidence before the Tariff Commission and promised them that their evidence would be welcomed by the Tariff Commission.

While taking part in the debate on the 'Resolution – Five Year Plan' on 15 and 16 December 1952, Saha pointed out many lapses in the planning and its execution. One of the members of Parliament mentioned that planning in the country started from 1946. But Saha reminded the House that a National Planning Committee was formed in 1938, and he was one of the members. Netaji Subhash Chandra Bose, who was then President of the Congress, convened a Conference of the Ministers of Industries and certain other scientists and industrialists at Delhi. There was complete unanimity in passing the resolution that India's problems of poverty, unemployment, national defence and economic regeneration could not be solved without large-scale industrialization. The Committee had published its report in 26 volumes. Saha compared the headings of the different topics of the National Planning Committee and found that headings of the new planning were almost identical with the omission of four items. Those were 'Chemical Industries', 'Mining and Metallurgical Industries', 'Manufacturing Industries' and 'Engineering and Scientific Instrument Industries', because, according to the resolution of the Congress Government in 1948, all industrial development had been relegated to the private sector, which Saha thought was a very dangerous and retrograde proposal.

The deliberations of the National Planning Committee were looked upon with derision by the powers that were then, but such was the force of public opinion and world opinion that a number of captains of industry met at Bombay in 1943 and produced what was called the *Bombay Plan* and, in deference to the recommendations of that plan, one of the members of that Committee, Sir Ardeshir Dalal, was appointed to be the Minister of Planning, and a Department of Planning was formed. He appointed about 36 industrial panels so that they might produce short- and long-term targets for the industrialization of the country. But, instead of confining itself to planning, the Department also tried to do the execution of the planning. The proper function of the Planning Commission was to be the architect of national reconstruction but not to take upon itself the burden of reconstruction. It was to be left to the Ministries, and it was on account of that reason that it was met with hostility from Ministries by which it was abolished.

The National Planning Committee as well as the Bombay Planners all thought that the standard of living in the country could not be raised without industrialization. The Bombay Planners, who were all hard-boiled industrialists, held that the standard of living in the country could be doubled in a period of 15 years if the country could spend about 10,000 crores of rupees in three stages, each of 5 years. Out of that amount, 45% was to be spent on industrialization. They thought that in the first Five Year Plan, it would be possible to spend 1400 crores of rupees, of which 790 crores of rupees were to be spent on industries. It was the money of 1939, and considering inflation, the country should spend 5600 crores of rupees in the first 5 years. The Treasury Benches could not find more than 2069 crores of rupees, and therefore they have dropped industrialization altogether, along with that education and health also.

He further stated that before the Second World War, the income of the average man in India was Rs. 65 in terms of the 1937 rupee. After 5 years of Congress rule, it was Rs. 59. There had been a steady deterioration about 10% in average income. The fact was that most of the profits had been concentrated in the hands of a few industrialists, some of whom had initially a mere figure of two crores and grew in net worth to be possessors of 200 crores. To arrest the worsening state of affairs, a Planning Committee was appointed just 2 years ago. and their plan was ready. According to them, income would be doubled in 27 years. The period of 27 years was too long, and even after 27 years, the income would come to about one tenth of the income of the average citizens of the USA. So that plan would lead average Indians to what might be called the economic extinction and political *nirwan* (eternal bliss).

Saha found that in the industrialists' plan for which the government accepted responsibility, it was envisaged that from 1.32 million tons of iron and steel in 1950–1951, the production would go up to 2.30 million tons after 5 years through the private sector. Iron and steel were the key industries. India had a production capacity of 1.2 million tons and actually produced almost that amount, but after that, the industrialists had been bent on purposely reducing the production. Their idea seemed to be 'produce less, if the country was in short supply, earn more'. That was the eternal policy of the industrialists. As per the information available, the requirements of iron and steel were two and half million tons, and India was buying the remaining 1.5 million tons or so from foreign countries by paying exorbitant prices.

In 1949 at the initiative of the Minister of Industries, the question was carefully conveyed to the Ministry of Industries which issued a press note: 'Government (therefore) intends to set up new works for increasing indigenous steel production by one million tons. Two alternative schemes were under consideration – the establishment of a unit with a capacity of one million tons and the setting up of two units, with a capacity of half a million tons each. Three engineering firms of international reputation, had been selected to make a rapid survey and submit a technical report to the Government, with regard to the types of units to be installed to see if they are actually working. The consultants have completed the survey…'. It was in early

1949 and the report was expected by the end of the month. They received the reports, and then they said: 'the Government expects to take the final decision in three months'.

Saha said that the country must have started these iron and steel factories for the production of one million tons of iron and steel. The obstacles should have been removed as far back as in 1949. They had surrendered to the iron and steel producers of the country. The country had given them about Rs. 14 crores on their own terms. The government had pleaded with them and requested them: 'please produce more iron and steel for us!' It was a shameful act.

Saha gave many other examples which showed that not only had the country's programme of industrialization been sacrificed but the country was moving in a direction which was absolutely ruinous for it. He mentioned the example of basic industries. The government said that it would take responsibility for the development of basic industries: power, iron and steel, aluminium, heavy chemicals, etc. He illustrated his point with the example of sodium carbonate which was needed for soap as well as glass industry. Both industries were in a state of collapse because of soda ash, which was a very important ingredient. The price of soda ash in England was equivalent to Rs. 160 per ton. In India, there were two very inefficient factories, whose work was reviewed by the Tariff Commission. They told the Tariff Commission that soda ash could not be produced at less that Rs. 300 per ton. The Commission gave them protection. The result was that production decreased every day because those producers, who, Saha suspected, were probably getting licences for the purchase of soda ash from abroad and making more money by buying it from abroad and selling it in India at a higher rate.

When Saha asked the price of soda ash, he was told that the price in England was equivalent to Rs. 252 per ton and therefore the price of Rs. 360 per ton in India was not exorbitant. He was not at all convinced and consulted *Chemical and Engineering News* and found that the price of soda ash in England was equivalent to about Rs. 160 per ton. He was puzzled as to why the Minister of Commerce and Industry conveyed always wrong information. Saha mentioned another example, which was about preferential duty on scientific instruments. For a product from England, the duty was 25% and from Germany it was 37.5%. The Hon. Minister in charge stoutly denied the fact. The following day, Saha gave him the schedule of the Tariff, and the Minister had to admit that he did not have that information.

Saha had thoroughly studied the Russian Five Year Plan and its effects. In his speech, he explained briefly the Russian Five Year Plan and what India should learn from it. He quoted from a letter from Lenin: 'we shall economize on everything, on our clothing, on our diet and even on our schools. We have to do this because we know that, if we do not establish heavy basic industries, we can not build any kind of industry at all and without that, we shall perish as an independent country'.

Saha suggested the nationalization of banks and insurance and a ban on the import of gold, jewellery and articles of luxury to control export and import trade so that capital may not disappear from the country. There should be a turnover tax. He requested the Minister of Finance to read the book of Baiko on Russian Planning.

More than 50–60% of the money, which was obtained by Russia for her plans came from the *turnover tax*.

At the end of the speech, he compared the observations of Dneiper Dam in Russia and the Damodar Valley in India. In India, the scene was miserable due to improper planning and negligence.

On 24 February 1953, during the general discussion on 'Railway Budget' Saha pointed out instances of mismanagement and malfunctioning of the administration. The Public Accounts Committee had shown that the financial administration of Railway Ministry was very unsatisfactory. In one of the rail link projects, for contracts, the open tender system was not adopted. Saha brought this to the notice of members of Parliament and asked for an explanation from the Ministry. The stores purchase system of the Railway Ministry was subjected to an enquiry presided over by Mr. A. D. Shroff and they revealed a state of affairs which was shocking. It said: 'The illustrative tables given …… reveal a state of affairs, which almost borders on an outrageous handling, of at least one branch of the stores organization in the railways. We particularly draw attention to certain items of stores, the stocks of which, in terms of average annual consumption would last from anything between 3 years to the extreme cases of 162 and 222 years'. And in spite of the fact that there was such a large stock, the stocks were still being added. Saha said: '… This country is suffering from poverty. There is no money for education, there is no money for health, there is no money for nation-building departments and here we find that this railway administration is wasting money like anything and though attention has been drawn to it nearly two years ago, very little action has been taken on this state of affairs'.

