FOUNDERS OF MODERN SCIENCE IN INDIA

C.N.R. Rao
Indumati Rao

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Azadi ka Amrit Mahotsav

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We dedicate this book to the memory of two dear friends,

Satish Dhawan and M G K Menon

Preface

The birth of modern science can be considered to have happened only a few centuries ago. This seems to be reasonably correct since the formal beginning of physics can be traced only to the late 17^{th} century. It seems to have taken more than two centuries for modern science, as we understand today, to make entry to India. In terms of recorded discoveries, we find clear evidence for the practice of modern science in India only in the 19^{th} century. Since those days, we have made much progress and contributed significantly to many areas of science. Some of the contributions are highly original and can be considered to be landmarks in the saga of science.

In the mad rush and unbelievable competition, many of us may not ponder on how modern science started in India, and who the early explorers and pathfinders were. Since the scientists of each generation make progress only by standing on the shoulders of giants of the past, it is important to learn about our great scientists of the past. We thank Ms. Sudha for her helping us in preparing the manuscript and Mr. Vinayak Pattar for formatting the book.

We must record that it was possible to write this book due to the lockdowns during the COVID-19 pandemic.

C N R Rao
Indumati Rao

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Prologue

There was science in India almost from the beginning of the first century. Our forefathers made implements of brass, bronze and copper almost 2000 years ago. They created a new system of medicine and used vegetable dyes as coloring materials. We had astronomers and mathematicians as well. While these impressive accomplishments of the past can never be forgotten, we should note that the modern world, especially in the last three centuries or so, has created science with extraordinary dimensions and unbelievable impact on society.

Developments in modern science are relatively recent. Physics of today got formally established as a science only towards the latter part of the 17^{th} century, thanks to Isaac Newton. Chemistry as a subject got recognized by the end of the 18^{th} century, thanks to Lavoisier. It is in the 19^{th} century that Darwin came out with his theory of evolution. The birth of molecular biology was only in the middle of the 20^{th} century.

We in India were a colony when most of the early developments occurred in modern science. By and large, we had no connection with the people and institutions that were responsible for the discovery of atomic structure, quantum mechanics, the chemical bond or the alpha helix. However, even as citizens of a British Colony, some great souls initiated research in modern science in India. Some of them were truly extraordinary and were all born in the 19^{th} century. Three of these great scientists were Srinivasa Ramanujan (in mathematics), J C Bose and C V Raman (in physics). These three pioneers form the first part of this book.

We have had many brilliant stars in science in the twentieth century and many of them started their work before we got freedom in 1947. Part two of the book deals with a few of these stars.

There have been great scientists in the past who provided great patronage and support to science and built major institutions. These brilliant scientists whom we owe much, form part three of this book.

We have kept the size of the book small enough to tempt people to read it. In choosing the scientists of whom we have written, we have used the criterion

that there would be no living scientist. Furthermore, the scientists we have written about were generally born in the 19th century or in the early 20th century. They all passed away before the 21st century or very close it. We trust that the book will be found useful and enjoyable by all concerned and that we will be excused for any error in judgment.

Three Pioneers

JAGADISH CHANDRA BOSE (1858–1937)

The first modern scientist of India

Childhood and early education

Jagadish Chandra Bose was born in Mymensingh (now in Bangladesh) on 30 November 1858, in an affluent family. His father, Bhagaban Chandra Bose, was a deputy magistrate and loved science. He was also a philanthropist and started a People's Bank for the poor. His business ventures unfortunately failed, and the family lost all its property. He had started a Bengali medium school and young Jagadish went to this school. After the transfer of his father to Burdwan (West Bengal), Jagadish joined an English medium school (St. Xavier's). He had trouble with English and felt isolated socially. After his schooling, Jagadish joined the BA (science) course (physics) of the Calcutta University. He passed the BA examination in 1879 with a second class.

To England

Jagadish Bose was keen to go to England for further studies. It was the determination and generosity of his mother that enabled him to do so since the family itself was bankrupt. His mother sold her jewellery and whatever possible to support Jagadish. Jagadish won a scholarship to study in Christ College, Cambridge and was the first Indian to be admitted to Cambridge. His illness during that period of time did not allow him to study medicine and he, therefore, took up science. He obtained the Tripos in natural sciences with a second class. He spent another year to get a science degree from London University. Overall, he spent four years in England (1881–1885). In Cambridge, he had the benefit of being taught by Lord Rayleigh and Sir James Dewar.

At home, in Calcutta

In spite of many reference letters, Jagadish could not get a job in the Imperial Educational Service. He was, however, appointed as the officiating professor of physics at Presidency College at less than half the salary of an english professor. The principal of the college (Prof. Tawney) was not too happy with Jagadish's appointment, since it was recommended by higher authorities. Jagadish had a full teaching load, but he refused to accept the salary offered. He fought with the authorities for a salary equal to that received by the english professors. After a prolonged fight, he won the case. Even the principal was impressed by his doggedness. He used his earnings to pay the debts incurred by his father. His father died two years later in 1892. Jagadish had P C Ray as a colleague and S N Bose and M N Saha as his students in Presidency College.

Jagadish got married to a highly spirited girl from Calcutta, Abala Das, in 1865. She had tried to study medicine in Calcutta but was denied admission since there was no provision in the university for women to study medicine. She was of great support to Jagadish in his fight for a proper salary.

Pathbreaking research

Jagadish Bose started serious research in 1894 on microwave optics. He discovered the coherer, and thus was born the modern radio. Two of his papers were communicated to the Proceedings of the Royal Society by Lord Rayleigh. He demonstrated the possibility of signalling by short electric waves in Calcutta Town Hall in 1895.

We should note that this seminal work was done by J C Bose in the 19th century when we did not know anything about the electron or the atom. Jagadish received the DSc degree from London University for this work in 1896. He underplayed the importance of his work and refused to patent it.

Visit to Europe

In 1896, Lord Rayleigh arranged a visit of Jagadish Bose to Britain to deliver lectures, through the Royal Society. The British government approved his visit to Britain in view of his reputation as a scientist. Jagadish went to Britain with his wife. His first lecture was in the British Association in Liverpool where he talked of his work on properties of electric waves and the coherer. There were many great scientists in the audience including Lord Kelvin. Lord Kelvin wrote to the Secretary of the State for India to provide adequate support to Bose's research. There was an overwhelming response to his lecture at the Royal Institution in London. Reports on his work were effusive. Bose later lectured in Paris and Berlin. On his return, Bose received a warm welcome in Calcutta. Rabindranath Tagore, his close friend and admirer, sent a bunch of flowers and composed a poem.

Jagadish Bose asked for a small grant from the government for his research but received a rude reply from finance member of the government. Sometime later, the government decided to support him with a grant of Rs. 2000 per year due to the intervention of the Governor and others. Lord Rayleigh came to Calcutta during that time and visited Jagadish's laboratory. Later, Jagadish received a letter from the principal admonishing him for receiving such a great personality without proper permission.

Bose contributed to areas of solid-state physics as well. As early as 1894, he worked on the anisotropic conduction of galena crystals. Amazingly, he anticipated the existence of *p*- and *n*-type semiconductors. Prof. Neville Mott has expressed his amazement for Jagadish's intuition at a time when electrons were not known, and solid-state physics did not exist.

Nobel Prize denied

While Jagadish Bose had already published and lectured on his work on the coherer, Marconi in Italy who was working along similar lines also described a coherer and demonstrated the transmission of the Morse code across the Atlantic in December

1901. He conveniently took patents on his work (probably with the full knowledge that Bose had no patents). To India's misfortune, the 1909 Nobel Prize was awarded solely to Marconi. Marconi was connected with aristocracy and royalty and had considerable influence. This is how India lost its first Nobel Prize in science.

Coherer

This problem was tackled by Hertz, but Hertzian waves would not do. Bose developed a new radiation at much smaller wavelengths. According to Bose, he succeeded in obtaining polarization effects with a crystal by reducing the wavelength of electric waves to about 5 nm. The reduction in wavelength allowed Bose to reduce the dimensions of quasi-optical applications. The demonstration of the discoveries took place publicly in the town hall of Kolkata. Bose demonstrated that his rays could travel through the air. Thus, began the invention of coherer where jute fibres rotate the polarization of electric waves.

That came to be known as invisible light. Bose converted the coherer which were metal filing in loose contact between two metal electrodes into delicate spring coherers. Bose invented the mercury coherer.

What is the justification that we have, for a lone Nobel Prize winner, Marconi.

Living and the Non-living

Around 1900, Jagadish Bose got interested in the similarities between the living and the non-living, even as he was improving the instrumentation for receiving microwaves. He wrote a paper on the topic and lectured on it at a conference in Paris. Swami Vivekananda, who was in the audience, was enthralled. Tagore wrote a poem on the occasion. Jagadish really belonged to the group of philosophically and spiritually inclined intellectuals, represented by Tagore and Vivekananda. All the three were intense nationalists. It is probably his belief in universality that made Bose bridge the gap between the living and the non-living. His ideas were not received well by some scientists. It is at this juncture, that Bose started working on plant electrophysiology. His work was criticized by a few physiologists, and Bose was in agony. He, however, received an enthusiastic response from the Linnean Society.

Jagadish Bose wrote a book titled The Nervous Mechanism of Plants in 1926 and dedicated the book to his dear friend, Rabindranath Tagore. While there may be some criticism of Jagadish Bose's work on plants, there is no doubt that he did come out with some fundamental truths.

Contribution to the growth of modern science

It is generally accepted that Jagadish Bose was the first scientist to usher in modern science to India. He initiated experimental research in a definitive manner. In the foreword to J C Bose's collection of papers, J J Thompson wrote that the papers mark the dawn of the revival of interest in India in researches in physical science. Jagadish Bose wrote several books on plant life as well.

Jagadish Bose wanted to establish a research institute in India similar to the Royal Institution in London. To achieve this objective, he gave his life savings (Rs. 4 lakhs), requesting the government to contribute to the cost of the building. The Bose Institute in Calcutta came into being in this manner. It was inaugurated in 1917. In his speech, Jagadish Bose said, "I dedicate today this Institute – not merely a Laboratory, but a temple – to the Nation." The Bose Institute was to carry out research in physics, plant physiology and other areas. It was to be like an ashram for research students. Clearly, Jagadish Bose was the first scientist who made pure science a purposeful profession for Indians.

Bose and Tagore

Jagadish Bose and Rabindranath Tagore were great friends. The bond of friendship was based on mutual respect and admiration. When Jagadish came back after his successful trip to Europe, Tagore wrote the following poem:

"Across the oceans, on the western shore,
Reigns the temple of the Goddess
Of wealth of science.
There you have journeyed, my friend,
And returned richly crowned.
You anointed the motherland,
Modest at heart, poor and shy."

When Tagore received the Nobel Prize (1913), Bose wrote to Tagore "I had felt deep anguish that you had not been bedecked with the greatest honour. I do not feel so anymore. How do I express my gratitude to almighty God?" Bose, like Tagore, was highly patriotic and they spent considerable time together. When Tagore renounced his Knighthood as a protest against the Jallianwala Bagh massacre (1919), Bose was delighted and wrote, "you have divine blessings on you."

Bose was also a good friend of Sister Nivedita. She got introduced to Tagore through Bose. She helped Bose with his manuscripts and admired him for his talent and hard work.

In search of the source of Ganga

The River Ganga flowed close to his house and Bose had an emotional bond with the river. He often asked the river, "Ganga, where do you come from?" He heard her reply, "From the matted hair of Mahadeva." One day, in his later years, he addressed the River and said, "you have been deeply involved with my life, but I do not know your source." He decided to travel along the course of the river to see where Ganga originated from. He walked and walked in what seemed like an endless journey, and at last, came to a point where his guide pointed to a mountain and said that the source of river Ganga can be seen beyond it. He kept trekking along the frozen river and walked up the mountain. It got increasingly difficult to breathe and he felt exhausted. Eventually, he collapsed at the feet of Nanda Devi. After a while, he woke up to the sounds of bells and chants. At a distance, clouded in the mist, was Ganga flowing in ice blocks. Jagadish Bose beheld Ganga's source in all its splendour, and continued to ask the River, "where do you come from?"

Honours

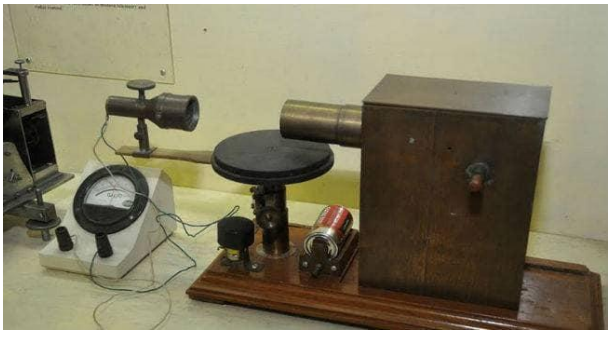
Jagadish Bose was knighted by the British in 1912, even before he became an F R S (1920). He was decorated by the King of Belgium with the title, *Commandeur Ordre de Leopold*. The Bose Institute continues to remind us of this great Indian scientist.

Last days

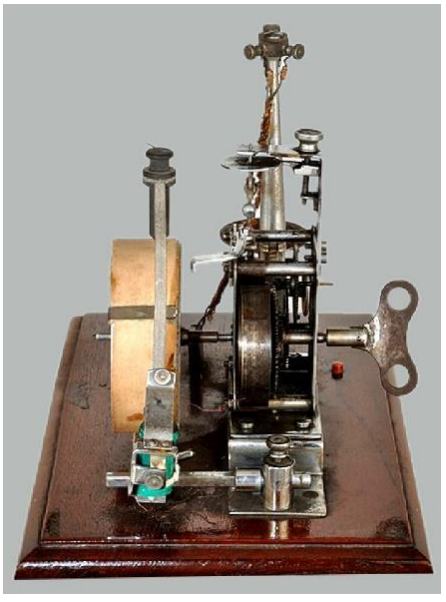
After a life of hard work and challenges, Jagadish Bose passed away in Giridih on 23 November 1937, leaving behind his dear wife. Jagadish probably did not realize that he had started a new era in India where science would be studied and practised by many countrymen. Tagore paid a wonderful tribute in memory of his great friend.

Major Source: Remembering Sir J C Bose, D P Sen Gupta, M H Engineer and V A Shepherd, IISc Press – WCPC Publication, 2009.

Bose Institute, Kolkata. *(Courtesy: Bose Institute)*



First radio prototype built by J C Bose. *(Courtesy: Bose Institute)*



J C Bose - Photosynthetic Bubbler. *(Courtesy: Bose Institute)*

SRINIVASA RAMANUJAN (1887–1920)

One of the greatest mathematicians the world has known

Early days

Srinivasa Ramanujan was born on 22 December 1887, in Erode, a small village in the Madras presidency in his maternal grandfather's house. When he was a year old, Ramanujan moved with his mother Komalatammal to Kumbakonam where his father, K Srinivasa Aiyangar, was a poorly paid accountant in a saree shop. Komalatammal supplemented the family's meagre income by singing in temples. They lived in a row house on Sarangapani Sannidi Street.

Ramanujan's family was orthodox, vegetarian and strictly followed traditions of the family. The family goddess was Namagiri of Namakkal, the divine consort of God Narasimha. Komalatammal was a staunch believer in the powers of the goddess

as Ramanujan was born after many years of praying to the goddess. Ramanujan also felt that he owed his mathematical prowess to Namagiri. He believed that while he was asleep, he had an unusual experience. He saw a red screen formed by flowing blood, as it were. As he was observing it, suddenly a hand began to write many elliptic integrals on the screen. As soon as he woke up, he wrote them down. An equation had no meaning for him unless it expressed a thought of God. Ramanujan's mother was a forceful personality and she became the focal figure in young Ramanujan's life. She told Ramanujan stories from the great epics, Ramayana and Mahabharata. They shared an intense bond and enjoyed each other's company. She decided every aspect of Ramanujan's life so that he could pursue his destiny single-mindedly.

Ramanujan joined Kangayan Primary School in Kumbakonam when he was 5 years old and later joined the English medium High School in January 1898. Ramanujan had a phenomenal memory. He performed well in all the subjects and his extraordinary gift in mathematics was evident even while he was in high school. Within two years of joining high school, he began to work independently on mathematical problems and summed up geometric and arithmetic series. He passed high school with a first-class and was awarded a scholarship for further studies. Ramanujan enrolled for the FA course in the Government College, Kumbakonam.

Towards the end of his high school studies, Ramanujan accidentally got a copy of *A Synopsis of Elementary Results in Pure and Applied Mathematics* by Shoobridge Carr. The book, published in 1880, was a compilation of notes meant for students taking competitive exams in mathematics in Cambridge and London. Carr did not solve all the theorems and problems, and gave only the results at the end. Students had to solve them on their own. Ramanujan was fascinated by the mathematical world that the book opened up to him.

By the time he was 17 years old, Ramanujan had begun research and carried out investigations of the series $\sum(1/n)$, and calculated Euler's constant to 15 decimal places. He also started to study Bernoulli numbers on his own.

As paper was expensive, he worked out problems on a large slate and wrote down only the final solutions on paper. When one of his friends called him a genius, he just showed him his elbow which was full of marks and bruises sustained by years of erasing the slate clean with his bare elbow. Ramanujan became obsessed with mathematics and no other subject mattered. Paying no attention to lectures in other subjects, he constructed magic squares - a grid of numbers which gave the

same total in whichever way the numbers were added. He also tried to find out if there was a pattern to prime numbers. The inevitable happened when Ramanujan failed in English composition and his scholarship was terminated. It is said that Komalatammal was so incensed that she confronted the principal and demanded that the scholarship be restored, as her son was a mathematical genius, but to no avail. This failure was a blow to Ramanujan's self-image and he needed the scholarship to pursue his college education.

