Pioneer scientists in pre-independence India

The lives of six physicists, who played important roles as 'tribal leaders' in establishing scientific institutions, may help to provide an answer to the question: Why pursue basic research in a less developed country?

William A. Blanpied

The conviction that scientific rationality can lead to intellectual liberation and thus convey benefits to a society that are at least as important as the material benefits derived from research has been central to Western thinking since the 17th century. That conviction is evident, for example, in the career of Benjamin Franklin, and is reflected in most of the official documents associated with the establishment of the American Republic. Studies by several scholars—most notably Joseph Needham in his *Science and Civilization in China*—indicate that the development of science in other societies has also been deeply rooted in a cultural tradition of tolerance. If so, then it can be argued that neither modern science nor the conditions required to capture its tangible benefits can thrive in any society unless science can be harmonized with the cultural traditions of that society.

In this article I will consider the careers of six pioneers of physics in India:

- Jagadish Chandra Bose, who died a decade before his country achieved independence
- Prafulla Chandra Ray, a chemist who was almost an exact contemporary of Bose
- Chandrasekhara Venkata Raman, who was the first internationally recognized physicist to receive all his education in India
- Satyendranath Bose, known primarily for his contributions to Bose–Einstein quantum statistics
- Meghnad Saha, whose principal research contributions were made prior to independence
- Homi Jehangir Bhabha, whose publications in nuclear and cosmic-ray physics spanned the pre- and post-independence periods.

In their careers these six, like many other non-Western physicists, were in the vanguard in defending both the universality of science and its importance to their society. As Raman put it,[1]

> Unless the real importance of pure science and its fundamental influence in the advancement of all knowledge are realized and acted upon, India cannot make headway in any direction and attain her place among the nations of the world.... There is only one solution for India's economic problems and that is science and more science and still more science.

Abdus Salam, who as director of the International Centre for Theoretical Physics at Trieste has devoted much of his inspired energy to improving conditions for research in less developed countries, has identified[2] "the supply of towering individuals, the tribal leaders around whom institutes are built," as "first and foremost among the factors that effect advanced scientific research in the developing countries."

In India, the conviction that a firm basic-research infrastructure is a necessary prerequisite to long-term technological progress dates back to the last century. Thus in 1901 Mahendralal Sircar, a farsighted Calcutta physician who had campaigned for 25 years to establish facilities for modern scientific research in India, maintained[3] that

> educated patriotic gentlemen are wasting their energies in the vain endeavour to promote technical education without even thinking about the necessity of a preliminary scientific education.

The six "tribal leaders" whose careers I consider here not only did pioneering work in physics, but also helped establish the institutional and financial bases for doing fundamental research in physics in India.

Roots of science in India

One of the most enduring, if unintended, consequences of the long period of British rule in India may have been the idea that the cultures of Asia and Europe can be harmonized for their mutual enrichment. Although that idea was ridiculed by the British colo-

William Blanpied is senior program manager in the Office of International Programs at the National Science Foundation. He was a staff scientist at NSF in New Delhi and has written extensively on the history of science in India. The opinions expressed here are his own and do not necessarily reflect the views or policies of the National Science Foundation.

0031-9228 / 86 / 0500 36- 09 / $01.00

J. C. Bose (1858–1937) with the staff of the Bose Institute in Calcutta. The institute, modeled after the Royal Institution, was founded with private donations in 1917. Bose is seated at center, fourth from left. (Except as noted, all photos come from the Indian National Council of Science Museums.)

nial government during much of the 19th and 20th centuries, it originated with an earlier group of British civil servants who in 1784 established in Calcutta the world's first society dedicated to scholarly studies of Asia, particularly India. Self-consciously modeled[4] on the Royal Society of London, the Asiatic Society of Bengal had as its objectives to explore "the History and Antiquities, the Natural Production, Arts, Sciences and Literature of Asia" and, even more grandly, to make inquiries into "Man and Nature, whatever is performed by the one, or produced by the other."