Saha was very critical about the basics of the Five Year Plan, its improper execution and absence of desired outcomes. In the debate on 'Demands for Grants' on 27 March 1953 in the Parliament, he presented some of his findings about the Five Year Plan. He said that according to the Five Year Plan, the per capita income of the average Indian, which was Rs. 236 in 1953, would rise to Rs. 472 in 25 years, in terms of the 1953 rupee. That was based on the supposition that the population remained constant. But if population increased with normal rate, by 1977 it would be 54 crores and the per capita income would be only Rs. 315. That was barely a 30% increase in 27 years. Saha compared those figures with other countries. The *Eastern Economists* had published a statement of the per capita income of some of the countries. For the USA, it was 1413 US dollars, which was 30 times the income of the average Indian, and in Great Britain it was about 20 times. People were aware that India's poverty had been brought about by British domination and India had been unable to take advantage of science and technology.

If even after 30 years the difference in the standard of living between an average Indian and an Englishman remained 20 or 30 times, one cannot call it a plan. Pandit Jawaharlal Nehru, the Prime Minister of India, in his book *Discovery of India* said: 'We calculated, that a really progressive standard of living would necessitate an increase of the national wealth by 500 to 600 percent. That was, however, too big a jump for us and we aimed at 200 to 300 per cent within ten years. We fixed ten year period for the plan, with controlled figures for different periods'. The Prime Minister had also laid down the priorities. He accorded the highest priority to food and agriculture, the highest being to industrialization. But in the current plan, there was no scope for industrialization. It had been relegated to the private sector. Out of a large amount of money, nearly about Rs. 2000 crores, the government was to spend only about Rs. 94 crores from the public sector and Rs. 234 crores from the private sector on industrialization. The term *private sector* meant industrialists. But the directive of the Prime Minister was first an increase in agricultural production and then an increase in industrial production. 'The original idea behind the National Planning Committee' had been to promote industrialization. The problems of poverty and unemployment, of national defence and of economic regeneration in general, could not be solved without industrialization. As a step towards industrialization, a comprehensive scheme of national planning was to be formulated. The scheme should provide for the development of heavy key industries, medium-scale industries and cottage industries.

It was found that the Planning Commission had evidently forgotten all ideas of industrialization. They had accepted the industrial plan which was laid down in 1948, without examining its effects, all 4 years. In industrialization, iron and steel was the main industry, on which every other industry was dependent. India had been producing about one million tons of iron since 1939. Industrialists reduced it to 0.8 million tons after the war and gave reasons which were purely fabricated stories. The government at that time acknowledged that the country's requirements of iron and steel were about 3 million tons, and the then Director-General of Industries was sincere enough to plan for iron and steel firms, each producing half million tons. And there was a communiqué from the government saying: 'All our plans are ready and we shall start all those industries within three months'. Nearly 4 years had passed and nothing had happened.

Saha analysed the problem and said that there were certain efficient government advisers who made plans, but as in the case of Pandora's box, there were some rats, which undid those plans in the dark. One could easily find out who those rats were. They were the invisible advisers of the Planning Commission for industries.

Saha calculated the loss on account of the non-establishment of the iron and steel factories. The economic price, which had been given by the Tariff Commission to the iron and steel industry, was Rs. 350. That was to prevent them from making excessive profit. But iron and steel from other countries was sold at Rs. 600. So, what happened was that under the pretence of scarcity of iron and steel, India issued import licences to several favoured persons. Import licences for about half a million tons were issued. They made about 15–20 crores of rupees by selling that iron and steel in the black market. So in this way, 15–20 crores of rupees disappeared into the pockets of black marketers every year.

Saha found that the industrial programme had been published by the Planning Commission to impose 'the turnover tax'. But that suggestion was not implemented. By calculating turnover tax, he showed that India could have raised Rs. 100 crores since 1949. But invisible rats foiled the idea.

The Deputy Speaker of the House interrupted Saha, for taking more time than allotted to him. But Saha was replete with information regarding planning and its consequences to be delivered to the House. It came from the bottom of his heart. It was fervour for the country's betterment. Saha begged pardon and continued his speech. He said that the policy, which was followed by the Planning Commission with respect to industries, was very nebulous. They had shown a lot of concern for consumer industries. All capital goods industries, that is, the industries which were responsible for the promotion of other industries, had been left to the private sector, which was not reasonable. The industry required iron and steel, aluminium, lots of heavy chemicals and so on. He illustrated by means of an example. Suppose you dig irrigation canals to irrigate the fields but there was no water in the main river, then those canals cannot fertilize fields.

Then he explained his points in greater details. He pointed out that the Chittaranjan Factory was turning out a large number of locomotives. The Planning Commission said that Chittaranjan and Telco (a Tata Company) could not perform their functions because there was no iron and steel in the country. No country in the world was so self-sufficient as regards iron and steel as India. It had been testified by the Coppers Corporation. The other countries, which were not so well placed as regards iron and steel had done far better. Japan had a very good iron and steel industry. They depended on Manchuria. After the war, that source was cut off. Within the previous 4 years, they had been able to have an iron and steel industry production of about four million tons and were soon having six million tons mostly out of scrap iron they were exporting out of India. Then Saha gave the example of Russia which was in the same position as India in 1920. They produced only half a million tons. It was increased to about 60 million tons. They did not call foreign experts on every occasion. They built the factory by means of American experts in Magnitogorsk and then decided to duplicate every factory by themselves. Saha further said that it was not his ideal dream. In the old days of the National Planning Committee, they had a very efficient man, the late Mr. P. N. Mathur. He was a top-ranking official of the Tata Iron and Steel Company. He gave a proposal for a national workshop, a gigantic national workshop where all machinery could be duplicated. India could do everything on her own if leaders had sturdy self-reliance like Russia.

Then he narrated the story of aluminium. It was a key industry. India produced 5000 tons in a most unprofessional manner by famous industrialists. There was an aluminium factory in 'Alwaye' in Travancore–Cochin. That factory obtained all its raw materials from Bihar. Then after the aluminium pig was made, it came to Calcutta for processing – for conversion into sheets and ingots. The price of locally produced aluminium was Rs. 2500, while Canadian aluminium could be bought at Rs. 1600. So that was the efficiency of reputed industrialists. The Travancore–Cochin factory was managed by the Canadian Aluminium Corporation which holds the aluminium empire of the world. They owned 70% of the shares, and they maintained such an inefficient factory in India. Saha said that it was beyond comprehension. The Planning Commission in all its innocence said that the country's industrialists would start all those capital industries, and they would do most of the work. But they had no capital. He pointed out at the address of the chairman of the Federal Chambers of Commerce that they could at the most raise 100 crores of rupees per year. It was an insufficient amount for even a single iron and steel factory.

The country subsidized them and placed herself entirely in their grip. He further said that the plan had been very highly applauded by all foreigners. Sir George Schuster had been brought to India by industrialists at their own expenses to bless the plan. He was the finance member of the Government of India in 1930 when the rupee was devalued and India suffered enormous losses to save the tottering British economy.

Saha appealed in the Parliament to discontinue such a plan. The Prime Minister had assured then that if there was anything wrong in that plan, he would change it for something new. He requested to change the plan because the planners and their visible and invisible advisers had created that moral prison-house far worse in its effects than the ‘Ahmedabad Prison Camp’. He further commented that ‘for lofty walls do not a prison make, nor iron bars a cage. But a group of unprogressive and reactionary officials and advisers can erect barriers which can not be penetrated by any fertilizing idea’. He called upon the Hon. Leader of the House to break those barriers and in that effort to reshape the country’s future.

Saha had studied financial planning, taxation and its consequences in Russia. The condition of Russia around 1920 and that of India around 1947 was more or less similar. So he was of the opinion that India should learn many lessons from Russia, who had made tremendous progress at various fronts. He mentioned it at various occasions in Parliament. While speaking on the ‘Finance Bill’ in the House on 14 April 1953, he said that the menace of growing unemployment and the mishandling of government enterprises – both evils – were results of the same government policy. The spiralling unemployment was due to the incapacity of the government in providing creative ways, and whenever they started a public enterprise to provide employment to the people, it was mishandled either financially or technically. The government found it very difficult to find sufficient capital for creative work. They said that in the 5 years, which started from 1950, the government should spend at the rate of 400 crores of rupees per year for creative work. The central and state budgets were expected to provide 738 crores of rupees, all kinds of savings worth 520 crores of rupees and foreign loan worth 800 crores of rupees, of which they had already gotten 158 crores of rupees. Many eminent economists said that the expected budget surplus would not materialize; it was very doubtful. Many members of opposition thought that the expected foreign loan was problematic, and its acceptance was highly controversial. But the most important point was that the amount of capital investment which was proposed to be made was too small to effect any change in the rate of industrialization of India or for providing employment to the people. It was barely 4.5% of the national income. Every country which had been forced to do planning for one reason or another had found that the rate of investment was too small.