Unable to bear the public humiliation and forced to give up his all-consuming tryst with mathematics, Ramanujan ran away from home for a while. He was traced and was reunited with his family in Kumbakonam. Ramanujan decided to try once more to get a college degree. He joined Pachiyappa's College in Madras for the FA course in 1906. Here, he had to study Physiology among other subjects. He failed in it miserably and decided to give it another try again in 1906, but the result was the same. This put an end to his efforts to obtain a college degree which would ensure a secure future. He tried to tutor high school students in mathematics, but he would often get lost in the beauty of the subject and his classes were of little use to the students preparing for examinations. Despite the disappointments, Ramanujan continued working on complex mathematical problems.

In 1910, Ramanujan worked out relations between elliptic modular equations. He published a research paper on Bernoulli numbers in the *Journal of the Indian Mathematical Society* in 1911 which gave him some recognition. Towards the end of 1909, even his mother's patience ran out and she got him married to 10-year-old Janaki, hoping that it would make him more responsible as a married man. While he was growing increasingly desperate for not being able to secure a job, he was getting noticed in the Madras University circles as a mathematical genius. Despite the efforts of many influential people, he could not get either a research job or a scholarship at the Madras University as he had not passed the FA examination.

In 1912, Ramanujan applied for the post of a clerk in The Port Trust of Madras. Based on the strong recommendation letter from E W Middlemast, professor of mathematics at the Presidency College, Ramanujan was appointed on 1 March 1912. The head of The Port Trust, Sir Francis Spring, and his assistant Mr. Narayana Rao who were to play an important role in Ramanujan's professional life, noticed his mathematical prowess. S N Aiyar, the Chief Accountant, was aware of Ramanujan's work and published an article on Ramanujan's work in 1913. He was able to earn enough to live a frugal life and his work was gradually gaining him a reputation as a gifted mathematician.

Passage to England

Prof. C L T Griffith of the Madras Engineering College became a patron of Ramanujan and was responsible for Ramanujan's journey to England later. He wrote to Prof. M J M Hill, professor of mathematics at the University College London enclosing a copy of the 1911 paper on Bernoulli numbers and some other works of Ramanujan. Hill was encouraging but was not too impressed by Ramanujan's work. It is indeed surprising that in colonial India, many Englishmen working in various capacities took interest in helping Ramanujan.

Ramanujan decided to write to E W Hobson and H F Baker at the Cambridge University, but there was no response from them. Ramanujan did not give up hope of finding support of at least one English mathematician. He had seen G H Hardy's book *Orders of Infinity* and wrote to Prof. Hardy in Cambridge in January 1913 enclosing his work. In his historic letter to Hardy, Ramanujan introduced himself stating that he had no conventional schooling which is usually followed by a university course, but had utilized his time striking out a new path in mathematics. Hardy and his colleague Littlewood, studied the long list of theorems which Ramanujan had sent along with his letter. Early in February 1913, Hardy replied to Ramanujan stating that he was impressed by his theorems but wanted to see the proofs to be able to evaluate the work. Ramanujan was over the moon by Hardy's reply and he wrote back *"I have found a friend in you who views my labours sympathetically... I am already a half starving man. To preserve my brains, I want food, and this is my first consideration. Any sympathetic letter from you will be helpful to me here to get a scholarship either from the university or from the government."*

Hardy's endorsement of Ramanujan's work opened the doors that were shut due to his inability to clear the FA examination hurdle. The syndicate of the Madras University in an extraordinary bending of rules gave him a research scholarship of Rs. 75/- per month. For the first time in his life, Ramanujan had a well-paying job and could do what he was destined to do.

Hardy was eager to get Ramanujan to Cambridge. He made arrangements for his colleague at Cambridge University, Prof. E H Neville who was on a lecture tour in India, to meet Ramanujan and allay his misgivings about life in Cambridge. Prof. Neville, impressed by Ramanujan's mathematical virtuosity, was determined to overcome bureaucratic hurdles for getting a grant to bring Ramanujan to Cambridge University. He also convinced Ramanujan that he could follow his religious practices and remain a vegetarian without any difficulty. Ramanujan was initially averse

to accept Hardy's offer. Only a divine intervention could change his mind. The command to go to Cambridge came from Namagiri in his dream.

Cambridge days

Ramanujan left for England on 13 March 1914 from Bombay by the P&O liner Nevasa. He arrived in London almost a month later on 14 April 1914 in glorious spring weather. He was met by Prof. Neville and Ramanujan stayed with him for the initial days. Prof. Neville and his wife helped him to get accustomed to the new culture and finally moved him to a room at Trinity College.

Ramanujan set to work almost as soon as he joined Prof. Hardy at Trinity. Hardy and Ramanujan hit it off right from their first meeting. They formed a perfect and formidable collaborative team each complementing the other's strength. While Hardy supplied the framework of modern mathematical tools, Ramanujan contributed rare insights and intuition in tackling problems. Ramanujan was initially reluctant to accept Hardy's gospel of the need of proofs, but in a short while, acquired the required discipline.

Life was exciting as Ramanujan was introduced to established mathematicians at Cambridge University and he basked in their attention. In 1914, he published only one paper; *The modular Equations and Approximations to Pi* (based mostly on his work in India) in the *Quarterly Journal of Mathematics.* In 1915, he published around 20 papers some of which he co-authored with Hardy. The path-breaking paper was the one he and Hardy published about partition numbers. They gave a reliable formula for calculating *partition numbers* by adopting what came to be popularly known as the circle method. They bewildered the mathematical world by arriving at the exact formula for calculating $p(n)$, the number of partitions possible for any integer. They showed that for $p(5) = 7$, the seven partitions were 5, $4+1$, $3+2$, $3+1+1$, $2+2+1$, $2+1+1+1$, $1+1+1+1+1$. Ramanujan discovered and proved that "5 always divides $p(5n+4)$, 7 always divides $p(7n+5)$ and 11 always divides $p(11n+6)\ldots$"

While the formula $P(n) \approx \frac{1}{4n\sqrt{3}} e^{\pi}\sqrt{2n/3}$ may not be exact as the value of n gets large, the difference between $P(n)$ and the asymptotic formula becomes small. This is the famous ***Ramanujan's congruence***. This discovery was a monumental contribution to number theory.

Ramanujan's mathematical wizardry was recognized by his peers at Cambridge. Even the World War I which had broken out in Europe within months of his arrival did not affect Ramanujan. 1915 and 1916 were the happiest years and were intellectually most rewarding. The only blip was that he fell ill in 1915 and had to be hospitalized briefly.

As warm spring gave way to cold, chilly and damp winter, Ramanujan found coping with the weather and the unfamiliar lifestyle almost insurmountable. Mahalanobis recounts how he found a shivering Ramanujan sitting in a chair wearing an overcoat and gloves, with the bed still neatly made and unslept. Ramanujan found eating with a fork and knife difficult. World War I had begun casting its shadow on the serene life at Cambridge. The disastrous effects of the war were no longer confined to Europe. However, there was good news from the Cambridge University.

Recognizing his unique mathematical ability, Cambridge University bent its rules and permitted Ramanujan to enroll for the Bachelor of Science by research. His dissertation **Highly composite numbers** had seven of his published papers. Ramanujan, who could not clear the FA examination in India even after 4 attempts, graduated from Cambridge University with a BA degree on 16 March 1916. This paved the way for an impressive list of mathematicians including Hardy and Littlewood for proposing Ramanujan's name for election to the Fellowship of The Royal Society, London. Ramanujan was elected a Fellow of the Royal Society in 1918. He was just 30 years old, one of the youngest to be elected an F R S. This was followed by his election as a Fellow of Trinity College, Cambridge.

By 1917, Ramanujan's health had deteriorated alarmingly, and the doctors almost gave up hope of his recovery. He had contracted tuberculosis (though the doctors had not diagnosed the problem correctly). The news of his election as a Fellow of the Royal Society had cheered him up enough for his health to show some improvement.

Ramanujan was lonely with no letters from home especially from his wife Janaki. (He did not know that his mother did not post his wife's letters as she did not want her son to be distracted from his work). These stresses affected Ramanujan's health, and he fell seriously ill. He was soon in and out of hospitals and nursing homes, sinking deeper and deeper into despair. What he needed was emotional support. Hardy, who was his intellectual bedrock, could be of little help. Towards the end of 1917, things got so unbearable that Ramanujan attempted to kill himself by jumping in front of a speeding train. He was miraculously saved by the quick response of the guard in the train.

Hardy visited him often in the hospital and on one occasion, to cheer up a morose Ramanujan, said that he came by a taxi with a very ordinary plate number

1749. Suddenly Ramanujan came alive and said, "on the contrary, it is a very special number since it is the smallest number which was the sum of cubes of two numbers":

$$1729$$
$$1^3 + 12^3 = 9^3 + 10^3$$

Taxi number, the Hardy-Ramanujan number.

$1^3 + 12^3 = 1 + 1,728 = 1,729$ and $9^3 + 10^3 = 729 + 1,000 = 1,729$. This number came to be known as **Ramanujan-Hardy number**. According to Ono, a number theorist, with this discovery, Ramanujan showed 30 years before the study of $K3$ surfaces became popular, how the number is related to elliptic curves and $K3$ surfaces. Ramanujan had anticipated the deep structures that have become fundamental to arithmetic, geometry, number theory and physics.

Back in India

Hardy had been in touch with authorities at the University of Madras about Ramanujan's health and had considered sending him back to India in 1917 but the threat of U boat attacks prevented it. In 1919, after the war ended and the armistice was signed, Ramanujan embarked the P&O liner S.S. Nagoya for his return to India. He arrived in Bombay on 13 March 1919 and was met by his family and adoring friends. But Janaki was not there.

Hardy had written to the authorities of Madras University a touching letter. *"Ramanujan will return to India with a scientific standing and reputation such as no Indian has enjoyed before, and I am confident that India will regard him as the treasure he is. His natural simplicity and modesty have never been affected by his success – indeed all that is wanted is to get him to realize that he really is a success."*

Last days

Ramanujan found out that his mother had successfully prevented any communication from Janaki to reach him and had literally banished her from Kumbakonam. His brother, acting as an emissary, brought her back. For the first time in his

life, Ramanujan rebelled against his mother and Janaki became part of his life. Tuberculosis was diagnosed as the cause of Ramanujan's ailing health condition and as a result, he was shunted between places till they found a suitable place to recover. The long battle with untreated tuberculosis and depression had affected Ramanujan's mind. Janaki bore the brunt of his failing health and irritabilities.

Ramanujan wrote to Hardy for the first time since coming back to India on 20 January 1920, informing of his discovery of **Mock theta functions**. In that sensational letter, Ramanujan explained how a new class of functions that were not theta functions but had crucial similarities, could be constructed. This was pure Ramanujan's genius at work which even terminal illness could not kill.

$$f(a,b) = \sum_{n=-\infty}^{\infty} a^{\frac{n(n+1)}{2}} b^{\frac{n(n-1)}{2}} \quad \text{(Ramanujan's theta function)}$$

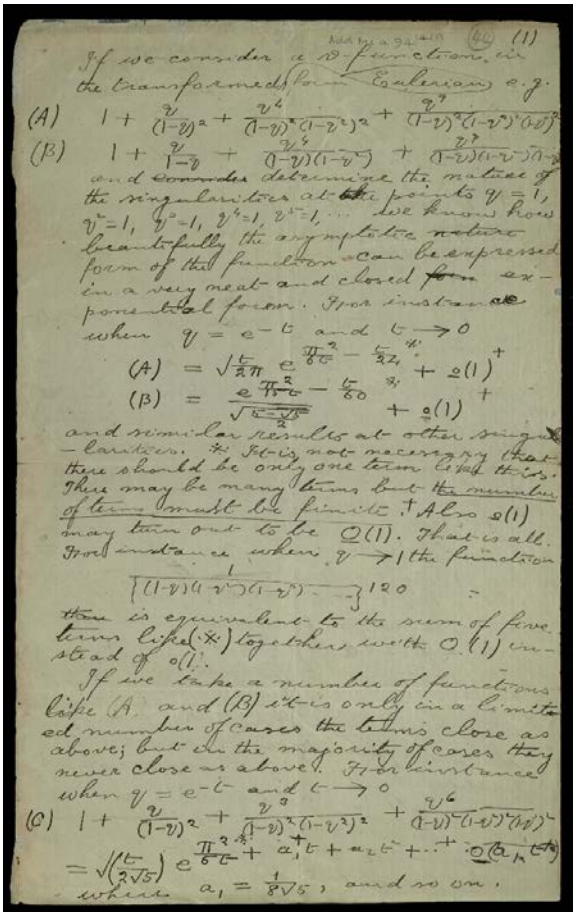
Ramanujan's theta function lies at the heart of string theory in physics.

Despite suffering a great deal of pain, he continued to work, scribbling on a slate or writing on paper. Janaki was to say later that even four days before his death he continued to immerse himself in mathematics. We must note that the full scope of Ramanujan's legacy has not been completely unravelled and many mathematicians from all over the world are engaged in solving his theorems and corollaries. Ramanujan kept a record of his work done between 1904 and 1914 in Notebooks 1 and 2. In Notebook 3, he recorded his work after his return to India during the last year of his life. Freeman Dyson has remarked, "That was the wonderful thing about Ramanujan. He discovered so much, and yet he left so much more in his garden for other people to discover."

On 20 April 1920, Ramanujan breathed his last. India and indeed the world lost a great genius in mathematics. Hardy, who has been credited with discovering Ramanujan, genuinely admired Ramanujan's genius. His spontaneous response on hearing of Ramanujan's demise, "For my part, it is difficult for me to say what I owe to Ramanujan – his originality has been a constant source of suggestion to me ever since I knew him, and his death is one of the worst blows I have ever had," is a true testimony to it. Ramanujan's collected papers were later published by the Cambridge University. Paul Erdös believed that if mathematicians were rated on the basis of pure talent on a scale from 0 to 100, Hardy would get 25, Littlewood 30, Hilbert 80 and Ramanujan 100.

During the celebrations to mark the 125th birth anniversary of Srinivasa Ramanujan, the then Prime Minister Dr. Manmohan Singh announced that December 22, would hereafter, be celebrated as the National Mathematics Day.

Major source: The Man Who Knew Infinity, by Robert Kanigel, 1991, Maxwell Macmillan International.



Excerpt from the letter by Ramanujan on mock theta functions. *(Courtesy: The Master and Fellows of Trinity College, Cambridge. Manuscript reference no. Add.Ms.a.94/14[1])*

Janaki Ammal, wife of Ramanujan, at the inauguration of the bust of Ramanujan at Raman Research Institute, Bangalore.

CHANDRASEKHARA VENKATA RAMAN (1888–1970)

The first Indian Nobel Laureate in science

Early days

Chandrasekhara Venkata Raman was born in Trichinopoly on 7 November 1888. His father Chandrasekhara Iyer was a school teacher who later became a teacher of mathematics and physics in a second-grade college in Vishakapatnam (Vizag). Raman was four years old when his father decided to go to Vizag. Raman spent the next 10 years in Vizag and became fluent in Telugu. He studied in the high school there and two years in a college. After passing the FA examination in 1902 in high first-class, Raman joined the Presidency College, Madras, at the age of 14. He had an excellent command over English but looked too young to be in college. He used to wear a loin-cloth in cylindrical style and a black cap. On the first day of his

English class, the professor asked Raman, “Do you belong to this class?" Raman answered, “Yes, Sir.” The professor then asked him how old he was.

Raman passed the BA examination in 1904 with the first rank. He then passed the MA degree examination in 1907 with record marks. The professor of physics was very fond of him and gave him the freedom to work in the laboratory. He published his first research paper at the age of 18 in 1906, in Philosophical Magazine, on unsymmetrical diffraction bands due to a rectangular aperture. His second paper was on a new method of measuring surface tension, published in 1907.

Raman married Lokasundari Ammal in 1907, and also appeared for the competitive examination for the Indian Finance Service in the same year. He topped the examination and was appointed Assistant Accountant General in June 1907 in Calcutta. He went to Calcutta with his wife to join the finance department. He was 18½ years old then. He rented a house in Scott Lane (off Bowbazaar Street). Lokasundari was devoted to Raman and did everything possible to support him in his scientific work.

Research in Calcutta

One day on his way to work by tram, Raman noticed the sign on a building which read ‘Indian Association for the Cultivation of Science.’ The postal address was 210, Bowbazaar Street. On his way back from the office, he knocked on the door of the building. The door was opened by the attendant, Ashutosh Dey. He then met the secretary of the Association who was delighted to hear Raman’s plan for research. He handed over the keys of the building to Raman. He spent the next eleven years (1907-1917) in the Association while continuing to work in the finance department.