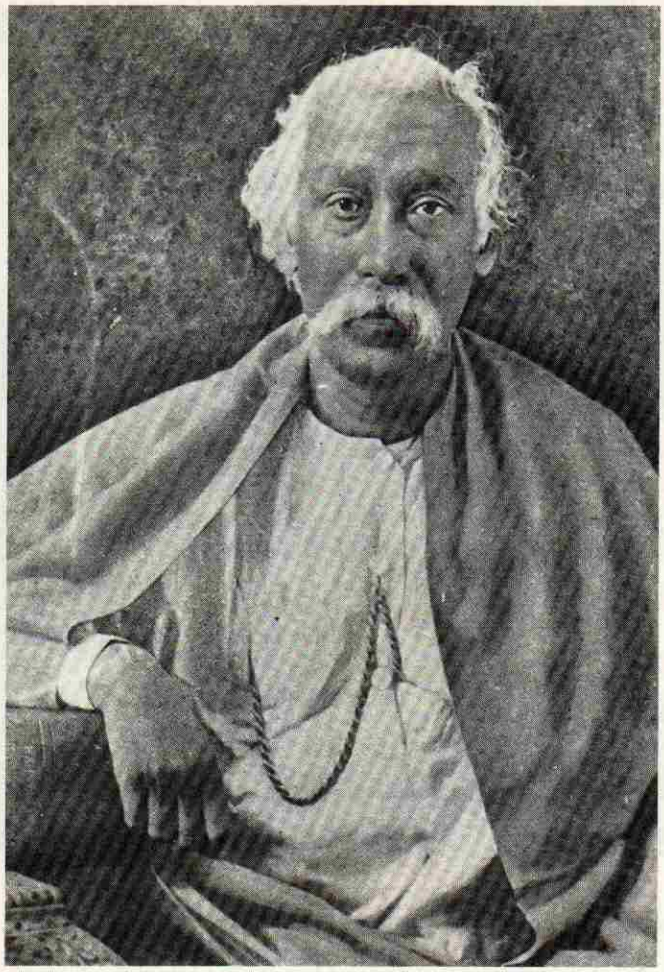
It is thus probably no accident that five of the six pioneers I consider here—Bhabha is the exception—all spent at least the formative years of their active scientific careers in Calcutta. As the administrative center of the Presidency of Bengal and later (1774–1921) the capital of all British India, Calcutta offered Indians the earliest, best and most sustained opportunities to be exposed to modern science and to reflect on its implications for their own society. Indeed, from 1915 until 1921, the activities of J. C. Bose, P. C. Ray, C. V. Raman, S. N. Bose and M. N. Saha, among others, made Calcutta for a few years one of the most intense sites of scientific activity outside of Europe.

The Asiatic Society provided the nucleus about which this scientific culture was able to grow. One of the first to argue that there was an intimate connection between modern science and genuine self-reliance was the 19th-century Bengali reformer Ram Mohum Roy, a member of the society. While Roy was devoted to his own country's traditions, he believed that their ossification was a principal cause of India's subservience to Britain. Motivated by his belief that the spirit of modern science had to be an integral part of the rejuvenation he sought, he raised, in 1816, a private subscription to establish the Calcutta Vidyalaya, the first school open to Indians to offer instruction in both European and Indian subjects in the English language. Seven years later, in a memorandum addressed to the Governor General, Lord Amherst, Roy asserted[5] that