Saha explained the condition of Great Britain as a country with a very high standard of living. But her economy was completely shattered in the course of the Second World War. Production fell, many of the industrial firms were destroyed and she lost her most important possession, India, which had been her economic shock absorber, her standard of living fell to a dangerously low limit. The conservative government which was in power in 1944 issued an election manifesto that there should not be much public spending and all tasks of industrial reconstruction should be relegated to the private sector. But the Labour Party came into power. They embarked on a scheme of reconstruction of the country. The amount of capital investment in Britain during the 6 years of Labour Government was on an average 20%. But it was found to be too scanty, and by practising economy, which meant forcing austerity on everybody, they had been able to plough back on the average 18–25% of their national earnings into productive enterprises. After 6 years, there was 30% increase in the national income. In the Indian plan, a 30% increase was contemplated for the period of 27 years. France was also in the same state after war. They spent 20–25% of national income on capital investment. Compared with examples of England and France, India should invest about 2000 crores of rupees per year. But it was only 400 crores. The Planning Commission was aware of it. They said that on account of the grinding poverty of India, it was not possible to plough back more of the national earnings to productive investment. If there was no investment, there was no chance of ever solving the problems of poverty, unemployment, malnutrition, defence and others. Though many people disliked the comparison with Russia, the condition was the same. It was generally thought that the Five Year Plan sprang from the brain of Lenin, but it was not so. They took about 11 years to find out what should be the proper pattern of the plan – from 1917 to 1928. But in India, the plan had been compiled very hastily, and it had been thrust down on people in spite of protest from the opposition.

In the same speech, he suggested to prepare the *economic* budget. The traditional budget was the Finance Minister's budget and it was orthodox. It was inherited from the British days. But in all other countries, they had found it advantageous to include, in addition to the Finance Minister's Budget, another kind of budget called the economic budget. It was first introduced by the Russians, but even England and France found it profitable to introduce it. It would give the whole nation's earnings under different heads, so much of foodstuffs, so much of power in kilowatt hours, so much of iron and steel, so much of soda ash and so on. It would tell us in quantity and also in money value what the country was producing. Without an economic budget, it was very difficult to form a plan. The planning becomes futile as India's planning had been. For drawing up an economic budget, the efforts of the Economic Section of the Finance Ministry, the Finance Departments of the different state governments, the Statistical Institute, the Tariff Commission, etc., had to be integrated. It would be for the interest of the country. There should be a complete economic survey and it should be managed by the State Planning Commission. There should be a number of workers all over the country giving information about production and the imports from outside so that at one place one can find out what was happening in the country and other countries in the economic sphere.

In April 1954, the House considered the demands of grants relating to the Ministry of Irrigation and Power and the multipurpose river schemes. After the Speaker of House moved the motions, members were asked to propose their cut motions.

In the earlier Parliament session, many members criticized the administration of the river valley schemes, and therefore the enquiry committee was appointed to probe into the matter. The findings of that (Rao) Committee showed that most of the allegations were true. The Committee had pointed out that the Damodar Valley was the ‘Ruhr Valley’ of India. It contained coal, iron and other minerals, and there should have been a Planning Committee for the development of those minerals. They were developed by private parties on a very erratic scale. But further development was prevented because of objection from the Railway Board. The Railway Board said that the Damodar Valley was too congested, and no factory should be built there for another 4–5 years.

Saha said that after spending 60–70 crore of rupees on the development of the valley, not taking advantage of natural resources due to the traffic problem of railway was like midsummer madness. The railway traffic problem could be solved by some other alternatives, such as putting new lines and improving communications. The exploitation of the resources for the interest of the nation cannot be stopped because other sections of the government stood in the way. In this speech, he further pointed out the lapses in the planning of other projects, namely, Bhakra-Nangal, Kosi, Bokaro and Tungabhadra.

Since his school and college days, he was closely associated with floods, relief works, the living condition of affected people and the area around them. At the end he said: ‘…Whenever we start these river valley developments, we always think that America had the last word on it; that was not so. Soviet Russia had constructed many multipurpose river valley projects, which were much more extensive in their concepts than the American projects. The great Volga river had been converted in to a number of lakes and it had been utilized, not only for navigation but also, irrigation of very large tracts of the country and power had been developed to an extent which was unheard of…. The river valley projects were the country’s greatest asset. The people had committed blunders in the past, but hoped they would learn from their mistakes and would be able to put them on the right track’.

The lapses and mismanagement in various projects of national importance, underutilization of natural resources, slow pace of work, corruption and leakage at various stages and improper and hasty planning made him restless. His speeches in Parliament were full of inner urge for the betterment of the common man, rapid progress of the country and excellence in nation building.

Not only did he study the administration of projects but also the financial and economic problems of the country. While participating in the ‘Debate on Finance Bill’ in 20 and 21 April 1954, he pointed out that when the government returns more than 10% of the budget because it could not spend it, it was an indication of very gross inefficiency on the part of the government. The Finance Minister had not explained to the Parliament the causes of shortfalls, why the money could not have been spent! … The government had neglected establishing goods industries during the preceding 5–6 years. For 7 years, the government could not take any decision on the installation of an iron and steel plant, though the plans were ready in 1948–1949. The losses incurred were something to the tune of Rs. 500 crore. The consumer goods industries could not flourish unless there was a goods industry. The dearth of steel, the planning commission said, endangered the growth of a large number of other industries, such as shipyards, locomotive factories, foundries, etc. The other example was the glass and soap industries. These industries could not prosper because of the dearth of soda ash, which was to be imported at higher price, because we could not produce sufficient quantity of it. The iron and steel industry existed for 40 years in India, and it was surprising that it could not develop a sufficient number of experts to draw plans for another iron and steel plant. When industry was left in private hands, they cared only for profit and not public interest. India had achieved political independence and should also aim for economic independence. The technical autonomy would terminate dependence on foreigners, where a huge amount of money was spent.

Atomic energy was one of the subjects of Saha's concern. He expected speedy progress in developing atomic energy in India. The major applications were for peaceful purposes, namely, cheap power generation, medical applications and basic research. In 1936, he was invited by Bohr to participate in a symposium on nuclear physics at Copenhagen. He had realized the tremendous potential of nuclear energy and was up-to-date in nuclear research.

Though Saha was a member of the Atomic Energy Committee of the Government of India, he was not included as a member of the Atomic Energy Commission (AEC) when it was formed. He initiated a debate in the Lok Sabha on 10 May 1954 on peaceful uses of atomic energy.

Later on in 1955 (February 24), while speaking at the 'Debate on the motion on address by the President' he criticized the work of the AEC. He said that the AEC was formed in 1949 with certain objectives. After 5 years, on 10 May 1954, he pointed out while debating on atomic energy in Lok Sabha that the efforts in developing atomic energy were extremely inadequate. This was admitted by the Hon. Prime Minister who also participated in debate, and he said that in future, there will be an increase in efforts and funds and there will be a better organization for the development of atomic energy.

In 1949, it was said that India could construct a reactor but had not constructed it. It was announced that India would purchase ten tons of heavy water, which was one of the materials needed for a reactor. The question was why it was not done 5 years back! According to Saha, the whole problem lay in the administrative policy, with respect to the development of atomic energy. From the beginning itself, there was a veil of secrecy about it. People were not allowed to talk about atomic energy. Members of the Atomic Energy Commission never said what they were doing and what researches they were financing. Everything was kept confidential. It was extremely ridiculous because other countries had imposed secrecy on atomic energy development simply because atomic energy was used to produce weapons of war. From the very beginning, it was said that atomic energy would not be used for any aggressive purposes. So, to have imposed secrecy on atomic energy work was not only the height of indiscretion but the height of folly. From other countries' experience, it was concluded that atomic energy could not be developed unless the services of thousands of scientists in the country were enlisted. Other countries would not help in this regard, and India had to develop the work with the help of her own scientists.

For 5 years, scientists of India had been precluded from taking part in the development of atomic energy.

Saha threw it as a challenge for the ruling people to justify why scientists of the country were not taken into confidence in the great task. After the debate, the Prime Minister said that there was no such secrecy and would invite scientists to a conference, the first atomic energy conference, and would discuss all these matters and formulate a new policy. The conference was held on November 26 and 27 but the outcome was nil. Neither administrative policy was decided nor was development work discussed. Saha said that the whole issue was in the same state as 1949, when secrecy was laid down on all atomic energy work. In his speech at the end, he said: 'Any scientist, however great he might be, cannot do this work alone. In scientific work, sometimes we find that it is not an Einstein or a Newton who can solve any problem. Sometimes the problem was solved by a man who may be a back-bencher. Scientific work was the result of co-operation of a large number of brains. Sometimes, a suggestion or a method of work comes from persons who were considered not very prominent or very able. In the development of atomic energy work in America, we find, suggestions have been made by persons whose names we do not know, we have not known till the other day. The most prominent scientists who were there had made absolutely no contribution. I want our government to take all these matters into consideration and lay down a sound policy for the development of atomic energy in this country'.