Raman’s work routine used to be as follows. He used go to the Association at 5.30 am and return home at 9.45 am for a bath and a quick lunch before he took a taxi to reach office. He would return to the Association at 5 pm on his way back from the office. Then he would reach home at about 9.30-10 pm. He would devote his entire Sundays to his work at the Association. There were little interruptions when Raman was transferred to Rangoon (1909) and Nagpur (1911), but he was back in the Association in 1911. Ashutosh Dey (Ashu Babu) was Raman’s reliable assistant and worked with him, carrying out experiments. Raman’s work in the Association in the early days was on acoustics. He published many papers with Ashu Babu as his co-author. The work included the study of musical instruments such as the *veena* and the *mrindangam*. In the finance department, Raman had a high reputation as an

excellent officer. He wrote an article on physics of musical instruments in Handbuch der Physique.

The great vice-chancellor of Calcutta University, Sir Ashutosh Mookerjee, was impressed with Raman and offered him the Palit Chair in physics in 1917. Raman took up the position and served in the university for 16 years (1917-1933). In 1919, Raman also became the honorary secretary of the Association. He could then have two laboratories. Due to the persuasion of Sir Ashutosh, he went to Europe for the first time in 1921 and met great physicists like J J Thomson and Rutherford. He visited the St. Paul's Cathedral in London and came out with a paper on the whispering gallery. During his voyage, he noticed the blue colour of the ocean and wondered why it was blue.

On returning to Calcutta, he decided to work on three areas: scattering of light by liquids, scattering of X-rays by liquids and viscosity of liquids. He wrote a monograph on molecular diffraction of light in 1922 and became convinced that the quantum nature of light should reveal itself in molecular scattering. In 1924, Raman was elected to the fellowship of the Royal Society at the age of 36.

Raman Effect

Radian from a source after being scattered by the sample can also be examined to yield information on vibrational and rotational energy levels through the frequency of scattered radiation. A modified frequency due to analogous to the Kramer-Heisenberg process results,

$$\nu' = \nu - (E_l - E_k)h$$

The scattered light has a lower frequency than that of the incident light. It is the scattered light that was responsible for the Raman Effect. The vibrational and rotational frequencies are the result of the scattered light. Raman Spectroscopy has immense applications in chemistry, physics and materials sciences.

Raman Effect

Raman and his students constituted the first big research group in physics in India. Scattering of light in water was studied in Raman's laboratory, as early as 1923 using sunlight as the light source. The scattered light was seen as a track in the

transverse direction. This was considered to be due to weak fluorescence, but it was not completely depolarized. Later this effect was observed in many organic liquids by K S Krishnan, despite distilling the liquids several times. By using large lenses, the intensity of the track was enhanced. The scattering phenomenon was later observed by using a simple spectroscope and a mercury arc as the light source. Raman informed the discovery to the media on 28 February 1928, which was published on 29 February by the Associated Press of India. He published a note on the discovery in the Indian Journal of Physics and another in Nature. This discovery was hailed by many physicists. There is a story that Raman bought tickets to Sweden thinking that the Nobel Prize would be awarded right away, but it happened in 1930. In 1930, he was awarded the Hughes Medal by the Royal Society.

Raman did not realize then the major impact that Raman effect would make. Today, it is used in a variety of ways and its applications are immense. It is used as a routine tool in many situations.

Indian Institute of Science (IISc)

Raman was offered the directorship of Indian Institute of Science (IISc) in 1933. Raman left his flourishing school in Calcutta and decided to go to Bangalore. He was to build a physics department at IISc as well. He was the first Indian director of IISc. Soon Raman made IISc Bangalore an attractive centre for physics. He had an excellent research group with brilliant young students like Nagendra Nath (Raman-Nath effect) and G N Ramachandran. Many great scientists from abroad visited IISc at that time. There were, however, murmurs in the institute and its management circles, about Raman's dictatorial nature. Some of the reorganizations that Raman had carried out was considered to be harsh and was not appreciated by some.

Work on light scattering by liquids continued in IISc. His new interest was in diamonds. Several other areas of work initiated included optical and other properties of crystals. The conflicts and clashes in the institute increased with time and resulted in Raman being relieved of the directorship in 1938. He, however, continued as a professor of physics till his retirement in 1948, but the conflicts and discomfort kept growing. There was bitterness all around and Raman refused to come to terms with the treatment meted out to him at IISc. He decided to build a new research institute, after his term at IISc.

Indian Academy of Sciences

Raman founded the Indian Academy of Sciences in 1934 and started publishing journals of the Academy. He published many of his papers in the Proceedings of the Academy and coaxed many others to do the same. Homi Bhabha supported the proceedings and encouraged his colleagues to publish there. An important aspect of the academy was the annual meeting, held in different cities. Raman gave the presidential lecture in every annual meeting. He was a great speaker and roared like a lion.

Raman Research Institute (RRI)

Raman used his savings and along with some donations, started building a new institute devoted to physics research. He was a National Professor at that time. In the beginning, there were no facilities in the new institute and Raman established a museum of crystals and developed a nice garden. He started taking students and worked on problems related to haloes, mirages, spectroscopy and physiology of vision. He seemed to have become a bit of recluse at that time. This is not difficult to understand. For Raman, scientific research was everything, and only science fulfilled his inner needs. Many young people carried out research with him in RRI and obtained doctoral degrees. The bitterness of Raman's experience in IISc, however, remained as an undercurrent for many years after he left the Institute.

In closing

Raman was not only a genius but was also a great nationalist. He got impatient with decisions and policies of the government that reflected our inadequacies and would not hesitate to express his unhappiness in public. One remembers Raman telling Pandit Nehru how just building laboratories would not usher in great science. He was also a charming man, who was nice and helpful to people who he considered sincere and honest. He had a sense of humour and could also be sarcastic.

Raman was not a member of any government committee and had refused the offer of vice-presidentship of India. He started some new areas of research in RRI despite various shortcomings. His loneliness made it difficult for him to deal with the world (and some people), but he had childlike enthusiasm when he was in a good mood. He did not lose his zest for life or science.

Raman once said, "I thought that I would try to build true science in this country, but all we have is a legion of camp followers of the west." "What India needs is science and more science."

In one of his speeches Raman said the following:

> *"I would like to tell the young men and women before me not to lose hope and courage. Success can only come to you by courageous devotion to the task lying in front of you and there is nothing worth in this world that can come without sweat of our brow. I can assert without fear of contradiction that the quality of the Indian mind is equal to the quality of any Teutonic, Nordic or Anglo-Saxon mind. What we lack is perhaps courage, what we lack is driving force which takes one anywhere. We have, I think, developed an inferiority complex. I think that what is needed in India today is the destruction of that defeatist spirit. We need a spirit of victory, a spirit that would carry us to our rightful place under the sun, a spirit which will recognize that we, as inheritors of a proud civilization, are entitled to a rightful place on this planet. If that indomitable spirit were to arise, nothing can hold us from achieving our rightful destiny."*

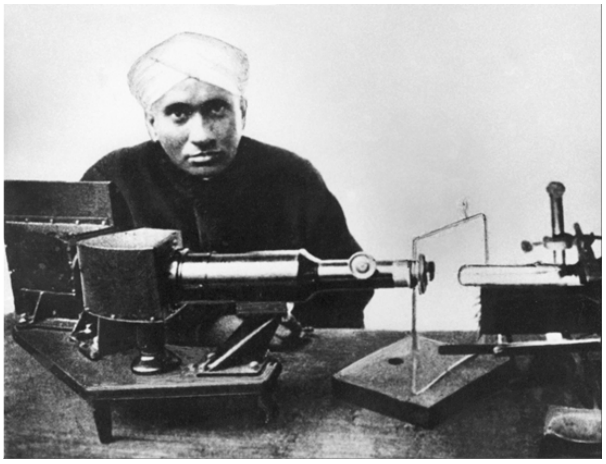
Last days

Many of us saw a happy Raman when we celebrated his 80th birthday in Ahmedabad in 1969 (organized by Vikram Sarabhai). He gave a lecture to children on 'Why is the sky blue.' A few months later in 1970, he chaired the annual meeting of the Academy in Bangalore. After a brief illness, he passed away early in the morning on 21 November 1970. He was cremated in the garden in front of RRI. The giant of science was no more.

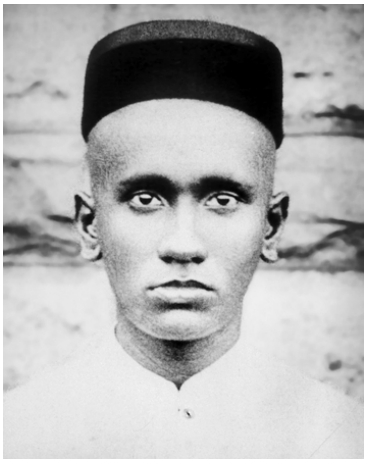
Honours

F.R.S. (1924); Hughes medal of the Royal Society (1930), Knighthood from Britain (1929), Nobel Prize (1930), Franklin medal (1942), Lenin Prize (1957), Member of Pontifical Academy, Foreign Associate of French Academy, Foreign member of the Academy of Sciences of USSR, Rajasabha Bhushana by the Maharaja of Mysore (1935), Bharata Ratna (1954).

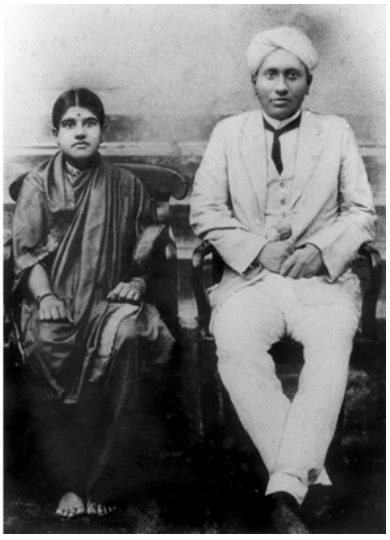
Major Source: C V Raman: A Pictorial Biography, Indian Academy of Sciences.



C V Raman with his Spectrograph, the first Raman Spectrum was obtained with his spectrograph in 1928. *(Courtesy: Indian Academy of Sciences- C V Raman: A Pictorial Biography)*



In 1906. *(Courtesy: Indian Academy of Sciences- C V Raman: A Pictorial Biography)*



Raman and his wife Lokasundari. *(Courtesy: Indian Academy of Sciences- C V Raman: A Pictorial Biography)*

Raman with Pandit Jawaharlal Nehru. *(Courtesy: Indian Academy of Sciences- C V Raman: A Pictorial Biography)*

Stars of Yesteryear

BIRBAL SAHNI (1891–1949)

The first palaeobotanist

Early Days

Birbal Sahni was born on 14 November 1891, in Bhera, Punjab (now in Pakistan). The family moved to Lahore as basic necessities like schools were lacking at Bhera. He was the third child of Ruchi Ram Sahni and Ishwar Devi. His father was a chemistry teacher in a government college at Lahore (later became a professor). The family frequently visited Khewra's Salt Range which was close to Bhera, and Birbal was introduced to the geology of the Salt Range at a young age. Birbal grew up in an intellectually stimulating environment of books, music and outdoor adventure, and was also exposed to the spirit of the independence movement. Motilal Nehru, Gopal Krishna Gokhale, Sarojini Naidu, Madan Mohan Malviya and other leaders used to visit his home in Lahore.

Birbal was greatly influenced by his father who encouraged him to think and act according to his own judgment. Birbal loved plants from a young age. He collected plants new to him, preserved them in bottles to study them at leisure. He started his education at the Mission School and completed high school education at the Central Model school. Birbal enjoyed the long treks with his father and brother through Pathankot, Rohtang, Narkanda, Chini Pass, Amarnath, Machoi Glacier and Jozila Pass in the Himalayas. This had a long-term influence on the choice of his career. After completing his schooling, Birbal Sahni joined the Government College, Lahore. In 1911, he obtained the BSc degree from Punjab University, where he came under the influence of the botanist Shiv Ram Kashyap (1882-1934).

To Cambridge University

After graduating from the Punjab University, Birbal went to England and joined the Emmanuel College, Cambridge, for a degree in natural sciences, and graduated in 1915 (Tripos Part I in 1913 and Tripos II two years later). Simultaneously, he completed the BSc degree at London University. Sahni started research under Prof. Albert Charles Seward, an internationally acclaimed palaeobotanist. In 1919, London University awarded the degree of Doctor of Science for his research work. While he was still in Cambridge, Sahni was asked to revise Lawson's textbook of botany for students in India. The book by Lawson and Sahni was a great success. He had an early introduction to the plants of the Gondwana when he co-authored the *Revision of Indian Gondwana plants* with Prof. Seward (Palaeontologica Indica, 1920).

Back to India

After working for a few months in Munich, Sahni returned in 1919 and joined the Banaras Hindu University, and Punjab University in India, a year later. In 1920, he married Savitri Suri who was a source of encouragement and a constant companion. He moved to Lucknow University in 1921 as professor of the newly established botany department and was there till his death in 1949. He also established the geology department there and was the head of both the departments. This proved to be a fortuitous move as palaeobotany requires the knowledge of geology. Under Sahni's guidance, palaeobotany began as a small unit in a corner of the botany department and within a short span became an active centre for teaching and research.

A palaeobotanist must have attributes such as the knowledge of botany, geology and anthropology and physical stamina and patience to trek for long distances in the mountains under hostile conditions to collect rocks with plant fossils in them. He must also have the ability of a detective to ferret out the presence of ancient plants in rock samples embedded in the ground. Sahni had these attributes in plenty.

His treks to Chamba, Leh, Baltal, Uri, Poonch and Gulmarg with Kashyap after his return from England between 1920 and 1923 enhanced his first-hand knowledge of Himalayan geology, the formation of rocks and the evolution of the flora through geological periods. He was able to get fossil materials from many countries. His knowledge of the Himalayas enabled him to understand the vast palaeobotanical and geological vista of our country. He firmly believed that research in palaeobotany should be conducted in the geological and geographical conditions under which the plants lived, died and got embedded in rocks.

Using his knowledge of ancient plants of the Indian sub-continent and using simple instruments, Sahni showed that the age of the salt range at Khewra (now in Pakistan Punjab) was 40 to 60 million years and not 100 million years as believed earlier. The Deccan Traps in Madhya Pradesh were rocks of the tertiary period, their age being around 62 million years. Based on the knowledge of the ecology of the plants and the altitude at which the fossils were found, he estimated the rate of uplift of the Himalayas. He also studied the Indian Conifers. His research interest in palaeobotany was so vast that he contributed to unravelling the mysteries of the palaeobotany of most of the regions in India.

Birbal Sahni's research on fossil plants was aided by his extensive knowledge of stratigraphy, palaeogeography and geology and covered anatomy and morphology of Palaeozoic Ferns and the fossil plants of the Indian Gondwana Formations. He was the first person to make a detailed study of the flora of the Gondwana region. Sahni studied fossil plants of the Deccan intertrappean beds and fossils of lower Narmada area. Based on this work, he concluded that the area around Chindwara and Nagpur were coastal areas in prehistoric times.

Sahni made an extensive study of fossils of ancient plants in Raj Mahal hills in Bihar where he discovered 'Pentoxylae'- a new group of fossil gymnosperms. He also studied Glossopteris - a genus of fossil ferns or fernlike plants of Permian and Triassic times. In 1932, *Palaeontologica Indica,* of the Geological Survey of India published his account of *Williamsonia Sewardi* (named by him as a tribute to his guru Seward), the Bennettitalean plant and *Homoxylon* (resembling the wood of a living homoxylous angiosperm, but from the Jurassic age). He compared the fossil of the flora of India and Australia with those of China and Sumatra. This study

confirmed the theory of the continental drift through the geological era. Sahni had the unique ability to apply his theoretical knowledge to observations on the ground and arrive at new hypotheses. His inference that people of the Harappan Valley must have had trade links with people living in the mountainous regions by finding wood remains of conifers in the rock fossils in Harappa is an example of this ability.

Institute of Palaeobotany

Birbal Sahni was the founder of the Institute of Palaeobotany in Lucknow. He had been nursing the idea of starting such an institute since the mid-thirties. He worked tirelessly to realise his dream. Initially, Sahni and his wife donated personal funds, library, and fossil collection to the Institute. He was able to get the government of Uttar Pradesh to grant land for the Institute. Pandit Jawaharlal Nehru laid the foundation-stone of the new Institute of Palaeobotany on 3 April 1949. Delivering the speech at the function, Pandit Jawaharlal Nehru said *"The real cause for my interest is that Professor Sahni symbolizes in him the kind of scientist that every scientist should be. He has devoted his life with all its energy at his command to his research and most assuredly he will continue to do so. This quality in a man connecting his work in such a devoted manner follows the right path, his work is good, the man is good. I was impressed by Dr. Sahni's sincerity. I was attracted by the proposal put by Dr. Sahni for building a research Institute for Palaeobotany partly because of his interest in the subject that he had developed during his stay at Cambridge, but mainly due to his personality. He is a balanced man, a man of even temper like every great scientist. Such men are always few."*

A polymath

Sahni was a passionate teacher. He believed that to be a good researcher, one has to be a good teacher. He was admired by students. He was a wonderful communicator who could communicate to an audience of all ages. He loved telling stories and entertained children with a monkey-hand-puppet named Gippy.

He was interested in classical music (he played the sitar and the violin)), clay-modelling, photography and numismatics. In one of the archaeological excavations in Khokra Kot in 1936, he examined coins and moulds dating back to 100 BC and published a paper on the probable methodology used to cast the coins.

The Numismatic Society of India awarded him its highest award (Nelson Wright Medal) for this work in 1945. His collection of coins is on display at the National Museum, New Delhi. He was good at sports as well.

Sahni led a simple life and was seen in white achkan and sherwani, and a white Gandhi cap.