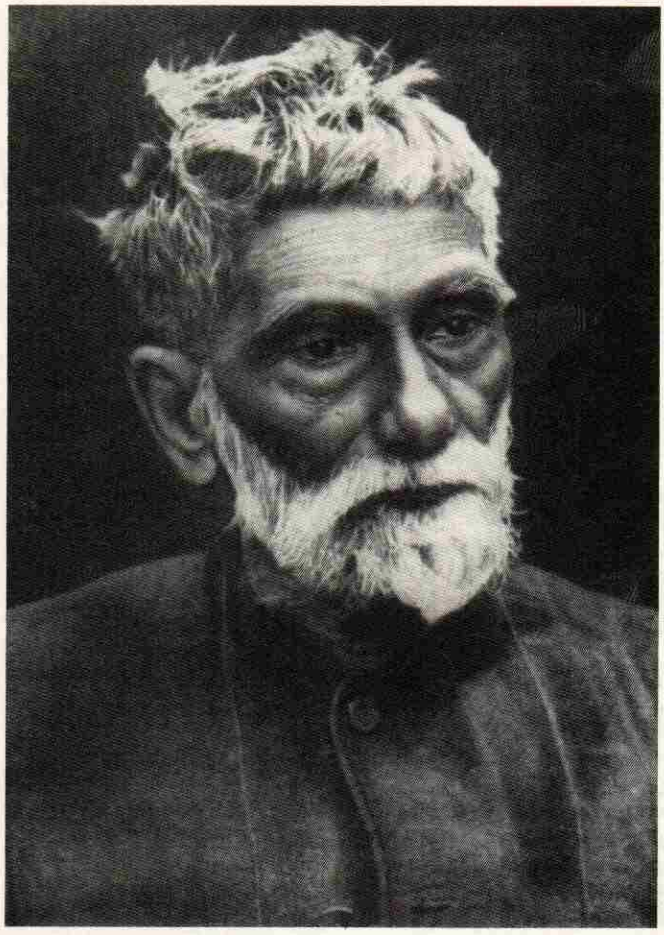
> as the improvement of the native population is the object of the Government, it [should] consequently promote a more liberal and enlightened system of instruction, embracing Mathematics, Natural Philosophy, Chemistry, Astronomy, with other useful sciences.

The first-rate science education Roy aked for was not to be forthcoming for at least another half-century. For by the time he addressed his 1823 memorandum to Lord Amherst, such prominent English intellectuals as James Mill, Charles Trevelyan and Thomas Macaulay and their political allies in the Liberal Party were openly ridiculing the idea that Indian culture had anything of value to offer Europe—or, in the extreme view of Macaulay, anything of value at all! Within another ten years, the colonial government was basing its policy on the explicit presumption that European culture was so innately superior to any Eastern culture that Europe had a moral obligation to impose its institutions wherever it possessed the political power to do so.

Thus when the colonial government began to establish schools, colleges and universities in the mid 18th century, it did so with the objective of training Indians for subordinate civil-service positions rather than providing them with a broadly based liberal education. As a result, throughout the 19th century and well into the 20th century even the best science instruction available to Indians was far from the best that Europe had to offer. Still, there were by 1870 at least three institutions in Calcutta teaching the rudiments of modern science. Judging from the careers of J. C. Bose and P. C. Ray, they must have taught it well enough to encourage an occasional exceptional



M. Sircar founded the *Calcutta Journal of Medicine* in 1868 and the Indian Association for the Cultivation of Science in 1876. Both the journal and the association played important roles in the development of modern science in India.



P. C. Ray (1861–1944) taught chemistry in Calcutta at Presidency College and the University College of Science. He and his students founded several very successful chemical industries.

student to think seriously about a scientific career.

The first of these institutions was the Medical College of Bengal, established by the colonial government in 1835 to train Indians as medical technicians. The Medical College was the first and for many years the only institution in British India with facilities for any real laboratory science.

The second of these notable schools was Presidency College. It was a government-run institution and was affiliated with Calcutta University.

Finally, perhaps the best scientific instruction in Calcutta, and probably in India, was offered[3] at St. Xavier's, a private, Jesuit school. St. Xavier's owed its reputation for excellence in science teaching primarily to its rector, Father Eugene La Font, a Belgian physicist who spent more than 40 years teaching there and became renowned in Calcutta for his public lectures and demonstrations.

La Font was a close friend of Sircar, whose views on the importance of science to the modernization of India I have already cited. Soon after his graduation from the Medical College of Bengal, Sircar scandalized his British mentors and colleagues by openly asserting that European medical theory and practice were not in any *a priori* sense superior to traditional Indian medicine. In an effort to establish Indian medicine on a more scientific basis, he founded, in 1868, the *Calcutta Journal of Medicine*. Three years later this advocate of traditional Indian medicine put forth[6] in that journal a scheme for an "Indian Association for the Cultivation of Science," where young Indians would have the facilities and opportunities to engage in scientific research on the same footing as their European counterparts. Because Sircar saw the association as a key to genuine independence, he insisted that it be established and supported entirely by the Indian community, with the British authorities giving little more than their acquiescence. He campaigned vigorously to raise funds for the association, saw it established in 1876 and fought to expand its scope throughout the remaining 27 years of his life.