Often, Saha's arguments were based on facts and findings. The points he raised and questions he asked in Parliament were difficult to face. The political leaders then, including Jawaharlal Nehru, sarcastically called him as 'used to be a scientist' or 'better confine to laboratory', etc.

In December 1954, at the time of discussion in Parliament about *Motion on Economic Situation*, the then Prime Minister and Minister of External Affairs and Defence, Pandit Jawaharlal Nehru, remarked: '…*An eminent Member of the other side, who used to be a great scientist, Prof. Meghnad Saha, but who drifted from the fields of science and has found no foothold elsewhere yet, told us many things, most of which I think are completely wrong. I have seldom come across a less scientific approach to a problem than that of Prof. Meghnad Saha, in fact, a less factual approach. I can only express my deep regret that such an eminent scientist should have fallen into such evil ways of thinking…*'.

Saha sharply retorted '…I may add that I have done very little in science, but my name would be remembered for some hundreds of years while some politicians here will go to unregretted oblivion in a few years'. He didn't attack Nehru personally.

Nehru's remark on Saha was unfair to Saha. He was elected as a representative of the people like other members of Parliament. The sarcastic remarks were uncalled for.

He took part in debates on diverse topics such as flood control, planning, industry, atomic energy, refugees and rehabilitation, railway budget, state reorganization and so on. His speeches in Parliament were full of information and based on facts. Many a time, it was difficult for the ruling party to counter his arguments.

The ‘Debate on States Reorganization’ continued for 4 days, from 18 to 21 December 1955. Saha participated in the debate on December 21, and it was his last major speech in Parliament. That speech revealed some glimpses of his amazing, comprehensive erudition about the origins of various languages and their literature.

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Chapter 15
Sudden End

From 1953 onwards, Saha was very busy. He was full-time director of IACS, honorary director of the Institute of Nuclear Physics and also a member of the Parliament. Of these three, every job was full time, requiring close attention. He was passionately involved in many tasks. At this time he worked on the Calendar Reform Committee also. It is probable that there must be some reason that kept him away from the Atomic Energy Programme and the National Planning Committee.

In 1953, the Central Government had appointed the State Reorganization Commission (SRC) to structure the reorganization of state boundaries. It consisted of Fazal Ali, K. M. Panikkar and H. N. Kunzru. After 2 years of study, the commission recommended India's state boundaries.

In December 1955, Saha wrote some articles in *Hindusthan Standard*, Calcutta on 'State Reorganization'. '… The SRC has entered into a puerile discussion over the retention of the coal areas in Bihar. They say that Rajmahal, though predominantly Bengali speaking, should go to Bihar, because otherwise the coal balance between Bengal (Raniganj Coalfield) and Bihar (Jharia Fields), would be disturbed, and Rajmahal coal will keep the balance. The SRC ought to have known, that coal in this age is such an important commodity, that it will be dangerous to say, that it belongs to Bengal or Bihar. It belongs to India, and if we wish to reconstruct the country according to the socialistic pattern, coal is going to be sooner or later nationalized, and therefore the question of the retention of coal areas in Bihar or Bengal have to be decided on other grounds. …Their arguments have been confusing and self-contradictory; e.g., in the case of the Kolar gold fields, they have recommended the retention of that area in Mysore or Karnataka, saying that the non-*Canarese* (*Kannada* language speaking) majority is a floating population, but in the case of Jamshedpur and Dhanbad, originally Bengalee speaking areas, and within Bengal, they have recommended the areas to be included in Bihar, – though the Bihari population is "floating".

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In fact, if the recommendation of the SRC on Assam and Bihar are carried out, the government will be creating a situation like that of '*Linguistic Groups*' under the parliamentary democracy in the former Austro-Hungarian empire, before World War I. Parliamentary democracy failed there, because the country had not adopted socialism, and the German and Magyar bourgeois, went on exploiting the other nationalities (or language groups) in spite of democracy, until there was an explosion which put an end to the Austro-Hungarian empire' [1].

There was the question of a possible merger between Bengal and Bihar. Saha was disturbed and in a very agitated state of mind. In the first week of February 1956, he addressed a public meeting at Calcutta on the Bengal-Bihar merger issue. See Fig. 15.1.

In early 1956, he suffered from high blood pressure. On 16 February 1956, in Delhi, on his way, he was only a few yards away from the gate of Rashtrapati Bhavan (President's House) where he collapsed due to a fatal stroke. He was rushed to the nearby Willingdon Hospital where doctors declared him dead. His body was flown to Calcutta in a special chartered plane. Thousands thronged the streets of Calcutta for a tearful farewell (see Fig. 15.2).

Fig. 15.1 Prof. M. N. Saha addressing a gathering to protest against proposed Bengal-Bihar merger at Calcutta (1956) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Fig. 15.2 The funeral procession of Prof. M. N. Saha in front of University College of Science & Technology, Calcutta (1956) (This photograph is provided by Saha Institute of Nuclear Physics, Calcutta, India)

Reference

1. *Hindustan Standard*, Calcutta, December 5, 6 and 7, 1955.

Chapter 16

Saha and a Symbol of Excellence

By birth Alfred Bernhard Nobel was Swedish but he had held no formal Swedish citizenship, since he left the country as a child. He stayed and controlled his empire mainly from homes in Paris and San Remo, on the Italian Riviera.

In 1888, Alfred's brother Ludvig died. A French newspaper erroneously published Alfred's obituary. It indicted him for his invention of the dynamite which is said to have brought about his decision to leave a better legacy after his death. The obituary stated – 'The merchant of death is dead. … Dr. Alfred Nobel, who became rich by finding ways to kill more people, faster than ever before, died yesterday'. Alfred was disappointed with what he read and concerned with how he could be remembered [1].

In 1895, at the Swedish-Norwegian Club in Paris, he signed his last will and testament and set aside the bulk of his estate to establish the Nobel Prizes. His testament reads as: 'The whole of my remaining realizable estate, shall be dealt with in the following way: The capital shall be invested by my executors in safe securities and shall constitute a fund, the interest, on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind. The said interest shall be divided into five equal parts, which shall be apportioned as follows: one part to the person who shall have made the most important discovery or invention within the field of Physics; ….. The prizes for Physics and Chemistry shall be awarded by the Swedish Academy of Sciences; … It is my express wish that in awarding the prizes, no consideration whatever shall be given to the nationality of the candidates, so that *the most worthy* (italic mine) shall receive the prize, whether he be a Scandinavian or not'.

The Nobel Prize is treated as a symbol of excellence. But the process of nomination and selection remain somewhat obscure. To become eligible for consideration, the candidate must be proposed by a nominator from the following two categories: The first category has a permanent right to submit names of candidates annually. In this, there are four sub-categories:

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1. All members of the Royal Swedish Academy of Sciences, both Swedish and foreign members, irrespective of their scientific disciplines.
2. Members of the Nobel Committee for Physics. The membership in the Academy was not necessary.
3. Prior winners of the Nobel Prize in Physics.
4. Permanent and acting professors in physics at Swedish and other Nordic (Denmark, Finland and Norway) universities and technical colleges existing in 1900.

In the second category, nominators are invited on an ad hoc basis each year.

5. Holders of professional chairs in physics in at least six universities, or comparable institutions of higher learning, to ensure an appropriate representation over different countries and their seats of learning.
6. Other scientists from whom the Royal Swedish Academy of Sciences might see fit to invite proposals.

The five-member Nobel Committee evaluates the nominations, prepares a report and makes a proposal to the Academy. The Academy's physicists then vote to approve the proposals or to make their own recommendations. Finally, the full Academy votes.

Nobel Committee members' understanding, scientific orientation and priorities, their own professional training and so on play a vital role in the overall process. The history of Nobel Prizes in Physics and the research on the newly opened Nobel Committee Archives put the question mark on; the prize is an impartial, objective crowning of the best in physics, excellence beyond dispute, unbiased faultless process and 'the most worthy' candidate.

Saha's name was proposed for Nobel Prize. His theory of *thermal ionization* was the breakthrough in astrophysics. He first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory.