Last days

Prof. Birbal Sahni did not live to see his dream come true. He died of a massive heart attack on April 10, 1949. He was 58 years old. Upon his sudden death, his wife, Mrs. Savitri Sahni was requested to act as the director of the institute (1949-1969). She worked tirelessly to make her husband's dream a reality. The institute was named Birbal Sahni Institute of Palaeobotany.

Honours

Sahni was a Founder Fellow of the Indian Academy of Sciences and a Fellow of The Indian National Science Academy. In 1929, Cambridge University honoured him with the honorary Sc.D. degree. In 1936, he was elected fellow of The Royal Society, London.

Major Source: Vigyan Prasar, Birbal Sahni Institute of Palaeobotany. iloveindia.com

Sahni with S S Bhatnagar. *(Courtesy: www.tifrarchives.com)*

MEGHNAD SAHA (1893-1956)

Our first astrophysicist

Early days

Meghnad Saha was born on October 06, 1893 in Seoratali, a village near Dhaka (Bengal of undivided India). He had four siblings. His father, Jagannath Saha, was a petty shopkeeper and his mother struggled to keep the large family from starvation. Meghnad faced social isolation and poverty during his high school days. Given their economic background and lack of social status, his parents could neither provide nor be enthused enough to educate the children beyond primary school. Saha's elder brother Jainath failed the high school examination and had to take a job in a jute company. His other brother discontinued going to school so that he could assist

his father. Only Meghnad got the benefit of going to the village school in 1900 when he was seven years old. He enjoyed the school from the first day, displaying an unusual hunger for learning. Meghnad faced an anxious time when he was not sure if he would be allowed to continue his studies. He faced challenges such as the absence of a middle school in his village (the nearest school being at Simulia which was 10 kms from home) and lack of monetary resources to afford to be in a hostel or stay as a paying guest. His father wanted him to assist in running the shop. When he had given up all hopes, Ananta Kumar Das, a local doctor came to the rescue of Meghnad by offering him free board and lodging so that he could continue his education. Saha was grateful to the doctor throughout his life for this help. Though he excelled in mathematics, he was also interested in the history of Rajasthan, Rabindranath Tagore's *Katha O Kahini* (about the valour of the Rajput and Maratha warriors) and Madhusudan Dutt's epic poem *Meghnad Badh*. In spite of facing discrimination often he managed to concentrate on studies. He was awarded a monthly scholarship of Rs.4/- for securing the first position in the entire Dhaka district.

Studies in Dhaka

Meghnad Saha moved to Dhaka in 1905 and joined the Government Collegiate School. With the scholarship amount, the generosity of his brother Jainath (who sent him Rs.5/- per month) and a small amount (Rs.2/- per month) from the Purba Banga Baisya Samiti, Saha could manage lodging, boarding and other expenses. Around this time there was a great political turmoil and Saha unwittingly got caught in a protest demonstration. He was rusticated and his scholarship was withdrawn. Just when his further education looked bleak, Kishori Lal Jubilee School, a private school, offered admission with a small stipend and fee waiver. Saha secured the first rank among all the successful candidates from East Bengal. He passed the Intermediate Examination of the Calcutta University in 1911 from the Dhaka College, Dhaka.

Presidency College

Saha moved to Calcutta and joined the Presidency College, Calcutta where S N Bose was his classmate and P C Mahalanobis was his senior by a year. He had inspiring teachers like P C Ray and J C Bose. Saha completed the BSc degree examination

with honours in mathematics in 1913 and MSc examination in Applied Mathematics in 1915. Saha stood second in the order of merit in both the examinations, with S N Bose securing the first rank.

Calcutta University

Saha (along with S N Bose) was appointed lecturer in the Department of Applied Mathematics (and later in the physics department) in the University College of Science in 1916. Saha had to give lectures to post-graduate students. Preparing for teaching physics to postgraduate classes was a challenging task as Saha had studied physics only when he was an undergraduate. Saha wanted to start doing research simultaneously, but this proved to be difficult as there was no laboratory to conduct experimental research in University College of Science. He had no guide to supervise his work. He had to depend completely on the knowledge acquired by studying books and papers published in Europe.

Even as he was exploring other topics, astrophysics became the main interest of Saha. He taught the subject by studying Planck's work on thermodynamics, Nernst's 'Das Neue Warmestaz,' papers on quantum theory by Arnold Sommerfeld and Niels Bohr and Clarke's 'A Popular History of Astronomy.' While teaching thermodynamics and spectroscopy to MSc students in 1919, Saha was getting interested in astrophysics. In particular, the theory of thermal ionization caught his attention. He wrote a seminal paper on 'Selective Radiation Pressure' in which he elaborated on 'the role of radiation pressure' acting on the atoms selectively, negating the action of gravity. He submitted the paper for publication to the Astrophysical Journal. To his disappointment, the editors wrote back stating that the journal was ready to publish if he bore a part of the printing cost as the paper was long. Saha could not afford to bear the cost and published a short note in the Astrophysical Journal (1919). Sometime later, he published the original paper 'Selective radiation pressure and Problem of Solar Atmosphere' in the Science Journal of the Calcutta University (1919). This journal had a limited circulation and was not known outside India.

1919 was a productive year for Saha as three of his papers got published in Philosophical Magazine, one in Physical Review and one in Astrophysical Journal. As there was no way of getting a PhD degree from the Calcutta University at that time, Saha decided to submit his papers for the Doctor of Science degree. He was awarded the degree in 1919. Saha received The Premchand Roychand Scholarship of

the Calcutta University for his dissertation on the 'Harvard Classification of Stellar Spectra.' The scholarship allowed the recipient to work in European laboratories for two years. Saha worked in Alfred Fowler's Laboratory in London for the first five months and moved to Berlin to Nernst's laboratory for the rest of the time.

Saha equation

$$\frac{n_i}{n_n} \approx 2.4 \times 10^{21} \frac{T^{\frac{3}{2}}}{n_i} e^{\frac{-u_i}{K_B T}}$$

n_i: Number density of ions
n_n: Number density of neutral atoms
T: Temperature
u_i: Ionisation energy
K_B: Boltzmann constant

The Saha's equation. *(Courtesy: S N Bose Archives)*

'Meghnad Saha's place in the history of astrophysics and in the history of modern science in India is unique' (S Chandrasekhar).

From January to June of 1920, Saha published four path-breaking papers based on his research in astronomy. His classic paper 'Ionisation of the Solar Chromosphere' was published in *Phil. Mag*. The other papers were 'On the Harvard Classification of Stars,' 'On Elements in the Sun,' 'On the Problems of Temperature-Radiation of Gases' and 'Origin of Lines in Stellar Spectra.' Calcutta University awarded the Griffith Prize to Saha in 1920.

Based on the above papers, Saha published his 'Theory of Thermal Ionization of elements.' Saha arrived at this by applying fundamental principles of thermodynamics and concepts of the quantum theory. This theory introduced a new chapter in astrophysics as it provided, for the first time, a tool which could be used to interpret stellar spectra which depend on the chemical composition of the light source. This research work resulted in Saha formulating what came to be known as the Saha Ionization equation. In the equation, the composition, the spectrum and the temperature of the light source are linked and can be used both to determine the temperature of stars or estimate the amounts of the chemical elements present in

them. Conversely, by studying the spectra of specific stars, one can first determine their temperature and calculate the ionization states of the various elements present. Saha equation thus provided a basic tool for interpretation of the spectra of stars. Based on their actual temperatures, astronomers could now predict the spectral classes of stars.

Back in Calcutta

After returning to India from Europe in 1921, Saha joined the University of Calcutta as the Khaira Professor of Physics. To Saha's disappointment, there were no funds available for research. After his efforts failed to change the situation, he moved to Allahabad University in 1923 as professor and head of the department of physics. The infrastructure for research at Allahabad was worse than at Calcutta University. He had to bring in much-needed improvement in the basic facilities required to do meaningful research. This, together with a heavy load of teaching, gave him little time for research. Despite these distractions, Saha was able to start research activities and publish with students. In addition to his own research, Saha introduced research in many other areas of physics. Saha wrote the famous *A textbook of Heat* (with B N Srivastava) in 1931. A concise version of this book titled *Junior Textbook of Heat* was published later for science graduates.

Saha returned to the Calcutta University in July 1938 as the Palit Professor and head of the department of physics as well as dean of the faculty of science. He remained there till his death in 1956. His main contribution during this period was reforming the MSc syllabus in physics and introducing nuclear physics and quantum mechanics as part of the course. His initiatives resulted in the first cyclotron to be built in India.

One cannot help but notice similarities in the professional lives of Saha and S N Bose. Both were superstar performers for a short period in their early careers.

Institution builder

Saha was instrumental in founding the Institute of Nuclear Physics in 1950 which was later named as Saha Institute of Nuclear Physics with him as the honorary director. Among the other important institutions that he nurtured was the Indian Association for the Cultivation of Science or IACS, of which he was the director during 1953-1956.

Saha founded the National Academy of Sciences (India) at Allahabad, and the Indian Physical Society (Kolkata), Indian Science News Association. He also played a crucial role in establishing National Institution of Sciences of India (later named Indian National Science Academy) of which he was the president during 1937-1938. He was the chair of the Indian Calendar Reform Committee in 1952 which brought out a common calendar for the country. In pre-independent India, states had their own calendars based on cultural and religious practices, climate, and sowing seasons. There were at least 30 calendars in the country then.

Foray into politics

"Scientists are often accused of living in the 'Ivory Tower'. . . I had lived in the ivory tower up to 1930. But science and technology are as important for administration now-a-days as law and order. I have gradually glided into politics because I wanted to be of some use to the country in my own humble way." (Saha).

As a result of this, Saha's scientific research took a backseat. Many feel that he was not a real politician, but the widening gap between his dream of a prosperous India and the ground reality, as well as the development plans of the Government, forced him to become a stormy petrel of science. In 1952, Saha was elected a Member of the Parliament as an independent candidate from the North-West Calcutta constituency. He advocated large-scale industrialisation for social development. He was convinced that the only hope for India to make progress was by developing modern science and technology. He wanted that the newly independent India should build the necessary infrastructure, and manpower trained in science and technology, before the state undertook other tasks.

Saha, the man

Saha was an austere man with few personal needs. He had high principles, and would neither compromise nor placate authorities. He was endowed with an undaunted spirit, untiring energy, a sense of social justice, dedication to the causes which he believed in, and resolute determination.

Honours

Saha was a fellow of the Royal Society. He was a fellow of the Indian National Science Academy and the Indian Academy of Sciences. He was a winner of the J C Bose Medal.

Untimely death

Saha died suddenly due to a massive heart attack on his way to the Planning Commission office in New Delhi on 16 February 1956. In a tribute to his guru, Prof. D S Kothari has said, "The life of Saha was in a sense an integral part of the growth of scientific research and progress in India...His dedication to science, his forthrightness and utter disregard of personal comforts in the pursuit of his chosen vocation will long remain an inspiration and an example."

Major Source: Vigyan Prasar. www.britannica.com; nobelprizesseries.

Saha with other scientists at Calcutta University. *(Courtesy: S N Bose Archives)*

Presidency College, Kolkata. *(Courtesy: S N Bose Archives)*

SATYENDRA NATH BOSE (1894–1974)

Bose of Bose-Einstein statistics, Boson and BEC!

Early Days

Satyendra Nath Bose was born in Kolkata on 1 January 1894, in a middle-class family as one of seven children. His father, Surendra Nath Bose, was interested in mathematics and science. His mother Amodini Devi was a homemaker. He was the eldest of the seven children and the only son. He went to a local school when he was five years old and joined the Hindu School in 1907 at the age of 13. He excelled in mathematics and science. Recognising his son's mathematical ability, his father devised a unique way to encourage him. He would write problems in arithmetic on the floor for his son to solve. Satyendra Nath loved this game

and would solve the problems before his father came back from work. Bose always stood first in his class.

After completing high school in 1909, S N Bose joined the Presidency College where J C Bose and P C Ray were teachers. They inspired S N Bose to choose a career in science. He majored in applied mathematics, graduating in 1913 at the top of his class, with first-class honours. Bose wanted to remain in academia and enrolled for a master's degree in applied mathematics at the University of Calcutta. In 1915 (aged 21), he graduated in the top of his class. At the age of 20, he got married to young Ushabala who hailed from a wealthy family.

The early 20th century was a period of political unrest and career prospects in science were not encouraging. Fortunately for young aspiring scientists like Bose and Saha, the Vice-Chancellor of the University of Calcutta, Sir Ashutosh Mukherjee, initiated far-reaching changes by establishing modern science laboratories, creating research scholarships and subscribing to important science journals to the library. Bose and Saha wanted to teach post-graduate students but the university rules stipulated that they must have research experience. Impressed by their willingness and enthusiasm, Sir Ashutosh gave them the newly established research scholarships to help them prepare to teach postgraduate courses in physics and mathematics.

Germany and France were at the forefront of scientific research, especially physics, in the first quarter of the 20th century. It was an exciting period in physics. Quantum theory had just appeared on the horizon. Areas like relativity and quantum theory were not included in the textbooks available to Bose. Planck, Einstein, and Bohr were just names to him. That was the season when theories of atomic structure and other aspects of physics were making a beginning. Bose learnt German and French to keep abreast of the research publications. Bose and Meghnad Saha prepared English translations of the papers of Einstein's special and general relativity in 1919. Sir Ashutosh allowed them to use his well-equipped library.

With World War I breaking out in Europe in 1914, it became increasingly difficult to get leading scientific journals in India. Bose could not register for a PhD degree since such a programme was not offered by the University of Calcutta at that time. Bose's resolve to be in academia seemed to have hit a roadblock. Bose and Saha befriended Austrian Paul Brühl, a physics lecturer at the Bengal Engineering College, who had a private collection of cutting-edge books in physics and mathematics. They upgraded their knowledge in various branches of physics such as electromagnetism, relativity, spectroscopy, thermodynamics and statistical mechanics.

Bose, the teacher

Bose joined the physics department of the Rajabazar Science College affiliated to the University of Calcutta as a lecturer in 1916 and began teaching applied mathematics and mathematical physics the following year. In 1921, Bose joined as a reader in the department of physics of the newly created University of Dhaka (now in Bangladesh). He got involved in setting up laboratories and taught advanced courses for MSc and BSc honours students. He enjoyed teaching thermodynamics and Maxwell's theory of electromagnetics.

Bose was a passionate teacher. His great scientific discovery, *Bose statistics*, came about because of his dedication to teaching. He prepared diligently for the lectures and hated if he did not fully understand everything he taught.

While preparing for his lecture on Max Planck's radiation formula, Bose faced a problem. The formula was Planck's solution to the failure of classical physics in accounting for the range of electromagnetic radiation frequencies emitted by a hot body. Even though Planck's formula suggested a way out, his equation coefficient $8\pi\nu^2/c^3$ was from classical physics. Such mixing of classical and quantum theories in one equation was nagging the minds of the physicists. In 1905, Einstein was able to describe the photon for the first time by applying classical Boltzmann statistics to Planck's equation. His work was brilliant, but many physicists rejected the idea of the wave nature of photons.

Reaching great heights in research

Not being satisfied with Planck's derivation based on Boltzmann's classical statistics, Bose employed his own statistical method of counting particles. In Boltzmann's method, particles were distinguishable from each other and could be counted separately. In Bose's statistics, particles at the same energy level were indistinguishable from one another. He studied the probability of finding such particles in various states in phase-space with a phase volume of h^3, considering the position and momentum of the particles as one variable.

Bose showed that Maxwell–Boltzmann distribution would not hold for microscopic particles. Instead, fluctuations due to Heisenberg's uncertainty principle would play a more important role. He discarded the distinct position and momentum of the particles and stressed the probability of the existence of particles with each state having volume h^3. By doing this, he was able to derive Planck's equation

without any reference to classical physics. Bose did not realize just how seminal his work was. He sent a paper titled *Planck's Law and the Hypothesis of Light Quanta* to the Philosophical Magazine. Unfortunately, the referees did not realize the far-reaching importance of the paper and rejected it. Undeterred by this rejection, he sent his paper to Einstein, with the following letter dated June 4, 1924:

"Respected Sir, I have ventured to send you the accompanying article for your perusal and opinion. I am anxious to know what you think of it. You will see that I have tried to deduce the coefficient $8\pi\nu^2/c^3$ *in Planck's Law independent of classical electrodynamics, only assuming that the ultimate elementary region in the phase-space has the content* h^3*. I do not know sufficient German to translate the paper. If you think the paper worth publication, I shall be grateful if you arrange for its publication in Zeitschrift für Physik."*

Einstein translated Bose's work into German and arranged for it to be published in *Zeitschrift für Physik*. Einstein himself sending a paper on the subject to *Zeitschrift für Physik* made physicists notice Bose's paper. Einstein wrote back to Bose on July 24, stating that Bose's work was an important step forward and he liked it very much.

Bose had founded a new field of quantum statistics and his paper came to be recognized as one of the most important theoretical papers. Bose's interpretation got to be known as Bose-Einstein Statistics. When Einstein and Bose met for the first time, Einstein asked Bose whether he was aware that he was the originator of a new type of statistics. Bose answered in the negative.

According to Bose-Einstein statistics, the aggregation of particles that obeys these statistics accounts for the cohesive streaming of laser light and the frictionless creeping of superfluid helium. Bose developed the theory of this behaviour in 1924–25. The Bose-Einstein statistics apply only to particles that do not obey the Pauli exclusion principle and have integer values of spin. Any particle that behaves according to Bose's statistics is called a Boson (in contrast to the Fermion).