Sircar's Indian Association for the Cultivation of Science was the first of two centers of modern science in Calcutta. The second was established through the vision and energy of his younger colleague Astoush Mookerjee, a gifted, published amateur mathema-

tician, judge of the High Court at Calcutta, active member of the Asiatic Society of Bengal and, from 1912 on, vice-chancellor of the University of Calcutta. Mookerjee succeeded in raising sufficient funds, principally among his Bengali compatriots, to establish a college of science at the university. This institution was to be the first in India to offer postgraduate instruction in mathematics and science. The funds raised by Mookerjee were sufficient to endow the first professorial chairs reserved for qualified Indian scientists—among them the Palit Professorships of Physics and Chemistry, whose first two occupants were C. V. Raman and P. C. Ray.

'Tribal leaders'

Thanks to the vision and labor of Sircar, Mookerjee and their supporters, Roy's half-century-old dream that Indians would achieve distinction in world-class science on their own terms now began to be realized. Four of the six pioneers I consider here were among the first faculty of Mookerjee's University College of Science. The oldest of the six, however, was well advanced in his career before that college was established; the youngest was able to build on the others' legacy elsewhere in India.

Jagadish Chandra Bose was the first Indian to establish an international scientific reputation.[7] He was born in 1858 in East Bengal—now Bangladesh—and in 1879 received his bachelor's degree from St. Xavier's College, where he was a protégé of La Font. In 1880 Bose traveled to England with the intention of studying medicine. However, with the encouragement of Lord Rayleigh, he decided instead to enroll in Christ's College, Cambridge, to pursue pure science. He received a BA degree from Cambridge and a BS degree from London University in 1884, and was awarded the DSc degree from London in 1896.

Following his return to Calcutta in 1884, Bose became the first Indian professor of physics at Presidency College, where he remained until he retired from the government education service in 1915. Originally Bose's salary as a professor was only two-thirds of that of British professors with comparable duties; when he discovered this Bose refused to take any salary at all, yet continued to teach on the grounds that teaching was an honor. The government authorities yielded within a year to that particular example of what Gandhi later made famous as "active nonviolence." In 1917 he became director of the Bose Institute, a research institution in Calcutta modeled after the Royal Institution in London and endowed from the proceeds of Bose's investments, private benefactions and a public subscription. He retained that position until his death in 1937. Bose was knighted in 1917 and elected to Fellowship in the Royal Society in 1920.

During the first phase of his research career, which extended until about 1902, Bose was concerned with the generation, reception and optical properties of electromagnetic radiation in the unexplored wavelength range from 5 mm to 1 cm. His first paper, on the polarization of electromagnetic waves by double refraction, was published in 1884 in the *Journal of the Asiatic Society of Bengal*. A refinement and extension of that research was communicated to the Royal Society by Lord Rayleigh a year later. For the next few years Bose carried out detailed investigations of the receiving properties of semiconducting materials and worked on photoconductivity.

In 1895 Bose gave a public lecture at Town Hall, Calcutta, in which he demonstrated for the first time wireless transmission of electromagnetic signals through solid walls; it quickly made him famous throughout Bengal. As a result of that growing fame, the government of Bengal sent him on a nine-month lecture tour of Europe, where in December 1896 he repeated his demonstrations of wireless transmission at the Royal Institution before an audience that included Lord Kelvin. That event anticipated by a year Guglielmo Marconi's more celebrated (and commercially exploited) wireless-transmission demonstrations in the same city.

In 1900 Bose became intrigued by the similarity in the absorptive responses of organic and inorganic matter to centimeter-wavelength radiation. During the next 30 years his research focused increasingly on comparative physiology, particularly plant physiology; he thus qualifies as one of the first biophysicists. For his explorations of the behavior of plants and of plant tissue, Bose devised a set of ingenious instruments to magnify and record extremely small movements in plants.

The colonial government in India recognized and sought to take advantage of Bose's international reputation by sending him abroad as a member of ten scientific delegations between 1896 and 1931. For his part, Bose was conscious of the example he was setting as a leader in the resurgence of Indian culture (and particularly Bengali culture) that Roy had advocated during the 1820s and 1830s.