The Volta Centenary Celebration was held in 1927, at Como, Italy. Many reputed scientists were invited, namely, Planck, Rutherford, Max von Laue, W. L. Bragg, Max Born, Niels Bohr, etc. Saha was also invited for this conference by the Italian Physics Society. His work was considered a landmark in the field of modern astrophysics.

In their nomination letter to the Nobel Committee on 25 January 1930, D. M. Bose and S. K. Mitra mentioned the scientific achievements of Saha under the title *References to original publications*. It contains seven publications on the treatment of the theory of *Thermal Ionization* and three publications on *Selective Radiation Pressure*. In the letter they wrote:

> 'The first is the most outstanding and fruitful contribution to the subject of Astrophysics, since Kirchhoff made his discovery of spectrum analysis in 1859, and opened a way for studying the physical conditions of the stars and the sun. Saha's theory, provides for a physical explanation of the data on stellar spectra accumulated for over half a century by the labours of Sir Norman Lockyer in England, and of Prof. Pickering and Miss Cannon in the

> Harvard College Observatory, U.S.A. The theory has stimulated further work, all over the world amongst physicists and astrophysicists. Further extensions have been made by H. N. Russel, R. H. Fowler, E. A. Milne and W. Wolther. Prof. Saha also has improved the theory in a further series of papers, published in the *Philosophical Magazine*, and has secured experimental verification of the theory'[2].

The report prepared by Carlheim-Gyllensköld discusses the detail of the papers, given by the nominee and its summary in the report of the Nobel Committee, and starts on the basis of Saha's ionization equation. It follows:

> Saha has started with some definite, already for long time well known facts about the appearance of the spectral lines of different characteristics, at different heights within the chromosphere of the sun. As the (spectral) lines of the arc are caused by the neutral atom, and the flash spectral lines are caused only by ionized atoms, the relative intensity of the two types of lines, should indicate the relative number of neutral and ionized atoms. Under the supposition, that one finds a relation between the relative number, the temperature and pressure, on the basis of the conducted spectroscopic observations, one can find the explanation on the temperature and pressure existing in the stellar atmosphere, …… shortly before Saha's first publication, Eggert had applied Nernst formula for the isobar reaction on the problem of the gas equilibrium, inside a star and had shown that many supposition about the inner constitution of the stars can be found. …… Saha applied Eggert's method on the problem of the state of the gases, on the outer surface of the stars. With the help of the formula which Saha obtained in this way, the ionization grade of an element under any pressure and temperature can be calculated, under the condition that the ionization potential of the element in known. The value of ionization potential for different elements, has been determined by Frank and Hertz, McLennan and others.
>
> In 1921 Saha had published a paper, in which he himself gave a summary of the fundamentals of the theory. Also, he named further applications of these fundamentals for the solar spectrum and the different classes of stellar spectrum. In his next paper, Saha gave more information about the application of the theory on the spectrum of celestial bodies. He concluded that the continued variation in the stellar spectrum only depends on the changing temperature of the stellar atmosphere. On this basis, the classification in different types B, A, F, G, K and M, which the Harvard astronomers set up as a result of several year-long studies, seems to get a deeper physical meaning. However, several minor differences can be realized. Saha mentioned several, but here, only one of these is mentioned – Adam and Kohlschutter have recently shown that there exists a considerable difference in the spectra of the giant and the dwarf stars of the same spectral class, when the intensity of a certain groups of lines is compared. But as Saha remarked, the spectrum is not only temperature dependent but also the concentration of atoms in the stellar atmosphere, and this may give the explanation for the deficiency shown in the conformity.

About the other scientific achievements, the nominators wrote:

> The theory of selective radiation pressure, was pronounced by Saha in a letter to *Nature* and in a paper published in the *Journal of Science* of the Calcutta University. This provides a basis for the explanation of abnormal heights of elements in the solar atmosphere. The theory has been further extended by Prof. E. A. Milne, in a series of papers to the *Month. Not. R. Astronomical Society* of England.

This achievement of Saha was not considered important. The Committee observed:

> The other important investigations by Saha which were mentioned partially seem to be considered to be logical consequences of the above-mentioned research work and by no means, have the same importance.

Singh and Riess [2] concluded that Saha's nominators were not influential persons and it seemed that they could not convince the Committee that Saha's work was revolutionary.

The Committee concluded:

> Saha's work is proved to be very important for modern astrophysics, but this can hardly be seen as a new physical discovery, more as an application to known physical accumulated astrophysical data. With all recognition for the value of Saha's achievements, the Committee finds itself not in a position, to recommend him for the reception of the Nobel Prize for physics.

S. K. Mitra nominated Saha again in 1939. A. H. Compton nominated Saha twice, in 1937 and 1940. For the Nobel Prize of 1940, Compton nominated E. Lawrence, Saha, O. Stern, O. Hahn and L. Meitner. About Saha's contribution he wrote:

> Second on my list I should place Professor M. N. Saha of the University of Calcutta, whom I recommended for the prize 2 years ago, because of his study of the ionization of stellar atmospheres. Not only has this work been fundamental to much of the recent development in Astrophysics, but it has also formed the basis of recent physical studies of the thermodynamics of high temperature ionization. [3]

When the Nobel Prize in Physics came into existence, physics was a broadly conceived field. When the Academy appointed its first Physics Committee, it was assumed that Nobel intended a wide understanding of physics. Meteorologist Hildebrandsson, astrophysicist Hasselberg and physical chemist as well as cosmical physicist Arrhenius were elected to the first committee.

Till 1923, nominations for contributions in meteorology, astrophysics, cosmical physics, theoretical physics and physical chemistry were not declared ineligible for consideration. Astrophysicists George Ellery Hale and Henri Deslandres entered the ranks of those candidates, declared worthy and lined up to wait for their time to come.[1]

In 1923, the scope of physics was restricted. Oseen[2] and Siegbahn[3] brought a different set of priorities for their discipline. Together with Arrhenius[4] and

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[1] The case of Nobel Prize for Hale and Deslandres and its consequences are described by Friedman [4].

[2] Oseen, Carl Wilhelm (1879–1944) was affiliated to Uppsala University and was Director of Nobel Institute for Theoretical Physics. His specialization was theoretical physics. He served as a Nobel Committee member from 1923 to 1944.

[3] Siegbahn, Karl Manne Georg (1886–1978) received the Nobel Prize in Physics in 1924. He was affiliated to Lund University, Uppsala University and Nobel Institute. His specialization was experimental physics. He served as a Nobel Committee member from 1923 to 1962.

[4] Arrhenius, Svante (1859–1927) received the Nobel Prize in Chemistry in 1903. He was affiliated to Stockholm University and Nobel Institute, and his specialization was physical chemistry and cosmical physics. He served as a Nobel Committee member from 1900 to 1927.

Gullstrand,[5] they considered the question of focusing resources and prestige more narrowly on fewer specialities to be urgent. They first eliminated astrophysics and the candidacies of Hale and Deslandres. Meteorology, not so easily disposed of, eventually followed once Oseen rhetorically bludgeoned the favoured candidate and his supporters.

Awarding or withholding prizes for contributions in specific research specialities could conceivably assist in promoting or hindering the advance of these fields in Sweden. The case of Hale and Deslandres highlights the campaign to redraw boundaries and define new priorities; it also reveals how, independent of the nominators, committee members themselves could either propel a candidate toward a prize or, just as readily, eliminate him from consideration.

Hale brought the methods and theories of physics into astronomy. As a pioneering American astrophysicist, he applied spectroscopy to the study of the physical and chemical characteristics of stars and in particular the sun. He invented a spectroheliograph, which advanced solar research. One of his important discoveries was magnetic fields associated with sunspots. In 1913, he figured in the list of nominees. In the same year French astronomer and meteorologist Henri Deslandres was also in the list of nominees. He independently and, subsequent to Hale, also had constructed a spectroheliograph. The Committee linked Hale and Deslandres together as equals. In 1914, American nominators again proposed Hale and the Committee declared him to be among the most deserving of the prize. But that year his work was not evaluated as Deslandres was not nominated that year. To ensure that Hale and Deslandres would be evaluated together once again, Arrhenius proposed the two in 1915. The Committee declared them worthy, but put them on hold because of names of William Henry Bragg and William Lawrence Bragg.