The Bose-Einstein Condensate

Einstein soon extended the idea to atoms of a gas. This led to the prediction of the existence of a dense collection of particles with integer spins or Bosons. This became known as the Bose-Einstein condensate (BEC).

It took over 70 years to prove the existence of the Bose-Einstein condensate. In 1995, it was demonstrated that when rubidium gas atoms are cooled close to very low temperatures below a Kelvin, about 2,000 individual atoms merge into a single

super-atom. This newly formed matter existed for less than 20 seconds. At or below 2.17 Kelvin, Helium-4 flows without friction. Superfluid helium-4, though not a pure BEC, behaves like a BEC with its atoms sharing the same quantum mechanical state.

The recognition received by Bose from leading physicists in Europe made Dhaka University grant Bose two years of leave of absence to work in laboratories at France and Germany. He worked with Marie Curie in France for a year and with Einstein in Berlin. In 1926, Bose came back to the University of Dhaka. Based on Einstein's strong recommendation, Bose (without a PhD) was made a professor and head of the physics department. He worked in wide-ranging areas and published an equation of state for real gases with Meghnad Saha. After rejoining Dhaka University, Bose could not, however, match his past performance. He admitted this by saying "On my return to India, I wrote some papers. I did something on statistics and then again on relativity theory, a sort of mixture, a medley. They were not so important...I was like a comet, a comet which came once and never returned."

Later days in Calcutta

Bose returned to Calcutta University in 1945 as Indian independence and the partition of the country loomed large, and taught there till 1956. He loved doing science and was committed to Indian independence. He was convinced that it was crucial for independent India to have well-educated citizens. To achieve this objective, he gave lectures and wrote about science in Bangla to reach a wider audience. He also conducted evening classes for the children of working-class masses. Bose loved poetry, music, chess and cats. During 1956-1958, Bose was the Vice-Chancellor of Visva Bharati University. Tagore dedicated the science publication for children, Visva Parichaya, to S N Bose. In 1959, Bose was appointed National Research Professor.

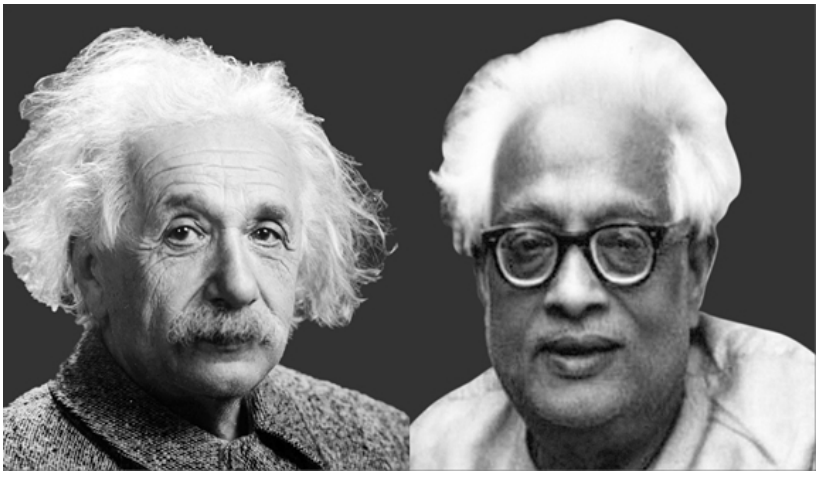
Honours

Bose was awarded Padma Vibhushan for his contributions to Indian science in 1954. He was elected Fellow of The Royal Society, London in 1948. However, the coveted international recognition, The Nobel Prize, was denied to him.

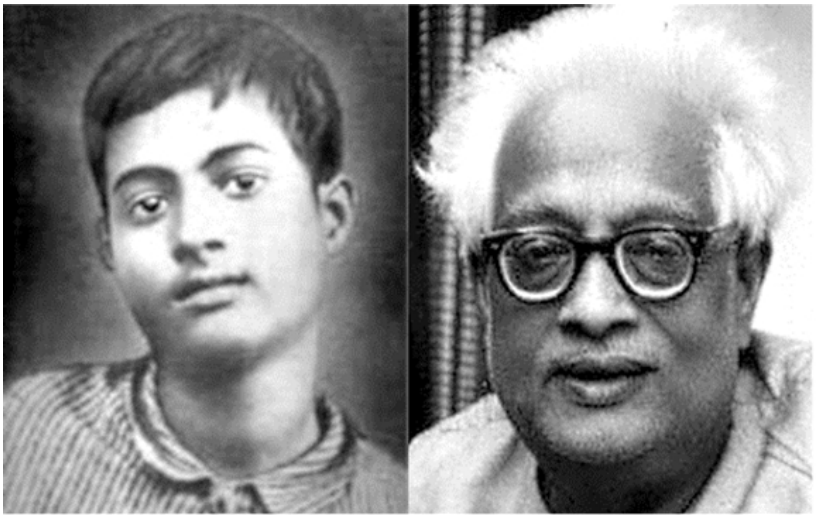
The government of India established the S.N. Bose National Centre for Basic Sciences in Salt Lake, Calcutta, in 1986 as an autonomous research institution.

Satyendra Nath Bose died of bronchial pneumonia in Calcutta on February 4, 1974. He was 80 years old.

Major Source: Vigyan Prasar. www.britannica.com; www.nobelprizeseries.in/tbis/sn-bose



Einstein and Bose. *(Courtesy: Wikipedia and Saha Institute of Nuclear Physics)*



Young Bose. *(Courtesy: Wikipedia and Saha Institute of Nuclear Physics)*

JANAKI AMMAL (1897–1984)

Early plant biologist

Early Years

Edavaleth Kakkat Janaki Ammal, known as Janaki Ammal, was born in a cultured Thiyya family in Tellichery (Thallassery) in Kerala on 4 November 1897. Her father Dewan Bahadur E K Krishnan, was a sub-judge in the Madras Presidency, and mother Deviammal was his second wife. Janaki Ammal was the tenth child of thirteen children. Her father was keenly interested in natural sciences and was a passionate gardener. Janaki Ammal inherited his curiosity and love for plants.

The thiyya caste occupied a low position in the caste system and Janaki Ammal had to face many hurdles like gender-and caste-based prejudices in the early years. Though matriarchy was the norm in Kerala, the society at large was male-dominated and conservative. Girls could not study beyond high school. Her father was a staunch believer in the empowerment of women and the family encouraged her to pursue her dream of an academic career.

After completing high school in the Sacred Hearts Convent at Tellicheri, Janaki Ammal shifted to Madras (now Chennai) for higher studies. She obtained the bachelor's degree from Queen Mary's College and the Honours degree in botany from the Presidency College (1921). She was encouraged by her teachers in Presidency College to focus on the study of plants in their natural habitat. Soon after obtaining the Honours degree, Janaki Ammal joined the Women's Christian College as a demonstrator in botany. She was not content with a career in teaching and longed to do research in botany.

Studies in the US

She was awarded the Barbour Scholarship for a post-graduate degree at the University of Michigan (USA) in 1924. After completing her master's degree in cytogenetics, Janaki Ammal returned to her teaching job at Women's Christian College in 1926. She soon went back to the University of Michigan as a Barbour Research Fellow for the doctoral degree. She obtained her doctorate in 1931. Her thesis was on chromosome studies in Nicandra Physaloids. Michigan University played a crucial role in her choice of research in plant sciences. She decided to work in cytology which focuses on the study of the nucleus and the chromosomes. On her return to India in 1932, Janaki Ammal moved to Maharaja's College of Science, Trivandrum, as professor of botany for two years (1932-1934). She was frustrated by the lack of importance given to research at the college and looked for an opportunity to move to a research-oriented job.

Sugarcane Research

The Sugarcane Breeding Institute (SBI) was set up by the Agriculture Department of Madras Presidency at Coimbatore in the early 1920s. Its research goal was to develop hybridization techniques which would improve the yield of Indian sugarcane and also develop new indigenous hybrid varieties of sugarcane. Janaki Ammal joined the Sugarcane Breeding Institute to work on the cytobiology of sugarcane. She succeeded in developing a high yielding variety of sugarcane suited for Indian conditions by manipulating the polyploid cells of sugarcane by cross-breeding hybrids. The increased sweetness of the Indian sugarcane is the result of her research. Her research included cytogenetic analysis of wild sugar *Saccharum spontaneum*, intergeneric hybrids such as sugarcane and maize (Saccharum and Zea) and sugarcane and grains (Saccharum and Sorghum). This research was pathbreaking

and contributed to food security. Despite her contributions, Janaki Ammal had to endure discrimination and a rather hostile atmosphere as an unmarried woman working in a male-dominant field. She, fortunately, found an unexpected solution to her problem.

Research in the UK

In August 1939, the 7th International Congress of Genetics was held at Edinburgh and Janaki Ammal went to attend the conference. Just as the conference ended, World War II broke out on September 1. Amid the chaos that followed, she was unable to come back to India. With her experience in cytogenetics of a variety of plants, she was able to join John Innes Horticultural Institution in London as an assistant cytologist to work with Prof. C D Darlington from 1940 to 1945. During this period, she conducted chromosome studies of a variety of garden plants. Her studies on ploidy and chromosome numbers in plants helped to understand the evolution of species. *The Chromosome Atlas of Cultivated Plants* which she wrote jointly with Prof. Darlington in 1945 included much of her own work on many species. It lists over 1100 plant species and contains comprehensive information about their chromosome numbers as well as information of their geographical distribution and cultural significance. Environmental scientists and botanists have used this as the preferred reference work for decades.

Janaki Ammal was invited by the Royal Horticultural Society to work as a cytologist in 1945. During her stay there, she concentrated on the study of cytology of magnolias and conducted experiments on their hybridization. This resulted in the easy propagation of magnolia shrubs with fused sepals and petals, tepals. In recognition of her work on the magnolia plant, a variety of the flower, *Magnolia Kobus*, was named after her.

Back to India

Janaki Ammal came back to India in 1951 on being invited by Pandit Jawaharlal Nehru to help reorganize the Botanical Survey of India (BSI). Established in 1890 by the East India Company, BSI had compiled extensive data of the plant species found in India. However, with the outbreak of World War II, it had lost its importance. Realizing the importance of the taxonomy of the flora of independent India, Janaki Ammal was tasked with reorganizing the moribund BSI. She recommended the

following changes: As the flora was different in the different climatic conditions in the country, BSI should have branches in the south (Coimbatore), east (Shillong), west (Pune) and north (Dehradun) to compile the data of the plant species of each region. Unfortunately, much to Janaki Ammal's disappointment the initial enthusiasm for ethnobotanical mapping of indigenous flora faded soon. Despite her scientific contributions, she was passed over and someone else was made the director of BSI in 1955. She became critical of the indifference of the government to the ethnobotanical knowledge of tribal communities. She foresaw the wanton destruction of forests in the name of development. To overcome her disappointment, she went back to the Malabar region of Kerala to work with the local tribes.

After she retired from BSI in 1959, Janaki Ammal joined the Regional Research Laboratory of CSIR in Jammu, as director. There, she carried out studies of the ethnobotany and biodiversity of the region and guided PhD students. After retirement in 1962, she continued in Jammu as an emeritus scientist till the end, publishing research papers.

Janaki Ammal travelled extensively, including Ladakh and Nepal. She showed that polyploidy was the reason for the higher rate of speciation in the flora of the cold and humid northeast Himalayas in comparison to the flora in the dry northwest Himalayas. The natural hybridization between the native flora and Chinese and Malayan elements in the flora of northeast India contributed to the biodiversity of the species there. She also worked as the head of Central Botanical Laboratory at Allahabad.

Janaki Ammal remained single and her love for plants did not allow any scope for emotional distractions. The one exception was her love for cats. She was a true Gandhian and led a simple life. She believed her personal life was of no consequence and her work would live on. Her colleagues remember her as professionally active and dynamic, but personally unassuming, and modest.

She was a fierce environmentalist and staunchly opposed the hydro-electric project in the Silent Valley in Kerala, one of the biodiversity hotspots in the world.

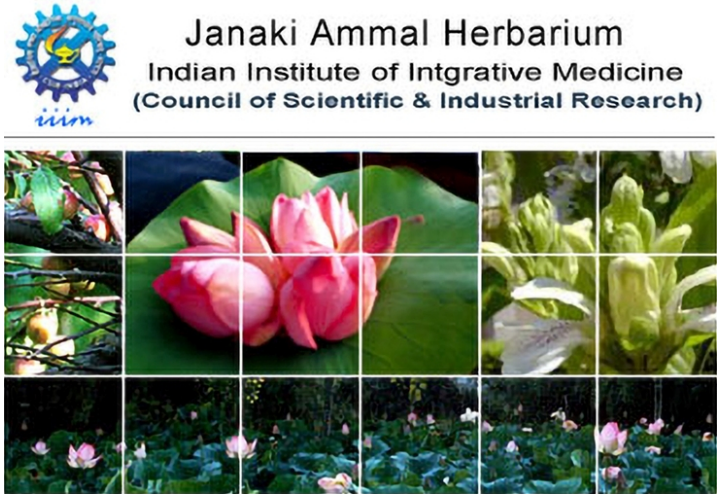
Honours

Janaki Ammal was elected a Fellow of the Indian Academy of Sciences in 1935 and a Fellow of the Indian National Academy in 1957. She was awarded the Padma Shri by the Government of India in 1977. The University of Michigan awarded the honorary LLD degree to her in 1956.

Janaki Ammal died on 7 February 1984, in Chennai. She was 87 years old.

Major Source: www.iim.res.in; www.scientificwomen.net; www.hindustantimes.com

Sugar Queen Janaki Ammal. *(Courtesy: Collage created from public domain by the authors)*



Janaki Ammal Herbarium. *(Courtesy: Director CSIR-IIIM, Jammu)*

Janaki Ammal. *(Courtesy: Wikimedia Commons)*

VALIMIRI RAMALINGASWAMI (1921–2001)

Physician, research scientist and humanist

Early days

Valimiri Ramalingaswami was born on 8 August 1921, in Srikakulam in Andhra Pradesh, in a family where scholarship and education were highly respected as was music. His grandfather was a headmaster of the high school founded by the Raja of the locality. Ramalingaswami was called Rama in the family, and that abbreviation of his name was used by his friends throughout his life. Rama grew up in a joint family and his religious grandfather used to talk to him about music, Sanskrit poetry and nationalistic ideas.

Research-oriented Physician

Rama obtained the MBBS degree from Andhra University in 1944 and an MD degree in internal medicine in 1946. He then went to Oxford University as a government scholar to the utter delight of his grandfather. He obtained the DPhil Degree (1951) from Oxford working on vitamin deficiency. This experience made Rama look into the cause of diseases and human suffering. He was a physician at heart, attempting to understand human disease. This led him to become a devoted researcher. He was interested in a whole range of areas, starting from laboratory studies and clinical pathology, eventually leading to human health. Typical of the problems of interest to Rama were malnutrition, iodine-deficiency disorders, nutritional anaemia and childhood cirrhosis.

Rama married Prabha in 1947 when he was 26 years old. Rama encouraged Prabha to develop professional interests and Prabha obtained BA, MA and PhD degrees, all after marriage. Prabha managed all matters at home and allowed Rama to concentrate on his professional interests.

Research contributions

Rama's first job was in the Nutrition Research Laboratory, Coonoor. He worked on nutritional pathology of kwashiorkor, a topic he pursued throughout his career. He initiated research on childhood cirrhosis and vitamin A and D deficiency. He had good collaborators in Coonoor. His first major research paper was published in Lancet in 1952. When ICMR was created, he was appointed deputy director (1954) and he got involved in formulating national plans for the health sector.

When AIIMS was established in New Delhi, he was appointed as a professor in pathology and head of the pathology department. He built an excellent research group and modernized the teaching of pathology. He worked in AIIMS for over two decades, first as the head of the pathology department (1957-69) and then as the director of the institute (1969-79).

Rama's research contributions from AIIMS were diverse and prolific. His main contributions were in nutritional pathology and protein-energy malnutrition. Thyroid, goitre and iodine deficiency were areas that he and his students worked on for an extended period of nearly 16 years, involving one lakh patients. Nutritional anaemia amongst young women occupied his interest for quite some years, to eventually find that it arose from iron deficiency. Based on his studies, national programmes were initiated to eliminate these diseases.

Rama worked on viral hepatitis after the epidemic in Delhi in 1955 and demonstrated hepatitis E to be responsible. Atherosclerosis amongst Indians was another area where he made important contributions.

AIIMS and medical education

Rama was a brilliant teacher and educator. His superb diction and delivery were legendary. People talked about Rama's Oxford English. His contributions to medical education are immense. He created several specialized centres in AIIMS (e.g.; cardiac thoracic centre, neurosciences centre, community medicine centre, etc.). He made AIIMS an outstanding place for education and research, besides patient-care.

Other important contributions

After two decades in AIIMS, Rama joined ICMR as the director-general in 1979. He revitalized ICMR and got its budget enhanced significantly. The support for health research got a boost nationwide. At the age of 65 years, he retired from ICMR in 1986.

Rama chaired the committee that dealt with the plague epidemic in 1993-1994. When HIV/AIDS became a threat in the world, Rama was involved in establishing many testing centres. Rama was always devoted to doing something important and useful in the service of humankind. He was committed to curing diseases of the common man. He was bothered by hunger and malnutrition suffered by a vast population in India and elsewhere.