One important aspect of Bose's cultural leadership was his 30-year friendship with the Nobel Prize-winning poet Rabindranath Tagore, as recorded by their extensive correspondence in Bengali. Bose was among the first to urge that Tagore's work be translated into English. Bose's influence on Tagore's thinking is evident in the textbook entitled *Our Universe*, which the poet wrote in Bengali in 1931 for use at his school at Shanti Nikaten. Remarkable both for its literary quality and for its grasp of the science of that era, this work ranks as a classic in the history of the popularization of science.

Bose himself was a talented poet, and published several articles in Bengali literary journals. He also served for four years as president of the Bengali Literary Society.

Prafulla Chandra Ray, who was born in East Bengal in 1861, was the second most senior of the Calcutta group.[8] After studying for two years at Metropolitan College, Calcutta, he received a scholarship to the University of Edinburgh, where he was awarded a BSc degree in 1885 and a DSc degree two years later for his research in inorganic chemistry. In 1889 Ray received a special appointment as lecturer at Presidency College, Calcutta, where J. C. Bose was already teaching, and soon became professor of chemistry. He remained there until 1916, when Mookerjee summoned him to the University College of Science. There he continued his research and teaching for another two decades, long after he became eligible to retire. He was knighted in 1919.

Ray was first encouraged to pursue research by Sir Andrew Pedlar, principal of Presidency College and a chemist, who is credited with having carried out, during the 1890s, the first significant investigations on the chemistry of cobra venom. With Pedlar's help, Ray raised funds to equip a reasonably good chemistry research laboratory at the college and began a search for some of the missing elements in the periodic table. While engaged in that search he managed to precipitate mercurous nitrite, a compound that had been regarded as unstable, in crystalline form. For several years

C. V. Raman (1888–1970), second from right, during a visit to Niels Bohr's institute in Copenhagen. The others are (from left) George Gamow, Thomas Lauritsen, Bohr, T. B. Rasmussen and Oskar Klein.

thereafter, he and his students carried out a systematic exploration of the properties of mercury salts and a range of nitrite compounds.

Like Bose, Ray lectured abroad on his researches, and his work received international recognition.

In addition to establishing a new school of chemical research, Ray was instrumental in laying the foundations for a chemical industry in Bengal. In 1901 he and a handful of former students started the Bengal Chemical and Pharmaceutical Works, Ltd, which by 1947 had grown into one of India's major chemical firms. He and his students also established the Bengal Pottery Works, the Calcutta Soap Works, the Bengal Enamel Works and the Bengal Canning and Condiment Works. Ray gave much of the money earned in these industrial ventures to workers, to students (as stipends and scholarships), to laboratories and to scientific organizations.

Like Bose, Ray actively promoted the ideals of traditional Indian culture, having abandoned Western dress and manners on his return to India in 1888. He too was a member of the Bengali Literary Society and also served as its president, for two years. His concern with the cultural roots of science is reflected by his scholarship in the history of science. The first volume of his *History of Hindu Chemistry* appeared in 1902 and the second in 1908. He was also an active supporter of the Indian independence movement, often urging greater participation on the part of his students.

Chandrasekhara Venkata Raman was born in 1888 in Tiruchirapalli, in what is now the state of Tamil Nadu.[9] He received his BA degree from the Hindu College of Vishakapatnam (where his father taught physics and mathematics) and his MA from Presidency College, Madras. Failing to find a position in which he could use his scientific talents, Raman joined the Indian Finance Department in 1907 and was assigned to a position in Calcutta, where (with brief interludes) he served for ten years. He discovered the Indian Association for the Cultivation of Science soon after his arrival in Calcutta, and began to conduct research there before and after his working hours at the finance department. By 1917, when Mookerjee appointed him to the Palit Professorship of Phyics at the University College of Science, he had authored or coauthored 25 papers published in *Nature*, the *Philosophical Magazine* and the *Physical Review*. Raman became Honorary Secretary of the Indian Association for the Cultivation of Science in 1919 and converted the association into the principal research arm of the College of Science.