Again their names appeared in 1916, 1917, 1922 and 1923. In 1923, Gullstrand was the chairman of the Committee. He suggested assignments for special reports. From the past criteria and prior evaluations, Gullstrand understood that Hale and Deslandres were the strongest candidates that year – but only if the Committee still wanted to consider astrophysics (as) part of physics. His message triggered expected reactions. Oseen informed Gullstrand that he had doubts whether their contributions belonged to physics and sought Arrhenius' authority in this matter. As chairman of the Committee, Gullstrand behaved as a neutral observer but he set his hidden agenda against astrophysics. To prevent surprises in the Academy, Gullstrand rigged the game. He urged Carlheim-Gyllensköld[6] to prepare a draft of his special report on the astrophysicists' work as quickly as possible. It prompted other members to act also. When the Committee had the draft as a basis for discussion, Arrhenius concluded that astrophysics had expanded so rapidly since 1900, when it was

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[5] Gullstrand, Allvar (1862–1930) received the Nobel Prize in Physiology or Medicine in 1911. He was affiliated to Uppsala University and his specialization was ophthalmology. He served as a Nobel Committee member from 1911 to 1929.

[6] Carlheim-Gyllensköld, Vilhelm (1859–1934) was affiliated to Stockholm University and his specialization was cosmical physics and mathematical physics. He served as a Nobel Committee member from 1910 to 1934.

declared eligible for the Physics Prize, and that it now encompassed all of astronomy. He declared that astronomy had become astrophysics. Since Alfred Nobel clearly had not intended astronomy to be eligible for his Prizes, astrophysics no longer could be eligible. He emphasized the importance of withholding the Prize to Dale and Deslandres. He warned that a Prize to Hale and Deslandres would set a precedent legitimizing astrophysics as being part of physics.

Carlheim-Gyllensköld protested. Arrhenius understood that the Committee's majority backed him fully. They edited the final draft of Carlheim-Gyllensköld's special report. Finally, the Committee's majority claimed that Hale's accomplishments had not resulted in solid achievements for an understanding of the sun. It was the first successful attack on the traditional broad understanding of physics. The denial of the Prize to Hale and Deslandres made it easier for the Committee to dismiss subsequent candidates. During the next few decades, leading astrophysicists who were nominated for the Prize were rejected, for example, Hans Bethe, Ira Bowen, Arthur Eddington, Edwin Hubble, Meghnad Saha and H. N. Russell. The Committee claimed that regardless of how important the astrophysicists' achievement might be for the field of astrophysics, it had no marked significance for physics in general (as per Committee's definition) to warrant a Nobel Prize. Saha and Bethe's work should not have been dismissed as being solely significant for astrophysics and not part of physics. In fact Bethe was not an astrophysicist and his brilliant theory of explaining how stars produce energy was part of nuclear physics. The major changes in the Committee's composition and pressure from prominent physicists changed the Committee's stance and Bethe received the Prize in 1967.

Unfortunately, the comprehensive history of physics, which is unbiased and free from any *ism*, is not written. It would have placed Saha in the proper context.

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Chapter 17
Epilogue

Saha's life span was in pre-independent India, except the last 8 years. In general, British India at the end of the nineteenth century was of poor people. Saha was also born in a poor family. Higher education or a research career was almost impossible for him. Saha had to struggle a lot at every stage. It created a deep impact on his personality.

He was bold enough to criticize even Mahatma Gandhi, without bothering about its effects. He was not an opportunist. After independence he was not included in the National Planning Committee, in spite of working hard on Planning in pre-independent India. It must have given rise to deep frustration. Many people, in the corridors of power, where power was centred in the ruling party, were confused about priorities, planning and its modus operandi in the National Reconstruction of independent India. Saha was of the firm opinion that in a country like India, the problems of food, clothing, poverty, education and technological progress can be tackled only with proper planning using science and technology. The forced march of the Soviet Union was his model. Today, looking back at history, one can argue about this; but it is a different issue.

> 'By his ceaseless writings and speeches, he has sought all these years to inculcate among his countrymen, a new scientific attitude and philosophy towards all problems of national development. It is this attitude and philosophy and, above all, his intense love for the country which had drawn him to Parliament and the people in this country. There may be disagreement about some of his views and programmes, but his objective and dispassionate approach to problems, on which a superb scientific and analytical mind, has been brought to bear, his sincerity of purpose, unflinching devotion to truth, courage of conviction and the great integrity of character, made him one of the rare thinkers of India. He was a man of action. He liked to see things happen. Nothing irritated him more than indecision, delay and excuses for inaction. … His outward roughness and outspokenness, often mislead the superficial observer. The soft, tender and affectionate heart, which was hidden inside was only open to those who came in close contact with him. A true friend, philosopher and guide of his students, he accommodated many of his research pupils in his own home, treating them as members of his family, both at Allahabad and at Calcutta. His efforts, and not infrequently financial help, enabled many of his students to go abroad for higher studies and research. He took immense pride in the achievements of his students' [1].

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He was a professor of the highest distinction, who could call forth the fiercest loyalties from his students. In the city of Calcutta, the Saha Institute of Nuclear Physics (SINP), the Indian Association for the Cultivation of Science (IACS) and the journal *Science and Culture* would ever remain monuments of his creative ability [2].

He was very disappointed by the performance of the government between 1947 and 1951, especially in matters of policy decisions on large-scale industrialization, mismanaged river valley development schemes and negligence in education and health.

He had two alternatives, either to observe in silence or raise his voice against mismanaged projects and improper planning. He was not the man to keep quiet. He entered Parliament for social causes. He did not want anything for himself. He was not a professional politician but circumstances forced him to enter Parliament.

Whenever questions asked by Saha in Parliament had no answers or exposed mismanagement or poor governance or policy lapses, the (ruling party) Congress members instead of answering made sarcastic remarks which were uncalled-for. For example, '…Prof. Meghnad Saha, who drifted from the fields of science and has found no foothold elsewhere……' It was impossible to prove that he drifted from the fields of science. He was an elected representative of the people at par with other members of Parliament. The personal attacks were unjustified. He entered Parliament with certain objectives. He thought it was his responsibility to compel the government to streamline projects of national importance. The range and depth of his knowledge reflected in his speeches in Parliament was amazing.

It seems from the historical details of nuclear science in India [3] that he was not given a free hand for research in nuclear science.

Apart from being a physics teacher and researcher, he was like a social teacher with a scientific attitude. He advocated and tried to inculcate scientific attitude through his various editorials and articles in *Science and Culture*, addresses and speeches at various occasions and debates in Parliament.

One may not agree with all his thoughts or opinions. Sometimes he appeared harsh, not trying to understand political and social compulsions. Yet his sole aim was to wipe out the tears of his poor countrymen, make rapid progress, optimize the country's resources and mould young people for the betterment of society.

The forced march like Soviet Union was not possible in India, where Parliamentary democracy was functioning with its advantages and disadvantages. Indians' ideas about their real and imaginary glorious past, feudalism, caste system, provincialism, regionalism, illiteracy and colonial past had a deep and long-ranging impact on society, which had resulted in intricate complexities.

I do not mean Saha was not aware of this. But from his writings, thoughts and criticism, it seems he was trying to simplify it or give less importance to it or may be overambitious or extremely optimistic rather than realistic.

While reading some of the articles and speeches, it feels that as if he sat in front of you and talked to you, making you understand or trying to convince you. His words came from the bottom of his heart. His writings were full of utmost sincerity, scientific approach, wide perspective, fervour for his countrymen's progress and betterment of the poor.

Scientists of Saha's stature, who have an intense desire for using science to solve the problems of society, and comprehensive thinking are very rare, always ready to put all efforts wholeheartedly in the form of time, labour, etc. in that direction. It is unfortunate that India could not use Saha's intelligence to the maximum extent.

Saha worked on various government committees. He was a member of BSIR and then CSIR. Bhatnagar was the Director General of CSIR, and the establishment of a string of national laboratories was his monumental work. Though he was an eminent scientist and Fellow of the Royal Society (FRS) of London, he was not allowed to contact the member-in-charge (corresponding to Minister) directly, but only through the secretary of the department who was either a civil servant or finance official man. It was Saha's pungent criticism of this system in *Science and Culture*, which compelled the Government to grant Bhatnagar the rank equivalent to that of Secretary and the right of direct approach to the Minister.

Saha had realized that bureaucracy was one of the causes of inefficiency of the Government, where scientific and technical knowledge was concerned.

In the establishment of Atomic Energy Commission, Bhabha reported directly to the Prime Minister and that was one of the reasons why Bhabha was successful in building an empire of DAE. One might (or could) suspect bureaucracy would have punctured many DAE projects.

Saha's research in physics at the beginning of his career gave him fame. His name was proposed for the Nobel Prize also. But due to various complicated issues, it was rejected. The Nobel Prize should not be the sole criterion of excellence. The manner in which a particular contribution changed, modified or affected a fundamental or application part of physics and to what extent should be the criterion of excellence. Let the historians of physics decide it!