Rama was one of the founders of the National Academy of Medical Sciences. He was a major adviser of WHO and was chair of the WHO committee on medical research (1982-86). He produced a report on *Health for all: an alternative strategy.* He was a national research professor until his death on 28 May 2001.

Honours

Bhatnagar Prize, Fellow of all the science academies of India, Fellow of the Royal College of Physicians, Fellow of the Royal Society (London), Foreign Associate of the US National Academy of Sciences, Foreign Member of USSR (later Russia) Academy of Sciences, Leon Bernard Foundation award (1976).

Major source: P N Tandon and M G K Menon, Memoirs of the Royal Society, London.

GOPALASAMUDRAM NARAYANA RAMACHANDRAN (1922-2001)

India's first structural biologist

Early education

Gopalasamudram Narayana Ramachandran was born on 8 October 1922, in Ernakulum. His father G R Narayana Iyer was a professor of mathematics in Maharajah's College, and later became principal of the college. Ramachandran was a brilliant student in high school, scoring 100% in the mathematics examination. He completed the high school and intermediate examinations with flying colours, ranking first among thousands of students in the Madras Presidency. He joined the St. Joseph's College in Trichy for the BSc (Hons.) degree in physics in 1939 and completed the course in 1942 with the first rank in the Madras Presidency. He then joined the Indian Institute of Science to study electrical engineering. Soon he found out that the subject was not his cup of tea, and went to see Prof. C V Raman

in the physics department. Raman was impressed by the young man and got him transferred to the physics department as a research student. Typical of Raman, he wrote to the reluctant head of the electrical engineering department, "I am admitting Ramachandran into my department as he is a bit too bright to be in yours."

DSc (Madras) and PhD (Cantab)

On the first day of his research career, Raman gave Ramachandran an important theoretical problem in optics to solve. In less than a day's time, Ramachandran was able to write down the equations to describe the problem along with the solutions. The equations had several hyperbolic sines and cosines. He showed the result to Raman who was delighted and sent the paper for publication. This work has since been of use to study crystal perfection and related problems. Raman recommended Ramachandran for a scholarship of 60 rupees a month and later increased it to 130 rupees a month. Ramachandran worked on a few other research problems, becoming an expert in crystallography in the process. He submitted a thesis on 'Optics of Heterogeneous Media' for the MSc degree of the University of Madras. The reports on the thesis were extraordinary.

After obtaining his MSc degree in 1944, Ramachandran continued in Raman's laboratory, working on several problems of his own. He submitted a thesis for the DSc degree of Madras University in 1947. His work involved the study of photo-elasticity and thermo-optic behaviour of diamond and other solids. He had employed X-ray topography for some of his studies. Amazingly, all the papers of Ramachandran had only his name. Raman was truly generous to Ramachandran.

Ramachandran married Rajalakshmi (Rajam) in 1945. She turned out to be a wonderful companion whose support played a major role in Ramachandran's life and science. She was generous and friendly.

Ramachandran received the 1851 Exhibition scholarship to go to Cambridge in October 1947. The Cavendish Laboratory was headed by Sir Lawrence Bragg. Ramachandran worked with Dr. Wooster on instrumentation and theory related to diffuse X-ray diffraction and obtained a Cambridge PhD in 1949. He was a 27-year-old DSc (Madras), PhD (Cantab).

Glorious days in Madras

Ramachandran joined IISc as an assistant professor in physics, after his return from Cambridge (1949). Just around that time, the University of Madras under

the vice-chancellorship of Sir Arcot Lakshminarayanaswamy Mudaliar decided to set up a physics department and requested Prof. Raman to suggest a suitable person for the professorship. Raman proposed Ramachandran for the professorship. The most productive phase of Ramachandran's career started in Madras (1952). The affection, friendship, and admiration of Sir A L Mudaliar were important factors in what happened in later years. 30-year old Ramachandran was the head of the physics department.

Ramachandran recruited a group of brilliant young people as faculty members, of whom Gopinath Kartha was to play a key role in Ramachandran's research. Based on his discussion with Bernal, Ramachandran decided to work on the structure of collagen, getting a specimen from CLRI Madras. The structure of collagen solved by Ramachandran and Kartha is a landmark in Indian science. It had a complex triple helical structure unknown at that time. Ramachandran was especially happy that he had worked on this complex helical structure, having been a great admirer of Linus Pauling discoverer of the alpha helix.

There was some early controversy about the structure of collagen. Two groups in Britain, one headed by Crick, had some reservations regarding the Ramachandran structure, but he found support from Bernal. Ramachandran's structure was correct, and his paper appeared in Nature (September 1955) before any other paper on this topic was published. One of the objections of Crick to Ramachandran's structure had to do with nonbonded distances. The final model is best described as a polyproline helix, where three separate polyproline chains are related by a three-fold screw axis.

Investigations of the stereochemistry of several polypeptides and proteins then led to the famous Ramachandran phi-psi diagram or the Ramachandran plot. This diagram became internationally recognized as an important way to understand the structures of polypeptide chains. Such calculations were later extended to carbohydrates and nucleotides. The work on collagen and the Ramachandran plot made Madras and Ramachandran famous.

Ramachandran worked on anomalous dispersion of X-rays and problems associated with Fourier analysis. Use of Fourier synthesis to unravel the complete structure of a molecule when only a part of it was known, was another contribution from Ramachandran's group. Ramachandran organised a major international symposium in 1963 which was attended by many noted crystallographers and other specialists, including Prof. C V Raman. Another important symposium on the conformation of biopolymers was organized in 1968. Linus Pauling came to Madras for the symposium and delivered the presidential address. He congratulated Ramachandran on the collagen structure in his address.

Ramachandran's students were all over the world doing biological crystallography. Ramachandran travelled widely and was a visiting professor in Chicago. Those great days of Ramachandran at Madras University came to an end when Sir A L Mudaliar retired as the vice-chancellor. The new vice-chancellor was not kind to people and took away the academic freedom that good professors enjoyed earlier. He did not consult professors in making appointments to departments. He did not allow Ramachandran to go to Chicago. Ramachandran had no freedom to work or even to go on casual leave. Satish Dhawan then offered him a professorship at IISc. Ramachandran left Madras University in 1970. At IISc, he was to set up the new Molecular Biophysics Unit.

Molecular Biophysics Unit

Ramachandran started the new Unit at IISc in 1971 getting some of his past associates as faculty members. He continued his visits to Chicago and made notable contributions to the 3-dimensional reconstruction of an object from 2-dimensional shadowgraphs, the so-called Computerized Axial Tomography. His frequent visits to Chicago had a rather adverse effect on the new unit at IISc. A feeling developed amongst some of the faculty that G N R was overbearing and authoritative. However, the unit grew during 1972–78.

In 1977, Ramachandran was elected to the Fellowship of the Royal Society, London. Too little, too late. Around this period, Ramachandran's mental health seems to have been far from satisfactory. He became a man of moods, shouting sometimes, and happy some other times. Another professor of the unit was made the head instead of Ramachandran. The new head was Ramachandran's former student. The new head started taking major decisions without consulting or informing Ramachandran.

Ramachandran went to NIH in the US for a year in 1978. While academically the visit was useful and exciting, Ramachandran found a completely changed department in Bangalore when he returned. He had no clue of the changes. In that atmosphere, Ramachandran found it difficult to work. He wanted to leave the unit. The new building planned by Ramachandran had been completed, but Ramachandran did not want to go near the place. Being generally upset with things, Ramachandran left IISc and went to Centre for Cellular and Molecular Biology, Hyderabad (1978–82). Ramachandran's research activities became limited. This was most unfortunate.

In 1982, a new unit entitled Mathematical Philosophy Unit was created at IISc with Ramachandran as the lone member. He was free to do whatever he wanted. He also had the Einstein professorship of INSA. He seemed to be happy during this period. Though he tried hard, it was not possible to come out with original ideas in mathematics.

Ramachandran was not the same since the mid-1970s and had many problems, mostly psychological. One remembers, how he would suddenly choke up while giving a lecture. It was particularly sad, when Ramachandran started his evening lecture in Prof. Raman's 80th birthday symposium in 1969, with "Dear professor, ladies and gentlemen," and choked up. It was heart-rending to see this. Although he had pulled through his earlier psychological problems, he had remained temperamental.

In closing

G N Ramachandran was a genius and took India to the world stage in structural biology. Unfortunately, he did not get due recognition in time for his contributions, particularly for the structure of collagen. Some of us thought that he would get elected to the Royal Society soon after the discovery (1955). Instead, he was elected 22 years later in 1977. We in India did little to boost his morale (no Padma award!).

Ramachandran was childlike and there was an innocence about him. There are many instances to illustrate this quality. Once he was visiting his wife in her parent's home. He had forgotten to take a gift for her. To compensate for this, he presented her reprints of his papers. He was a cultured person interested in music. He was very generous and respectful of people whom he considered to be good friends or outstanding scientists. His frequent nervous breakdowns were the result of the feeling that he was not getting sufficient attention.

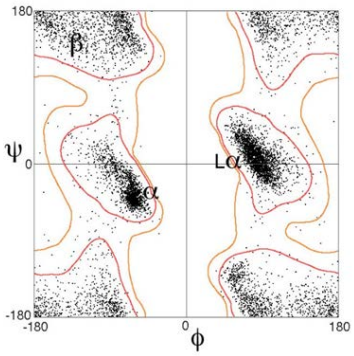
Rajam, his wife, supported Ramachandran like a rock. She was always with him. She was a delightful person, radiating happiness. Unfortunately, she died in 1998 of a massive heart attack. They had been married for 53 years. Just a few months before her death, they had moved to Ahmedabad to be with their son.

Ramachandran was lost without Rajam. He developed serious neurological disorder and could not walk. He somehow survived for a while, being attended to by an old helper who knew him. One of us saw G N R before he passed away in Madras. He had lost the sense of recognition. He was alone in a lonely place. It was distressing to see him in that state. He passed away on April 7, 2001. A sad ending of a great scientist indeed.

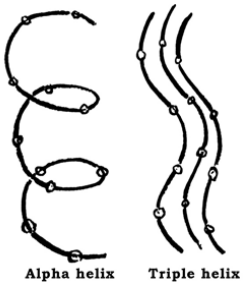
Honours

G N Ramachandran received the Bhatnagar Prize in 1961 and the CSIR Golden Jubilee award for life sciences in 1991. He was a FASc and an FNA, as well as an FRS. The auditorium in CLRI in Chennai is named Triple Helix, to remember Ramachandran.

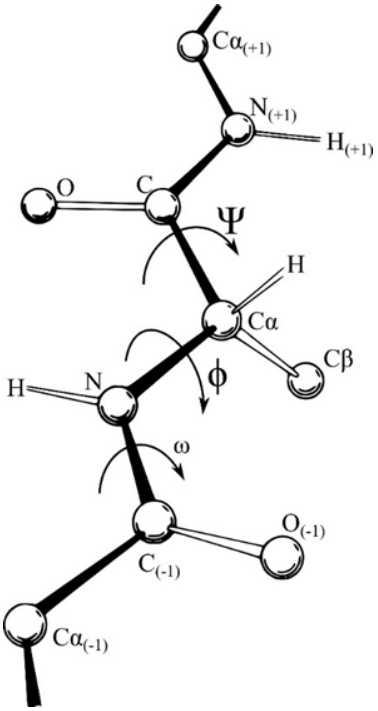
Major source: Ramachandran, R Sarma, 1998, Adenine Press.



Ramachandran plot and contours from 100,000 high-quality datapoints. *(Courtesy: Wikimedia commons)*



Alpha Helix. *Nature Structural Biology* Vol. 8, pp. 489–491 (2001). *(Courtesy: Reproduced with permission from SpringerNature)*



Rama plot- Backbone dihedral angles φ and ψ (and ω). *(Courtesy: Wikimedia Commons)*

Architects and Patrons

PRAFULLA CHANDRA RAY (1861–1944)

A patron of chemistry and chemical industry

Early days

Prafulla Chandra Ray was born on 2 August 1861, in Raruli-Katipara village in East Bengal (now Bangladesh). He was the third child of Harish Chandra Ray, a zamindar and Bhubanmohini Devi. The Rays were an influential and progressive family which supported modern education. Prafulla Chandra's father benefitted from this outlook and received a liberal education in Krishnagar Government College. On returning to his village, he introduced English as the medium of education in the village school and pioneered women's education. Prafulla Chandra joined the village school run by his father as a five-year-old and when he was around ten years, his father moved to Calcutta with the family to provide better educational opportunities to his children. Ray joined Hare School there. However, his formal schooling came to an abrupt end in 1874 as he had severe health problems. This disruption was probably a blessing

in disguise as it allowed him the freedom to read many literary works in Bengali and English besides scientific works. He also learnt many languages like Sanskrit, Greek, Latin and French. Ray returned to Calcutta in 1876 and joined Albert School completing matriculation examination in 1878. He then joined Vidyasagar College where he was taught English by Surendranath Banerjee. He was a contemporary of J C Bose (1858-1937). Ray was influenced by his deep commitment to the rejuvenation of Indian values. However, Ray preferred the more flexible and liberal Sadharan Brahmo Samaj.

In 1881, Ray joined the University of Calcutta for his bachelor's degree in Fine Arts where chemistry was a compulsory subject. He developed a fascination for the subject and carried out simple experiments with friends.

Ray won the Gilchrist Prize Scholarship (for which, the knowledge of at least four languages was a prerequisite). He decided to go to the University of Edinburgh in 1882 for BSc degree and completed it in 1885. During that period, he also published patriotic essays highlighting the ground realities of the British rule in India. For his doctoral work, Ray worked with organic chemist Crum Brown but soon changed his interest to inorganic chemistry. He worked on double sulphates for his thesis (1988). Ray received the Hope Prize which allowed him to work for a year after receiving his doctorate. Ray was popular in the university circles and in 1888 was elected Vice-President of the University of Edinburgh Chemical Society.

Ray returned to India in August 1889. He joined the Presidency College as a temporary assistant professor since he could not get any position in the imperial service despite his qualifications.

In the University of Calcutta

P C Ray's main contributions to inorganic chemistry deal with metal nitrites. He was one of the first to make mercurous nitrite and ammonium nitrite. In 1896 Ray noticed that the reaction of mercury and dilute nitric acid resulted in the formation of a yellow crystalline solid.

$$6Hg + 8HNO_3 \longrightarrow 3Hg_2(NO_3)_2 + 2NO + 4H_20$$

The Journal of Asiatic Society published the paper first and immediately it came to the attention of Nature issue of 28 May 1896. This work received considerable attention. According to Ray, the unanticipated discovery of mercurous nitrite started a new chapter in his professional life.

One of Ray's important achievements was to synthesize stable ammonium nitrite by the double displacement ammonium between ammonium chloride and silver nitrite.

$$NH_4Cl + AgNO_2 \longrightarrow NH_4NO_2 + AgCl$$

Ray successfully prepared several similar compounds by double displacement. He also worked on compounds of gold, platinum and iridium.

In 1921, when he completed 60 years, Ray donated his entire salary from that day onwards in perpetuity to the Calcutta University to develop the chemistry department of the University College of Science and further research in chemistry there. In 1924, a new Indian School of Chemistry was started by Ray.

After retiring from the Presidency College in 1916, Ray joined the Calcutta University College of Science (Rajabazar Science College) as the first Palit Professor of Chemistry. On retiring from active service when he reached 75, he was appointed Emeritus Professor. He continued to help and support many research students till the end of his life. Many of us have personally known several outstanding chemists who owed their career to P C Ray and his timely advice and support. Besides his academic contributions to chemistry, he set up the first pharmaceutical company of the country, Bengal Chemicals and Pharmaceuticals.

Ray remained a bachelor. As a true rationalist, he did not subscribe to irrational social taboos and was against the caste system. He was determined to use chemistry to uplift the poor masses of Bengal.

Ray, the writer

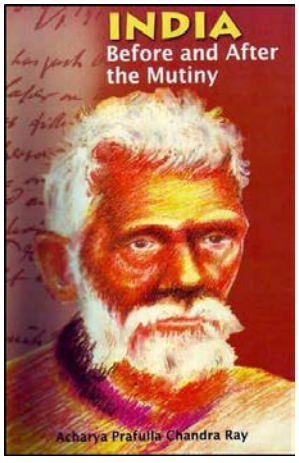
Ray published the first volume of *A History of Hindu Chemistry from the earliest times to the Middle of the Sixteenth Century* in 1902 and the second volume in 1909. Later he published the first volume of his famous autobiography *Life and Experience of a Bengali Chemist* in 1932 and dedicated it to the youth of the country. The second volume was published in 1935. He was closely involved with the Journal of the Indian Chemical Society. P C Ray was a self-effacing person and almost a sanyasi.

Honours

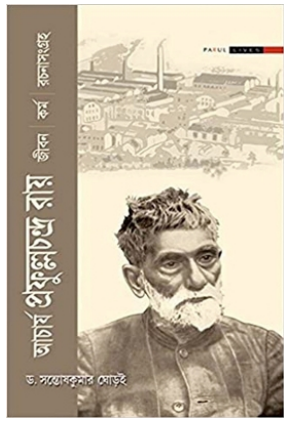
Ray was an FNA and was knighted by the British monarch.

P C Ray passed away in June 1944. He is considered to be the father of chemistry in India.

Major source: Study.com



Book by Prafulla Chandra Ray.