Initially Raman's research focused on vibrations and sound and on the theory of musical instruments, particularly the violin family and Indian drums. That research led to his election to Fellowship in the Royal Society in 1924. Beginning in the early 1920s his interests turned increasingly to physical optics, a field that was to absorb him throughout his life. His interest in optics appears to have derived in large measure from his fascination with the aesthetics of color. For example, during the course of a round-trip voyage to England in 1921 he became intrigued by the color of the sea. He convinced himself that its blue color cannot be ascribed completely to Rayleigh scattering. Fascinated with the aesthetic problem, he conducted[10] a series of experiments immediately after returning to Calcutta that led to the first adequate explanation of the sea's color.

Raman's early research in physical optics was concerned with the scattering of light by gases and liquids. Later he turned his attention to the optical properties of crystals, and—after 1950—particularly the optical properties of gems and minerals. His early investigations of crystal optics also led him to explore new approaches to the dynamics of crystal lattices, explorations that he carried over into his studies of gems. During the last years of his life, he focused[11] much of his attention on the physiology of vision. Although his ideas about color perception are provocative, most of his research in this field has been dismissed by contemporary physiologists.

Raman's best-known research contributions were an outgrowth of his research on the Compton effect in 1927. Having derived a semiclassical explanation of Compton scattering that attributed the wavelength shift of x rays to the dynamics of the scattering electrons in their planetary orbits, Raman supposed that there might be an analogous wavelength shift in the molecular scattering of visible light, arising from dynamic fluctuations in the structure of the scatterers. These considerations led him to discover what is now called Raman scattering. An ardent nationalist, Raman first announced his discovery at the March 1928 meeting of the South Indian Science Association in Bangalore. It earned him a knighthood in 1929 (which he later resigned because of his strong nationalistic sympathies) and the Nobel Prize in 1930.

In 1933 Raman left his professorship in Calcutta for the privately endowed Indian Institute of Science in Bangalore, in the present state of Karnataka, where he served as president until 1937 and as head of the physics department until 1948. During these years his research interests turned to the diffraction of light by ultrasonic and hypersonic waves, Brillouin scattering and the scattering of light by colloids. After retiring from the institute he became director of the newly established Raman Research Institute in Bangalore, and retained that position until his death in 1970.

Raman was instrumental in establishing, in 1934, the Indian Academy of Sciences, and served as editor of its proceedings until 1969. Like all the Calcutta pioneers, he was noted as a great teacher and considered it "the principal function of the older generation of scientific men . . . to discover talent and genius in the younger generation and to provide ample opportunities for its expression and expansion." Although he was convinced that science had to play a central role in the economic development of India, there is little doubt that it was also his conviction that science had to be pursued because it is integral to culture. As he said[12] in 1951, "Science is the fusion of man's aesthetic and intellectual function devoted to the representation of nature. It is therefore the highest form of creative art."

Satyendranath Bose was born in Calcutta in 1894; in 1909 he entered Presidency College, Calcutta, where his teachers included J. C. Bose and P. C. Ray.[13] He received his MSc degree in mixed mathematics in 1915, ranking first in his class, with his classmate M. N. Saha ranking second. In 1916 Mookerjee appointed him and Saha as lecturers at the University College of Science. Two of his first four published papers (which were on statistical mechanics) were coauthored with Saha,

AIP NEILS BOHR LIBRARY: M. BOHR COLLECTION

and he and Saha translated Einstein's papers on special and general relativity in 1919; that translation, published by Calcutta University Press, was one of the first complete anthologies of those papers in English.

Bose left Calcutta in 1921 to become reader in physics at the newly established University of Dacca. Three years later, in July 1924, he sent a short manuscript entitled "Planck's law and the light-quantum hypothesis" to Einstein for criticism. In it Bose developed a method for deriving the Planck blackbody-radiation law without any reference to classical electromagnetic assumptions, a problem that had defied European physicists for almost 20 years. Einstein personally translated the paper into German for publication in the *Zeitschrift für Physik*, and in a later paper extended the ideas to particles with nonzero mass.

Einstein's endorsement of his work earned Bose a two-year paid leave from Dacca to study in France and Germany. During his year in France he conducted experimental studies on radioactivity under Paul Langevin and became closely associated with Maurice and Louis de Broglie. In late 1925 he had a brief and (by his own account) cordial meeting in Berlin with Einstein, whose interests by then had turned away from the statistics of identical "bosons."