Subjects like technical and professional education, university structure, research at universities and other institutions, industrialization, river management, calendar reform, etc. were dearer to him. When the Damodar Valley Corporation Act was adopted by the Government of India and they appointed a Tennessee Valley Authority expert Mr. Voorduin to draw up a preliminary plan for Damodar Valley, Saha congratulated the government. The Voorduin report closely agreed with the specific recommendations given in Saha's article (with K. Ray) in *Science and Culture* on *The Planning of the Damodar Valley*. The report did not acknowledge it or conveniently forgot it. But history will never forget it.

'Indian science has been the victim of the triumph of Nehru's decision to place nearly all of India's scientific eggs in the Government basket. Saha's idea would probably have served India's interests better' [4].

Various reports on today's education in India[1] indicate that Saha's concern, expressed in his Parliamentary speeches and at other places, about education in general and higher and technical education in specific was not unnecessary.

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[1] More than 65 years after independence and various plans, their reviews and re-plans, one of the reports says that there are 5.23 lakh vacancies of teachers at primary school level, 5.1 lakh additional primary teachers are needed to meet the Right to Education Act and 7.74 lakh of the existing primary teachers are not qualified enough. There are 35% of vacancies at 24 older central universities,

On Saha's 60th birthday, E. O. Lawrence said: 'Indeed, I shall never forget the intellectual thrill, I derived from learning about *Saha's ionization equation* in my early days as a graduate student…' [1].

I dare to borrow Lawrence's words.

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3. J. Phalkey, *Atomic State: Big Science in Twentieth-Century India* (Permanent Black, Ranikhet, 2013)
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50% or more vacancies in 19 out of 77 state universities and at least 40% of vacancies in 14 others. In technical institutes there is 1 lakh faculty deficit [5]. Only 10% of students have access to higher education (beyond higher secondary schooling) in India. In China it is 22% and in USA it is 28% [6]. Another report says that to go from having islands of excellence to being a major world player in science, India must solve such problems as dearth of teachers and a divide between research and teaching [7].

Appendix I

Meghnad Saha: A Chronology

6 October 1893	Born in *Seoratali*, District of Dacca, East Bengal
1909	Entered Dacca College for Intermediate Science
1911	Joined Presidency College, Calcutta
1916–1919	Lecturer at the University College of Science, Calcutta
1918	Obtained D.Sc. degree of Calcutta University Married to Radharani Roy
1920	Visit to Europe with Premchand Roychand Studentship plus patronage of Brahmo Samaj
1921	Joined as Khaira professor of physics, Calcutta University
1923	Joined as professor and head of Physics Department, Allahabad University
1927	Elected as fellow of Royal Society (FRS), London
1934	President, Indian Science Congress
1935	Founded a monthly journal *Science and Culture*
1936	Visit to Europe and the USA with fellowship of the Carnegie Trust of the British Empire
1938	Joined as Palit professor and head of Physics Department, University College of Science and Technology, Calcutta
1944	Visit to various research facilities in the UK, USA and Canada – tour arranged by Prof. Hill
1945	Visit to USSR to attend 220th Anniversary of Russian Academy of Sciences
1948	Foundation of Institute of Physics (INP), Calcutta
1950	Opening of INP
1952	Contested and was elected as member of Parliament (MP), from Calcutta North-West constituency
16 February 1956	Sudden death due to fatal stroke in New Delhi

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Appendix II

Some Indian Personalities

1. Prafulla Chandra Ray (1861–1944) popularly known as *Acharya* (means great teacher) obtained D.Sc. in chemistry from Edinburgh University in 1887. He joined Presidency College Calcutta, as assistant professor of chemistry in 1889. In 1916, he joined Calcutta University College of Science as its first Palit professor of chemistry. He worked on compounds of gold, platinum, iridium, etc. He was awarded knighthood in 1917. He founded India's first pharmaceutical company 'Bengal Chemicals and Pharmaceuticals'.
2. Ashutosh Mukherjee (1864–1924) was one of the great personalities of Bengal in pre-independent India. His contribution to higher education was monumental. In November 1879, he passed the matriculation examination and joined Presidency College. In 1884, he topped the list of successful candidates in B.A. examination and won the *Harischandra* Prize. In 1885, he was the first in M.A. in natural sciences. In 1888, he took the bachelor of law degree and enrolled himself as a *Vakil* (advocate) of the Calcutta High Court. Between 1880 and 1890, when he was preparing for various examinations, he published around 20 original mathematical papers of high quality and merit. One of his papers 'A note on elliptical functions' (*Q. J. Pure Appl. Math.*, 21, 212–17, 1886) was considered by Cayley of Cambridge, as a contribution of 'outstanding merit'. By 1893, Ashutosh had been elected Fellow of the Royal Society of Edinburgh, of the Society de Physique of France and of the Royal Irish Academy. In 1908, the Doctor of Sciences, *Honoris Causa* was conferred on him by the Calcutta University. He received the doctor of law based on a thesis, and in 1897 he was elected as the Tagore professor of law. He became a member of the Syndicate of Calcutta University, when he was 25. He was appointed a judge of the Calcutta high court in 1904 and was the chief justice for a couple of years. He took a great deal of interest in the affairs of Calcutta University. He was a member of the Senate and Syndicate for 16 years, in which for 11 years he was a

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president of the board of studies in mathematics. He represented the university in the Bengal council from 1899 to 1903. Besides, he was an additional member of the Viceroy's Council representing Bengal in 1903–1904 and a member of the Indian Universities Commission in 1902. He was appointed as vice-chancellor (VC) of the Calcutta University in 1906 and served till 1914 and again in 1921–1923.

3. Basanti Dulal Nagchaudhuri (1917–2006) studied at Banaras Hindu University and Allahabad University where he was Saha's student. With Saha's recommendation, he went to the University of California to complete a doctorate in nuclear physics under the guidance of E. O. Lawrence. After completing his doctorate, he joined Saha's research group at the Calcutta University. He played a major role in building the first Indian cyclotron. After Saha's retirement in 1952, he was named director of SINP. He was chairman of the Cabinet Committee of Science and Technology of Government of India from 1969 to 1972. He also served as a scientific advisor to the Ministry of Defence and DRDO.
4. Daulat Singh Kothari (1905–93) studied at Allahabad University under the guidance of Saha and then obtained a doctorate from the Cavendish Laboratory, University of Cambridge, under the supervision of Ernest Rutherford. He was a scientific advisor to Ministry of Defence, Government of India, from 1948 to 1961 and then appointed chairman of the University Grants Commission in 1961 where he worked till 1973.
5. Debendra Mohan Bose (1885–1975) was an Indian physicist who made contributions in the field of cosmic rays, artificial radioactivity and nuclear physics. He worked with J. J. Thomson and C. T. R. Wilson at Cavendish Laboratory. In 1914, he was appointed as Rash Behari Ghosh professor of physics in Calcutta University College of Science. In 1935, he succeeded Professor C. V. Raman as the Palit professor of physics. He was director of Bose Institute, Calcutta, during 1938–1967. For about 25 years, he edited the science monthly *Science and Culture*.
6. Jawaharlal Nehru (1889–1964), popularly known as *Pandit*, means scholar, was the first prime minister of independent India from 1947 to 1964, till his death. He was by profession a lawyer (barrister), the central figure in the independence movement and later in Indian politics of twentieth century, and is considered an architect of modern India.
7. Jivatram Bhagwandas Kripalani (1888–1982) popularly known as *Acharya* (great teacher) Kripalani was one of the prominent leaders of Indian National Congress, a Gandhian socialist, environmentalist and an independence activist.
8. Mohandas Karamchand Gandhi (1869–1948) was known as *Mahatma*, which means in Sanskrit *high souled* or venerable. He is widely described as father of the nation. After matriculation in Gujarat, he left for England to study law. For some time, he practised law in Bombay. Then, he went to South Africa as a lawyer. There he started the civil rights movement. In 1915, he returned to India and then was involved in the Indian National Congress activities. He became leader of the masses through various movements. He was assassinated in 1948.