Book on P C Ray by Dr. Santoshkumar Gharai. *(Courtesy: Parul Prakashani)*

Bengal Chemicals. *(Courtesy: getbengal.com)*

PRASANTA CHANDRA MAHALANOBIS (1893–1972)

One who ushered statistics and sample surveys

Early days

Prasanta Chandra Mahalanobis was born on June 29, 1893, in Kolkata in a cultured family, which was involved in Bengal renaissance in the 19th century. After his schooling in Brahmo Boys' School, he joined the Presidency College in 1912. In Presidency College, J C Bose and P C Ray were his teachers. After graduating in physics, he went to King's College, Cambridge for studies. The main subjects he studied there were mathematics and physics, and accidentally got an introduction to statistics. He then carried out research with C T R Wilson. Srinivasa Ramanujan was a contemporary of Mahalanobis in Cambridge.

After his return to India, he taught in Presidency College, becoming a professor in 1922. Statistics became his passion during this period, his interest being applications

of statistics to various problems in anthropology, meteorology and so on. He sought to establish statistics as an important subject of immense practical value to society.

ISI and Statistics in India

Mahalanobis founded the Indian Statistical Institute (ISI) in Kolkata in 1931. ISI has emerged to become a well-known centre for statistics and has had many distinguished alumni and faculty members. Prof. C R Rao, who was a student of Mahalanonis, later became the director of the institute and carried out some of his important work from ISI. The journal *Sankhyā*, The Indian Journal of Statistics, was launched by Mahalanobis in 1933. This was an important initiative. J B S Haldane was a research professor in ISI during 1957-1961.

Statistician at heart

Prof. C R Rao considered Mahalanobis the most well-known of the statisticians in the world of that period. He also states that Mahalanobis was a statistician by instinct and an economist by conviction. The main characteristic of Mahalanobis was his flair for empirical studies to help in decision making.

There are many important contributions of Mahalanobis to statistics. A well-known one is the so-called Mahalanobis distance (D), which is a measure of comparison between two data sets used commonly in cluster analysis. This was proposed in 1930 in connection with a racial likeness. He introduced the concept of Inter Penetrating Network of Subsamples (IPNS) as a built-in safeguard to cross-check the accuracy of data. According to Deming, the main features of IPNS were its simplicity in detecting both the unconscious blunders of selection, recording and processing, and the ease of evaluating the differences among those involved in various stages of processing the data. The importance of this novel technique can be judged by the fact this is now acknowledged as the forerunner of Bootstrap and other similar resampling procedures. The concept of Systematic Sampling and Random Permutation Modelling (adopted by Mahalanobis, Majumder and Rao) in the anthropometric survey conducted in Uttar Pradesh is another example of his out-of-the-box approach. He was convinced that statistics could play an important role in solving problems of agriculture. Mahalanobis analysed a great deal of anthropometric data. To fully understand the data, he initiated genetical studies.

Mahalanobis used a simple instrument fabricated in his institute. The use of coordinatograph to correctly show the boundaries of fields on maps and the use of

the instrument Photographic Profiloscope, which he built with a lens made especially from Carl Zeiss and Company to study the accuracy of measurements, are examples of his use of innovative ideas. He recommended its use after conducting the statistical analysis of accurate measurements obtained in the comparative anthropometry studies.

Another important contribution of Mahalanobis relates his advocacy of employing the technique of random sampling to carry out large scale sample surveys in the area of agriculture. He advocated the use of sampling methods in many areas of importance to society. Because of Mahalanobis, the Government of India started making use of statistics in its various ventures. The technique of sample surveys became an important development due to the work in ISI.

Early contributions of Mahalanobis and their relevance even now (from T J Rao, with slight modifications)

In the Foreword of the paper "Bengal Anthropometric Survey: 1945", Mahalanobis defined group as "...individuals belonging to the same caste, religion and tribe and living in the same district, that is, the classification adopted is two-way, one representing caste, religion or tribe, and the other geographical habitat (district)" and noted that further sub division would result in very small sample size or no samples at all giving estimates with large errors.	Exactly same situation encountered in Small Area Estimation techniques of current interest.
In the forties, Mahalanobis studied the demand for currency notes and coins as well as average life of currency notes. Survey on economic and demographic factors leading to Indebtedness.	Reserve Bank of India had projects on the same topic recently. Recent Surveys of NSS on all India Rural Indebtedness and Landholdings.
Public Opinion (including tea drinking habits) and Radio Listeners Preference Survey of war time.	Opinion Polls, and Market Research Surveys, Exit Polls etc.
Reference Period (week or month) Study by Mahalanobis and S B Sen (1954).	Reference Period Pilot Survey by NSSO Expert Group (2003).
Problems of Brahmani River floods in Orissa.	Problems of Vizag Airport Floods (cf. T J Rao, 2010b).

Other contributions

Mahalanobis was Chair of the UN sub-commission on sampling (1947-51). He played a major role in preparing the second five-year plan (1956-61). He helped to establish the National Sample Survey Office. He analysed years of data on the floods of Odisha, based on which the Hirakud dam was constructed. Mahalanobis's work helped planners and policymakers. He was a member of the planning commission for nearly twelve years. Data science has become a hot subject today, and one could consider Mahalanobis as an early data scientist.

Mahalanobis and Tagore

Mahalanobis was close to Rabindranath Tagore and acted as his secretary during the latter's foreign travels. The families of Rabindranath Tagore and P C Mahalanobis were friends for two generations. Mahalanobis's remark that he was introduced to Rabindranath's writings almost at the same time as he started learning alphabets is testimony to this lifelong friendship. Mahalanobis met Rabindranath Tagore for the first time in 1910, and he recounted the momentous meeting that rekindled his life.

Mahalanobis shared Tagore's idealism of creating a new movement of self-contained and self-reliant villages with an emphasis on 'life in its completeness' with music and education. Tagore called it the Sriniketan Experiment. Mahalanobis was attracted to this idea and joined Tagore in this exciting project. Visva Bharati was born out of this revolutionary idea and Mahalanobis was the Founder Secretary of Visva Bharati. However, he was disillusioned with many policies of Visva Bharati and resigned from it in 1929 much to Tagore's disappointment.

Honours

He was awarded the Padma Vibhushan by the President of India. He was both an FNA and FASc. He was a Fellow of the Royal Society, London (1949), foreign member of the USSR (now Russian) Academy of Sciences and Fellow of Royal Statistical Society, UK (1954). He was awarded the title OBE by the British.

Mahalanobis passed away on 28 June 1972. His birth anniversary is celebrated as the National Statistics Day.

Major source: Articles of C R Rao and Partha Majumder; www.isical.ac.in; www.britannica.com; wikipedia

Mahalanobis and his wife Nirmal Kumari. *(Courtesy: P C Mahalanobis Memorial Museum and Archives, Indian Statistical Institute, Kolkata)*

Pandit Jawaharlal Nehru and P C Mahalanobis at Amrapali in 1945. *(Courtesy: P C Mahalanobis Memorial Museum and Archives, Indian Statistical Institute, Kolkata)*

SHANTI SWARUP BHATNAGAR (1894–1955)

Architect of the chain of national laboratories

Early days

Shanti Swarup Bhatnagar was born on 21 February 1894, in Bhera (now in Punjab, Pakistan). He lost his father when he was a child and was brought up by his maternal grandfather who was an engineer. His elementary education was in Sikandrabad. In 1911, he joined Dayal Singh College in Lahore and passed the intermediate examination in 1913. He obtained a BSc degree in physics and an MSc degree in chemistry (1918) from the Forman Christian College (University of Punjab). As a student, he wrote poetry and acted in plays.

Bhatnagar went to England on a scholarship awarded by the Dayal Singh College Trust and Department of Science and Research (DSIR) of Britain. He obtained a

doctorate in chemistry from University College, London in 1921. His supervisor was Prof. Frederick Donnan, a famous colloid chemist.

Professorships

Bhatnagar returned to India after receiving the doctorate degree in London. He joined the Banaras Hindu University (BHU) as a professor of chemistry soon after returning to India in 1921. He composed the famous kulgeet of BHU and has been remembered in BHU ever since. After three years, he moved to the University of Punjab (Lahore) as a professor of physical chemistry and the director of Chemical Laboratories. That was his most active period in research. His work mainly related to magnetochemistry. He developed a magnetic interference balance (with K N Mathur) and wrote a book on Magneto Chemistry. Bhatnagar also solved many problems of direct benefit to industries. Some of them related to the petroleum industry, a typical one being the improvement of the procedure for drilling crude oil.

Bhatnagar was a professor for 19 years (1921-1940), first at BHU and then at Panjab University. He was destined to contribute to the development of India through the creation of institutions devoted to pure and applied scientific research.

CSIR, his brainchild

In 1940, the Indian government decided to set up a Board of Scientific and Industrial Research (BSIR), comparable to the British BSIR, thanks to the efforts of Sir Arcot Ramaswamy Mudaliar. An annual budget of rupees five lakh was granted for the board. Mudaliar was the chair of BSIR and Bhatnagar was the director. In 1941, the government set up the Industrial Research Fund with an annual budget of Rs. 10 lakhs. These developments eventually gave birth to the Council of Scientific and Industrial Research (CSIR) in 1942. Bhatnagar succeeded to get the approval of the governing body to create five national laboratories which included NPL, NCL and CGCRI.

After Indian independence in 1947, Pandit Nehru supported CSIR strongly and Bhatnagar could establish 12 national laboratories. These included NML, CFRI, CFTRI besides NCL and NPL. Bhatnagar was appointed the first director-general of CSIR. He later established NRDC. Bhatnagar also served as the secretary of the ministry of education and was involved in producing a report of scientific

manpower (1948). He was one of the favourite scientists of Nehru, besides Homi Bhabha. Bhatnagar was an extraordinary planner and architect of the chain of national laboratories.

Honours

Bhatnagar was elected FNA as well as FASc. He was elected fellow of the Royal Society in 1943 and Knighted by the British in 1941 for his contributions to the advancement of science.

Bhatnagar passed away at the age of 60 on January 1, 1955. The coveted science award of CSIR, Shanti Swarup Bhatnagar Prize for Science and Technology was created in honour of this great Indian.

Major Source: www.tifr.res.in; www.ssbprize.gov.in; Vigyan Prasar

S S Bhatnagar with Pandit Jawaharlal Nehru in 1954. *(Courtesy: tifrarchives.com)*

S S Bhatnagar and Homi Bhabha. *(Courtesy: tifrarchives.com)*

Pandit Jawaharlal Nehru, Maulana Azad and S S Bhatnagar. *(Courtesy: National Physical Laboratory)*

HOMI JEHANGIR BHABHA (1909–1966)

Champion of nuclear science and atomic energy

Early days

Homi Jehangir Bhabha was born on 30 October 1909 in Bombay to wealthy and cultured parents. After his early education in Bombay, young Bhabha went to Cambridge, as an undergraduate in Caius College in 1927, when he was 18 years old. He obtained the bachelor's degree in mechanical sciences in 1930 with a first-class. He then proceeded to do research in theoretical physics. He carried out research in theoretical physics in Cambridge as well as in many great centres such as Copenhagen (with Bohr), Zurich (with Pauli) and Utrecht (with Kramers). He stayed in Cambridge till 1939, when the Second World War began. He returned to India and joined the Indian Institute of Science (IISc), Bangalore, as a reader in 1940. Prof. Raman was the director of the institute and professor of physics at that time.

Bhabha was a connoisseur of music and art. He learnt much about western music from his parents even when he was young. He also became a good artist and his drawings were much appreciated.

Tata Institute of Fundamental Research (TIFR)

In IISc, he started research on cosmic rays. It was during his five-year stay in Bangalore that Bhabha became entirely Indian. He became conscious of the great cultural heritage of India and got interested in the future of the country. This led him to write his famous letter to Sir Dorabji Tata Trust about the need to set up an outstanding school of fundamental research in theoretical and experimental physics. He also emphasised on the importance of nuclear energy and various areas of physics for economic development. This letter led to the establishment of the Tata Institute of Fundamental Research (TIFR) in Bombay in 1945. The institute was housed in the old yacht club until a new building could be built. The foundation stone of the TIFR building was laid in 1954 by Pandit Jawaharlal Nehru. Homi Bhabha was the director of the institute.

Homi Bhabha was very active in cosmic ray research and high energy physics. He published several outstanding research papers during the first 22 years of his amazing career. He later got intensely involved in efforts to usher in a new era of science in the country. Prime Minister Nehru shared his interest in this respect and they became close friends. Bhabha was an active member of the Scientific Advisory Committee of the cabinet.

Department of Atomic Energy (DAE) and Atomic Energy Commission (AEC)

Bhabha proposed the idea of setting up the Atomic Energy Commission (AEC) and an associated Department of Atomic Energy (DAE) to the Prime Minister. The AEC act was passed by the government in 1948. Just a year after the setting up of TIFR (where nuclear physics was to be practised at a high level), the first atomic bomb was deployed on humanity. The DAE under Bhabha set up a research centre in Bombay in temporary quarters and later got relocated in Anushakti Nagar. Today, there are around 8000 scientists and 1500 students in Anushakti Nagar, one of the biggest R&D laboratories in the world.

In 1964, Bhabha was primarily responsible for setting up the Indian National Committee for Space Research with Vikram Sarabhai as the Chair. The space

programme of India started actively in 1965. Bhabha was the Chair of the Government Electronics committee. He was very much interested to make India an important player in electronics.

Under the DAE, many institutions were created. The Physical Research Laboratory, Ahmedabad was created as part of the same initiative. The atomic power plants in India are a result of Bhabha's magic. There are other centres created or supported by DAE. These include the Tata Memorial Cancer Hospital in Bombay, the Institute for Mathematical Sciences in Chennai and the Institute of Physics, Bhubaneswar.

Spokesman for science

Bhabha was not only highly respected as a leader of science in India, but also as a leading spokesman and statesman in international programmes dealing with atomic energy. He was the president of the first international conference on atomic energy (1955). He was a leading participant in the UN conferences on peaceful uses of atomic energy.

Honours

Bhabha became an FRS in 1941 and a foreign associate of the US National Academy of Sciences in 1963. He was an FNA and FASc. More importantly, he was a great Indian without whom India would not have had the atomic energy programme. He was a great builder of institutions and organizations.

Tragic end

To the great misfortune of all of us in India, Bhabha died in an air crash on Mont Blanc on 24 January 1966, when he was hardly 57 years old. The country honoured him by naming the atomic research centre in Bombay as the Bhabha Atomic Research Centre (BARC). It is difficult even to guess what all he would have achieved if he had lived longer. Certainly, India would have become an electronics capital. Bhabha was an extraordinary Indian, a real Bharat Ratna.

Excerpts from Bhabha's impassioned lecture

In an impassioned lecture, Homi Bhabha analyzed the problems of development of science in India and his solutions for circumventing them. Bhabha shared Nehru's vision that the essential role of science in its historical perspective, not only transforming the material environment, but in transforming man.

> "Science has developed at an ever-increasing pace since the beginning of the century so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India, with its traditions of scholarships and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today."

If a scientific outlook is to be made a part of the mental make-up of every individual, then clearly their education has to be moulded accordingly. Not only must science be taught at the secondary school stage, scientific education must commence much earlier with the help of scientific models and toys. But to be able to do this implies that scientific activity should already have been well-developed in the country. Above all, scientific teaching and research at the universities must be strengthened and expanded. The universities are, however, autonomous organisations, guarded against external interference, and the process must necessarily be slow and time-consuming. It is probably for this reason that it has been considered expedient in many countries to set up national laboratories and other scientific organisations for specific subjects.

The aim of establishing science as an important national activity has been attempted to be achieved in India through a number of governmental and quasi-governmental organisations working more or less independently; the most important among these being Atomic Energy, the council of Scientific and Industrial Research and Defence Science. The methods followed in all these have been different. But the method for filling up the posts has been the same.

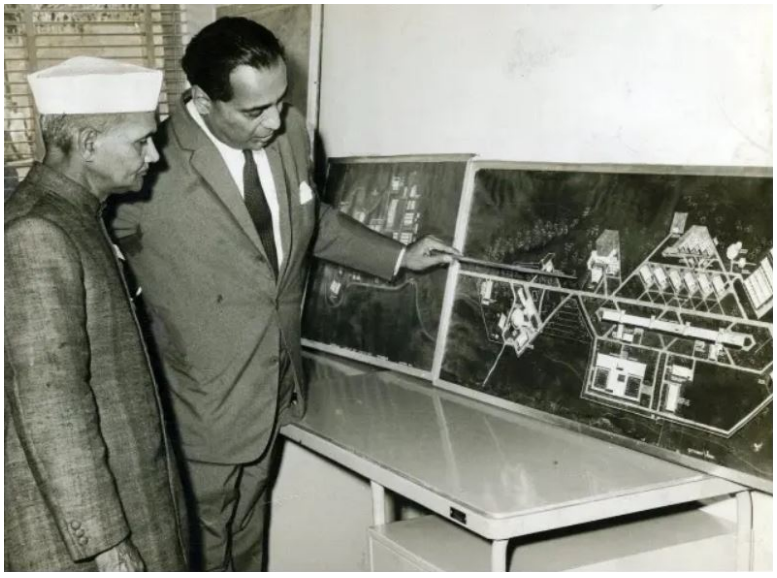
The standard method of planning laboratories and filling posts is often forced on many by the administrative and financial requirements of the government. As Prof. Blackett has said, "We must endow ability whenever it is found, and we must guard against subsidising mediocrity." The standard method is certainly not conducive to achieving this aim. Government is spending large sums now on supporting scientific research and technical development, and it is in Government's interest to study and devise *de novo,* the best administrative and financial procedures for scientific institutions and for getting the maximum return on the money spent. To apply the existing administrative and financial procedures, devised for an entirely different purpose, to scientific institutions is largely to defeat the purpose which the Government has in view by letting the tail wag the dog.