Although the two years Bose spent in Europe witnessed the most pivotal developments in 20th-century physics, they do not appear to have had any direct influence on his subsequent research. His 26 published papers include contributions to statistical mechanics, ionospheric electromagnetism, x-ray crystallography and thermoluminescence.

Bose returned from Europe in 1926 to become head of the physics department at Dacca. He stayed there until 1945, when he returned to Calcutta as Khaira Professor of Physics. He was elected to Fellowship in the Royal Society in 1958.

As a teacher, Bose strongly encouraged his students, and often subsumed his own research contributions into papers bearing only the students' names.

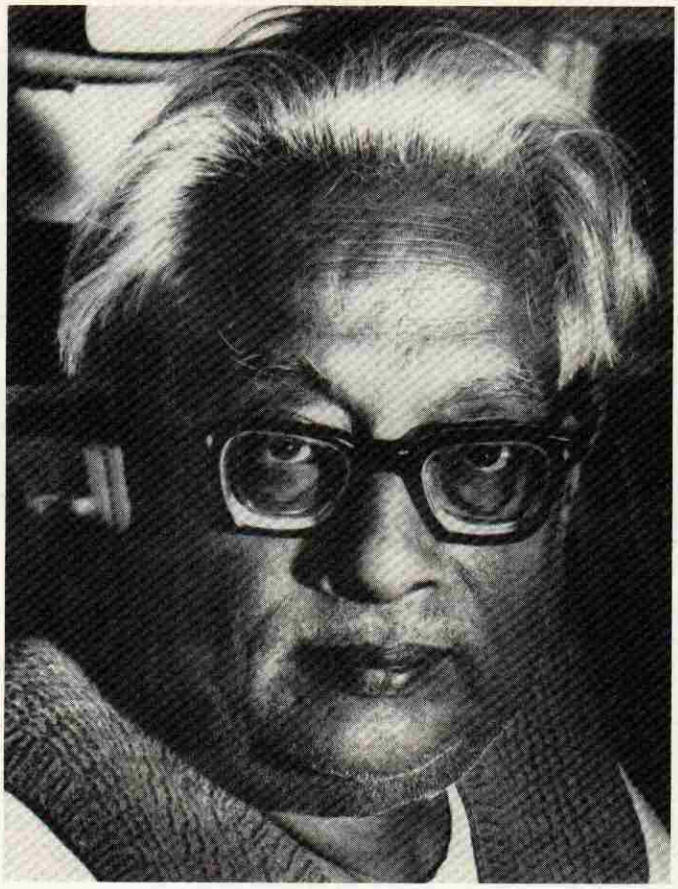
He was deeply attached to and knowledgeable about the history and culture of India, stating on one occasion that he revered Gautama Buddha above all other human beings. He was a staunch supporter of Tagore's Bengali cultural-renaissance movement and, like Tagore, loved poetry, which he read and quoted in Bengali, Sanskrit, English and French. In 1948 he founded the Science Association of Bengal as a means for popularizing science in his native language.

Meghnad Saha, born in East Bengal in 1894, was the most politically active of the Calcutta pioneers.[14] As I have mentioned, he received his undergraduate training at Presidency College, Calcutta, where his classmates included, besides S. N. Bose, P. C. Mahalanobis, who became founder and moving spirit of the Indian Statistical Institute; Rajendra Prasad, later the first President of India; and Subas Chandra Bose, who became one of Jawaharlal Nehru's most serious rivals for leadership of the Indian National Congress. Saha was appointed lecturer at the University College of Science in 1916. His first publications, which qualified him for a DSc from Calcutta in 1918, dealt with electromagnetic theory, radiation pressure and the theory of stellar spectra.

In 1919 Saha was awarded a fellowship that enabled him to spend two years in Europe: five months with Norman Lockner and Alfred Fowler at the Royal College of Science in London, and the balance of the time with Hermann Nernst at the University of Berlin. He returned to Calcutta in 1921 as the first Khaira Professor of Physics, but relinquished that position in 1923 to become professor of physics at the University of Allahabad, in the city that was the home of the Nehru dynasty. During his 15 years at Allahabad, he devoted a great deal of attention to teaching and organizing research in statistical mechanics, atomic and molecular spectroscopy, high-temperature dissociation of molecules and the physics of the upper atmosphere. Saha returned once more to Calcutta in 1938 as Palit Professor of Physics; there his research interests centered on nuclear systematics, the propagation of electromagnetic waves in the ionosphere, and the solar corona. When he retired from the university in 1953, he was appointed as the first Director of Laboratories at the Indian Association for the Cultivation of Science. He was elected to Fellowship in the Royal Society in 1928.