9. Mokshagundam Visvesvaraya (1860–1962) was a great Indian engineer, scholar, statesman and *Diwan* (chief minister) of Mysore from 1912 to 1918. He was chief designer of the flood protection system for the city of Hyderabad and chief engineer for the construction of the *Krishna Raja Sagar* dam in Karnataka. He was awarded the highest Indian civilian award *Bharat-ratna* in 1955. His birthday, 15th of September, is celebrated in India as Engineer's Day.
10. Prasanta Chandra Mahalanobis (1893–1972) was an Indian applied statistician. He studied initially at Presidency College, Calcutta, for his B.Sc. in physics and then at King's College, Cambridge, England. After a tripos in physics, he worked with C. T. R. Wilson at the Cavendish Laboratory. He developed interest in statistics and made pioneering studies in anthropometry. Later he founded the Indian Statistical Institute at Calcutta. His most important contributions are related to large-scale sample surveys. He became FRS of London in 1945.
11. Rabindranath Tagore (1861–1941), popularly known as *Gurudev* (revered teacher), was a Bengali polymath. He was an outstanding creative artist of modern India. His anthology of poems *Gitanjali* made him Nobel Laureate in literature in 1913. He was highly influential in introducing the best of Indian culture to the west and vice versa.
12. Sarvepalli Radhakrishnan (1888–1975) was the President of India from 1962 to 1967. He was a philosopher, educationist and one of the India's best and most influential statesmen of the twentieth-century scholar of comparative religion and philosophy. He was awarded the highest Indian civilian award *Bharat-ratna* in 1954. Since 1962, his birthday, 5th of September, has been celebrated in India as Teacher's Day.
13. Shanti Swaroop Bhatnagar (1894–1955) earned D.Sc. from the University College London in 1921 under chemistry professor Frederick G. Donnan. Later on, he worked as a professor of chemistry in Banaras Hindu University at Allahabad. Then he moved to Lahore as professor of physical chemistry and director of University Chemical Laboratories of the University of Punjab. He became director of the Board of Scientific and Industrial Research (BSIR) in 1940, which later became Council of Scientific and Industrial Research (CSIR). The establishment of a chain of CSIR National Laboratories was his monumental contribution in the Science and Technology in India. He was appointed as an officer of the Order of the British Empire (OBE) in 1936. He was knighted in 1941. In 1943, he was elected as fellow of Royal Society (FRS) of London.
14. Sisir Kumar Mitra (1890–1963) obtained D.Sc. from the University of Paris in France. He developed interests in radiocommunications and ionospheric research. In 1923 he joined the Calcutta University as a Khaira professor of physics. He was elected as fellow of Royal Society (FRS) of London in 1958.
15. Subhash Chandra Bose (1897–1945) was popularly known as *Netaji*, which means respected leader. He was a leader of the younger, radical wing of the Indian National Congress and later president in 1938 and 1939. Due to differences with M. K. Gandhi, he resigned as president. Later he founded the Indian National Army with Japanese support for Indian freedom. He died in a plane crash.

Appendix III

Research Papers by Meghnad Saha

1. On Maxwell's Stresses: *Phil. Mag.*, Sr. VI, **33**, 256 (1917)
2. On the Limit of Interference in the Fabry-Perot Interferometer: *Phys. Rev.*, **10**, 782 (1917)
3. On a New Theorem in Elasticity: *Jour. Asia. Soc. Bengal*, New Sr. **14**, 421 (1918)
4. On the Pressure of Light (with S. Chakraborty): Jour. Asia. Soc. Bengal, New Sr. 14, 425 (1918)
5. On the Dynamics of the Electron: *Phil. Mag.*, Sr. VI, **36**, 76 (1918)
6. On the Influence of the Finite Volume of Molecules on the Equation of State (with S. N. Bose): *Phil. Mag.*, Sr. VI, **36**, 199 (1918)
7. On the Mechanical and Electro-dynamical Properties of the Electron: *Phy. Rev.*, **13**, 34 (1919), *Phy. Rev.*, **13**, 238 (1919)
8. On Radiation Pressure and the Quantum Theory, A Preliminary Note: *Astro. Phys. Jour.*, **50**, 220 (1919)
9. On the Fundamental Law of Electrical action: *Phil. Mag.*, Sr. VI, **37**, 347 (1919)
10. On Selective Radiation Pressure and the Radiative Equilibrium of the Solar Atmosphere: *Jour. Dept. Science*, *Calcutta University*, **2** (Physics), 51 (1920)
11. Note on the Secondary Spectrum of Hydrogen: *Phil. Mag.*, Sr. VI, **40**, 159 (1920)
12. Ionization in the Solar Chromosphere: *Phil. Mag.*, Sr. VI, **37**, 472 (1920)
13. Elements in the Sun: *Phil. Mag.*, Sr. VI, **40**, 809 (1920)
14. On the Problem of Nova Aquila III: *Jour. Astr. Soc. Ind.*, **10**, 36 (1920)
15. On the Problems of Temperature Radiation of Gases (Paper C): *Phil. Mag.*, Sr. VI, **41**, 267 (1921)
16. The Atomic Radius and the Ionization Potential: *Nature*, **107**, 682 (1921)
17. On the Physical Theory of Stellar Spectra, *Proc. Roy. Soc.*, London **A99**, 135 (1921)
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19. On Electron Chemistry and its Application to Problems of Radiation and Astrophysics, *Jour. Astro. Soc.*, Ind., **10**, 71 (1921)
20. The Stationary H and K-lines of Calcium in Stellar Atmosphere, *Nature*, **107**, 448 (1921)
21. On the Ionization of the Gases by Heat (with P. Gunther), *Jour. Dept. Sci.*, Cal. Univ., **4**, 97 (1922)
22. On the Temperature Ionization of the Elements of the Higher Groups in the Periodic Classification, *Phil. Mag.*, Sr. VI, **44**, 1128 (1922)
23. On the Physical Properties of Elements at High Temperatures, *Phil. Mag.*, Sr. VI, **46**, 534 (1923)
24. On Continuous Radiation from the Sun, *Nature*, **112**, 282 (1923)
25. On the Experimental Test of Thermal Ionization of Elements (with N. K. Sur), *Jour. Ind. Chem. Soc.*, **1**, 9 (1924)
26. On an Active Modification of Nitrogen (with N. K. Sur), *Phil. Mag.*, Sr. VI, **48**, 421 (1924)
27. The Pressure in the Reversing Layer of Stars and Origin of Continuous Radiation from the Sun, *Nature*, **114**, 155 (1924)
28. Ionization in Stellar Atmospheres and Steric Factor, *Mon. Not. Roy. Astro. Soc.*, **85**, 977 (1925)
29. Influence of Radiation on Ionization Equilibrium (with R. K. Sur), *Nature*, **115**, 377 (1925)
30. The Phase Rule and its Application to Problems of Luminescence and Ionization of Gases, *Jour. Ind. Chem. Soc.*, **2**, 49 (1925)
31. The Spectrum of Si^+(once ionized silicon), *Nature*, **116**, 644 (1925)
32. On the Absolute Value of Entropy (with R. K. Sur), *Phil. Mag.*, Sr. VII, **1**, 279 (1926)
33. On Entropy of Radiation II (with R. K. Sur), *Phil. Mag.*, Sr. VII, **1**, 890 (1926)
34. On the Influence of Radiation on Ionization Equilibrium (with R. K. Sur), *Phil. Mag.*, Sr. VII, **1**, 1025 (1926)
35. Nitrogen in the Sun, *Nature*, **117**, 268 (1926)
36. *Uber einen experimentellen Nachweis der thermischen Ionizierng der Elemente* (with N.K. Sur and K. Majumdar), *Zeit. F. Phys.*, **40**, 648 (1927)
37. *Uber das Mainsmith –Stonersche Schema des Aufbaus der Atome* (with B.B. Ray), *Physik Zeitschr.*, **28**, 221 (1927)
38. *Uber ein neues Schema fur den Atomaufbau*, *Physik Zeitschr.*, **28**, 469 (1927)
39. On the detailed explanation of Spectra of the Metals of the Second Group, *Phil. Mag.*, Sr. VII, **3**, 1265 (1927)
40. On the explanation of Spectra of Metals of Group II, Part II (with P.K. Kichlu), *Phil. Mag.*, Sr. VII, **4**, 193 (1927)
41. A Note on the Spectrum of Neon, *Phil. Mag.*, Sr. VII, **4**, 223 (1927)
42. On the Explanation of Complicated Spectra of Elements, *Estratto dagli Atti del congress Internazionale dei Fisici ComoSettembre*, 1927 (V)
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45. The Origin of the Spectrum of the Solar Corona, *Nature*, **121**, 671 (1928)
46. Negatively Modified Scattering (with D.S. Kothari and G.R. Toshniwal), *Nature*, **122**, 398 (1928)
47. On the Method of Horizontal Comparison in the Location of Spectra of Elements (with K. Majumdar), *Ind. Jour. Phys.*, **3**, 67 (1929)
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About Names of Places

The names are kept as then prevailing.
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