I turn now to Atomic Energy for a case study of a scientific organisation which has been built up by an entirely different method, a method which might be described as growing science.

To summarise, of the two ways of establishing science as a national activity in an underdeveloped country, the standard method on one hand, and the alternative method of what I have called, growing science on the other, the second seems to lead to better results in the end with greater potential for continuous growth. While it may seem much slower and harder at the beginning, it has the capacity for continuous growth and to develop the people it needs, and its faster growth rate in later years more than compensates the slow beginning. Moreover, it may lead to concrete results sooner than the other method in developing countries, in which there is not a large pool of mature scientists to draw from.

Source: Tribute to a Titan-Birth Centenary of Homi Jehangir Bhabha. 2009. Dipan K Ghosh and Arun K Grover (Eds.). Indian Physics Association, IIT Bombay.

Homi Jehangir Bhabha with Pandit Jawaharlal Nehru. *(Courtesy: images.inuth.com)*



Homi Jehangir Bhabha with 2nd Prime Minister India, Lal Bahadur Shastri. *(Courtesy: beaninspirer.com)*

VIKRAM AMBALAL SARABHAI (1919–1971)

Champion of the Space Programme

Early days

Vikram Ambalal Sarabhai was born on 12 August 1919, in Ahmedabad as one of the eight children of Ambalal Sarabhai who was an industrialist and nationalist. He first studied in Gujarat College, Ahmedabad, and shifted to St. John's College, Cambridge, where he took a tripos in natural sciences in 1940. Because of the Second World War, he had to return to India after his degree. He joined the Indian Institute of Science as a student under the formal guidance of Prof. C V Raman and started research in cosmic rays in association with Homi Bhabha. He returned to Cambridge in 1945 and obtained the PhD degree in 1947. His thesis was on cosmic ray investigations in tropical latitudes.

Physical Research Laboratory (PRL)

After his return to India, he was able to establish the Physical Research Laboratory (PRL) in Ahmedabad, when he was just 28 years old. It was to be a centre for research in physics, in particular, space physics including the upper atmosphere and cosmic rays. Dr. K R Ramanathan was appointed the first director. Sarabhai worked in PRL as a professor.

Space programme

Sarabhai set up the first rocket launching station in Thumba near Thiruvananthapuram with the support of Homi Bhabha. The first flight was launched in 1963. Establishing the Indian Space Research Organization (ISRO) in 1962 was his major achievement. Fabrication of satellites was another major initiative. The first Indian satellite, Aryabhata, was sent in orbit in 1975 from the Russian cosmodrome. He created the Space Application Centre in Ahmedabad. This Centre carried out a nation-wide satellite-based television programme for students and teachers.

Sarabhai believed in the relevance of the space programme for the development of India. India owes much to this great nationalist and institution builder. Other major institutions that he was responsible to establish are the Indian Institute of Management in Ahmedabad and the Community Science Centre. The latter is devoted to science education. He established the Nehru Foundation for Development (in 1965) devoted to problems of the society and individual development.

AEC and other organizations

After the death of Homi Bhabha in 1966, Sarabhai was asked to be the chairman of the Atomic Energy Commission. He made major contributions in this capacity which include establishing many power reactors. He took considerable interest in industry and business as well and founded the Ahmedabad Textile Industry's Research Association. He played a major role in setting up the Centre for Environmental Planning and Technology (1962).

Sarabhai was a renaissance man. He was deeply interested in performing arts. Along with his wife, Mrinalini, he founded the Darpana Academy of Performing Arts. Mrinalini herself was a well-known classical dancer.

Honours

Shanti Swarup Bhatnagar Prize; Padma Bhushan 1966; Padma Vibhushan, Posthumous 1972. August 12 is celebrated every year as the Space Science Day. The community science centre in Ahmedabad is named after Sarabhai. The International Astronomical Union has named the lunar crater, Bessel A, in the Sea of Serenity as the Sarabhai Crater.

Vikram Sarabhai was a very hardworking and devoted scientist. He gave everything in his power to the causes that he believed in. He passed away on 12 August 1971, at a young age of 52.

Major source: Current Science, April 2020 issue; Vigyan Prasar; www.isro.gov.in; www.britannica.com.

Vikram Sarabhai with his wife Mrinalini. *(Courtesy: Times of India)*

Vikram Sarabhai with son, Kartikeya, and daughter, Mallik. *(Courtesy: Darpana Archives)*

Vikram Sarabhai with C V Raman. *(Courtesy: Indian Academy of Sciences)*

Vikram Sarabhai with Pandit Jawaharlal Nehru at Physical Research Laboratory. *(Courtesy: prl.res.in/~library/photos)*

In Closing

The galaxy of scientists presented here is of those who have made monumental contributions. It has been a difficult task to choose among them. In addition to them, we have added a well-known geologist and a plant biologist. And thus, we will close the narrative.

DARASHAW NOSHERWAN WADIA (1883–1969)

The man who traversed across the Himalayas

Darashaw Nosherwan Wadia was born on 23 October 1883, in Surat Gujarat. He was the fourth of the nine children of Nosherwan and Gooverbai Wadia. As his father was a station master at a small town, Wadia spent his early years with his maternal grandmother in Surat where he completed primary school in Sir J J English School. His family moved to Baroda in 1894 to provide better educational opportunities. Wadia joined Baroda High School when he was 11 years old. Here, he came under the influence of his eldest brother who nurtured a love for science and scholarship and a rational outlook in Wadia. These became the hallmark of his adult personality. Wadia joined Baroda College when he was 16 years old. He received his first BSc degree in botany and zoology in 1903. While doing his BSc, he came under the influence of Prof. Adarji M Masani who was responsible for Wadia's developing interest in Geology. Wadia obtained another BSc in botany and geology in 1905.

Wadia was a self-taught geologist as a degree in geology was offered only in the Universities of Calcutta and Madras at that time. He became proficient in geology by studying the specimen maintained in the Museum of Arts and Science at Baroda. Wadia completed his MSc in Geology in 1906.

Wadia had the proverbial lucky break when he was appointed professor of geology and english at the Prince of Wales College in Jammu in 1907 where he taught for 14 years. He married Ms. Alan G Contractor, who unfortunately passed away in the 1930s. Those were crucial years for him as the daily *darshan* of the magnificent Himalayas was his primary source of inspiration. Wadia needed to make the study of geological structure and stratigraphy of the Himalayas his life's mission.

Wadia spent his vacations undertaking intensive field trips to the foothill regions of the Himalayas, collecting specimens of fossils, rocks, minerals to help him teach the subject at the college. He encouraged his students to accompany him on field trips to the Sivaliks and he was fortunate to discover the 3-metre long fossil tusk of a mammal which resembled an elephant in the upper regions of Jammu. It was identified to belong to the Stegedontinae sub-family and was named Stegodon Ganesa. He also found the fossilised skull of Actinodon risinensis from the lower Gondwana field near Zewan, Kashmir. The discovery of skull along with fossils of fish and plants was instrumental in concluding that the rock formation in Kashmir Himalayas belonged to the Carboniferous age.

Geological Survey of India (GSI)

Thirty-seven-year-old Wadia joined the Geological Survey of India (GSI) as a Scientific Officer in 1921. He began his illustrious start at GSI by mapping the mountainous region in Poonch and Punjab. One of the most important outcomes of this exercise was his explanation of the knee bend or the syntaxial turn of the Himalayas at the Nanga Parbat. Wadia made innumerable trips to the Nanga Parbat region. He was awestruck by the grandeur of its cliffs. He described Nanga Parbat as a peak of arresting grandeur as its cliffs of 12,000 feet pierce the sky in a leap. As it was impossible to trek at that barren snow-covered height, Wadia deduced the geology of the higher region by studying the moraine deposits. He deduced from his 9 years' study of the region that the knee bend was the result of the tectonic disturbances that took place during the geological periods of the Himalayan uplift. His detailed study of the geology of the Nanga Parbat region has been an invaluable source for research in the tectonics of the region. He also contributed to the discovery

of limestone minerals in old rocks amid sub-Himalayan region and vast deposits of minerals of economic importance such as sulphide ores of many metals. The first soil map of India created by Wadia, along with M S Krishnan and P N Mukherjee, was published by the Geological Survey of India in 1935. This extensive study of the types of soil and their distribution across the country had a considerable impact on the agricultural practices in India.

Wadia took a year off in 1926 (study leave) and worked at the British Museum and also visited Germany, Austria, Czechoslovakia. Later in 1935, he visited China, Japan and the USA.

Post-retirement from GSI

Wadia retired from Geological Survey of India in 1938. He accepted the invitation of Government of Sri Lanka to be the Government Mineralogist. There he met and married his second wife Meher Medivala, an established mineralogist. On his return to India, Jawaharlal Nehru invited him to be the geological advisor to the National Government led by him. He set up the Mineral Advisory Board to advise the Government on the development of the mineral wealth of India in 1947. He was appointed as the first director of the Indian Bureau of Mines (1948). After a year, he joined the Atomic Energy Commission (1949) to work in the Raw Materials Division.

Wadia's monumental contributions to the understanding of Kashmir Himalayas

Wadia focused his research on studying and identifying the structure, palaeontology of Kashmir Himalayas in the North-western Himalayas. He was a dedicated field geologist who trekked daily for 30-40 kilometres in the difficult terrain, leaving before the break of dawn and his first meal being a late lunch. He was instrumental in establishing the Indian Institute of Himalayan Geology in Dehradun and was appointed as its first honorary director. In recognition of his monumental contribution to the study of the Himalayan geology, in 1976 it was renamed as the Wadia Institute of Himalayan Geology after his death.

He was instrumental in setting up the National Institute of Oceanography as one of the CSIR laboratories in Goa. Wadia summarised his lifetime work in his Meghnad Saha Memorial Lecture on 'The Himalayan Mountains: Their age, origin and sub-crustal relations.'

Writer

Wadia was a prolific writer. When he started teaching in Jammu, there were no good textbooks on the geology of India. He decided to write one and his classic book *Geology of India for Students* was published by Macmillan London in 1919. The book, a compendium of his vast knowledge of Geology of the Indian subcontinent, is still a standard reference book. Among other important books he wrote are:

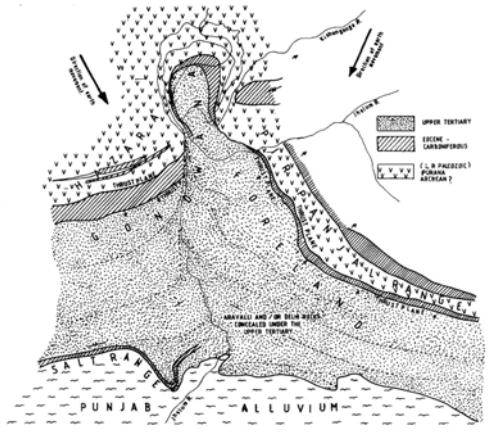
Syntaxes of North-western Himalayas: Its Rocks, Tectonics, and Orogeny (1931). *Geology of Nanga Parbat and Gilgit District* (1932). *Cretaceous volcanic Series in the Great Himalayan Range of Kashmir* (1937). *Structure of Himalayas and of the North Indian Foreland* (1938).

Honours

Wadia was a highly decorated Geologist. He was elected a Fellow of the Royal Society in 1957. He received the Back Award of the Royal Geographical Society (1934) and the Lyall Medal of the Geological Society, London (1943). The Government of India honoured him with Padma Bhushan in 1958 and appointed him as the National Professor in 1963.

Wadia died on 15 June 1969, at the age of 86.

Major source: V C Thakur, Resonance Feb. 2003 and Vigyan Prasar.



Courtesy: Research Contributions of D N Wadia by VC Thakur, Resonance (2003)

PANCHANAN MAHESHWARI (1904–1966)

Innovator of test-tube Fertilization of Angiosperms

Panchanan Maheshwari was born on 9 November 1904, in Jaipur, Rajasthan. His father, Vijaypal, an ordinary clerk, wanted to give his son the best possible education. Young Maheshwari was a voracious reader and spent most of his spare time in the school library. He passed his matriculation examination when he was only 13 years old. His father decided to send him to Allahabad for his collegiate education. Maheshwari joined Ewing Christian College affiliated to Allahabad University. Here Maheshwari came under the influence of the American Missionary, Winfield Scott Dudgeon, who taught botany. Dudgeon had found the same special qualities of dedication and uncompromising hard work in Maheshwari, as in himself. Dudgeon took Maheshwari with him on field trips to collect plant specimens. Soon Dudgeon and Maheshwari developed a relationship akin to a father and son.

Maheshwari completed BSc (1925), MSc (1927) and DSc (1931) from Allahabad University. He specialised in anatomy and embryology of angiosperm. It is said that when he went to pay *guru dakhshina* to Dudgeon, he asked Maheshwari to "do for your students what I have done for you." He spent a large part of his meagre salary on buying a microscope and microtome. Maheshwari married young Shanti at a young age.

Maheshwari studied the fertilization and formation of seeds in angiosperms. He made a detailed study of different species of angiosperms and documented the differences in seed formation.

Maheshwari visited Europe and England for a year (1936–37). He worked with Prof. Birbal Sahni and later at Dhaka University. His career-changing move came when he was invited by the vice-chancellor of Delhi University. His personal qualities of exceptional memory, inexhaustible energy and his scholarship all contributed to establishing a department of world standard.

Maheshwari, the father of plant embryology, was a dedicated teacher in the same mould as his mentor Dudgeon. Maheshwari invented the technique of test-tube fertilization of angiosperms. He was able to cross-fertilize a number of angiosperms to breed many new varieties of angiosperms. It proved to be a boon to plant breeders and opened up new avenues of economic possibilities. His book *An Introduction to Plant Embryology of Angiosperms* is a classic.

Test-tube Fertilization

Maheshwari solidified a nutrient medium in a test tube which acted as soil, and sprinkled fresh pollen grains and ovules on it. After a while, fertilization occurred when pollen tubes of the germinated pollen grain released sperms into the ovules embryo sac resulting in the plant seed. The test-tube fertilization eliminates the role of pistil and stigma and the long period of seed formation. The rest of the process of development of the seed is the same as in nature.

Honours

Panchanan Maheshwari was elected to the Indian Academy of Sciences in 1934 and the Indian National Science Academy in 1935. He received the Birbal Sahni medal in 1959. He was an elected Fellow of the Royal Society, London (1965).

Panchanan Maheshwari died in 1966 and left behind shocked scientists all over the world.

Major Source: Resonance, Indian Academy of Sciences.

P Maheshwari at about 1960 in his office room in Delhi University. *(Courtesy: Current Science, Vol. 104, No. 4, 25, 2013)*

Epilogue

We trust that we have done justice to the history of modern science in India by recounting the lives and contributions of some great science pioneers. There may be some omissions in the choice of scientists in this book. We had to restrict the number of scientists covered not only to limit the size of the book but also because of the period we wanted to cover. We realize that there have been a few other outstanding scientists who have contributed to science as well as to the planning and administration of science. Many of them are our close friends. We hope that senior scientists will enjoy going through the science-oriented biographies of the outstanding scientists that we have written about, and that young scientists will find the book to be a source of inspiration.

C N R Rao is the National Research Professor, Linus Pauling Research Professor at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) and Honorary Professor at the Indian Institute of Science (IISc). He is an author of 1750 research papers and has written and/or edited 53 books dealing with spectroscopy, solid state and materials chemistry, superconductivity, nanomaterials and such topics. Some of his books are meant for school and college students. He has received 81 honorary doctorate degrees from Indian and foreign universities. He is a member of most of the major science academies including the Royal Society (London) and U. S. National Academy of Sciences, as well as French, Japanese and Pontifical Academies.

C N R Rao has received numerous prizes and medals of which mention must be made of the Marlow medal of the Faraday Society (1967), Bhatnagar Prize (1968), Einstein gold medal of UNESCO (1996), Hughes medal (2000) as well as the Royal medal (2009) of the Royal Society (London). He is the first recipient of the India Science Award of the Government of India (2005) and received the Dan David Prize for science in the future dimension in 2005 for his work on advanced materials, The August-Wilhelm-von-Hoffmann Medal (2010) by the German Chemical Society (2010). He received the Ernesto Illy Trieste Science Prize (2011) and was Albert Einstein Professor of the Chinese Academy of Sciences (2012). He was conferred the title Bharat Ratna (2014) and the Order of the Rising Sun, Gold and Silver Star (2015).

He was the first Asian to receive the von Hippel award by the Materials Research Society (2017). He was President of The Academy of Sciences for the Developing World (TWAS). He is Founder-President of both the Chemical Research Society of India and of the Materials Research Society of India. He has been a distinguished professor at the Universities of Oxford, Cambridge and California. He was President of the International Union of Pure and Applied Chemistry.

Indumati Rao has degrees in English, Sociology and Education and has taught at school and college levels for several years. She is involved in science outreach programmes and in the preparation of educational material for school children. She received D.Litt (honoriscausa) from the Women's University, Bijapur, in 2015. She is a Fellow of the National Academy of Sciences, India.

Indian Academy
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