Saha's most original and significant scientific contribution was his research on the theory of high-temperature ionization and its application to stellar atmospheres and spectral classification. He began this work in Calcutta in 1919 and developed and refined it during his two years in Europe and the first years after his return to India. It remains the basis of much work on stellar atmospheres.

Saha began to become seriously interested in the use of science for economic development and national planning in the early 1930s, recognizing that a prerequisite would have to be the establishment of a closely linked network of modern research facilities. By that time he was already engaged in making Allahabad one of the most active centers of research in physics in the country. He established, in 1948, the Institute of Nuclear Physics at Calcutta University (which was renamed the Saha Institute after his death), and he improved the research facilities at the Indian Association for the Cultivation of Science. He also



S. N. Bose (1894–1974) was educated in Calcutta and taught in Dacca (from 1921 to 1945) and in Calcutta (until 1952). His research concentrated on statistical mechanics, electromagnetism and crystallography.

attempted to link the scattered university research centers in India into a strong national scientific community, but largely failed in those efforts because of a chronic lack of funds, a paucity of well-trained scientists and the bureaucratic organization of the university system.

In 1935 Saha founded *Science and Culture*, a journal he was to use for the next 21 years as a means for airing his incisive views on such topics as national planning, public-sector industrialization, hydroelectric and nuclear power, and the modernizing role of science and technology—as well as on Indian art, archeology and science in the ancient and medieval periods. Beginning in 1938 he served as a member of the Planning Committee of the Indian National Congress, headed by Nehru, and from 1942 on he was a charter member of the Council for Scientific and Industrial Research. Saha was elected to the Lok Sabha (the lower house of Parliament) in 1951 as an independent, and frequently used that forum to criticize many of the government's policies for science, technology and development until his sudden death from a heart attack in 1956.

Saha had a serious amateur interest in Indian history and archeology, and published several scholarly papers in those fields. He was also an excellent teacher with the ability to provide his students with the breadth and confidence required to branch out in new directions. Many of his students and younger colleagues went on to play significant national and international scientific and science-policy roles in their own right.

Homi Jehangir Bhabha was born in 1909 in Bombay.[15] He was connected through the marriage of a maternal aunt to the Tata industrial family of Bombay and that association provided him with an understanding of business and industry. Likewise, his association with Cambridge University was to help give him access to Nehru, who was also a Cambridge alumnus. Both the Bhabha and Tata families were nationalists and received some of the most important of the independence-movement leaders, including Mahatma Gandhi, in their homes.

Bhabha enrolled in Gonville and Caius College, Cambridge, in 1927, where he expected to study mechanical engineering in preparation for an industrial career with the Tata enterprises. However, his obvious talent and preference for pure science led him to a BA degree in theoretical physics in 1930; Paul A. M. Dirac served as one of his tutors. He received his PhD in 1935 for research at the Cavendish Laboratory, Cambridge, on cosmic-ray-produced electron showers. Bhabha's research activities continued to revolve around the Cavendish until 1939, but he also traveled extensively on the continent, where he paid extended visits to Enrico Fermi's group in Rome, Wolfgang Pauli's group in Zurich and Niels Bohr's institute in Copenhagen.

Bhabha's most notable research contributions during his years in Europe included the first calculation (done with Werner Heitler in 1937) of the cross section for the production of electron–positron pairs by fast primary electrons, the first suggestion (1938) that the behavior of the observed "penetrating" particles in cosmic-ray showers could be attributed to "heavy electrons" (later identified as muons) and the first suggestion that the observed lifetime of muons should be governed by relativistic time dilation. Heitler was later to remark that the 20 scientific papers Bhabha published prior to 1939 were in themselves sufficient to have earned him a lasting reputation in theoretical physics. He was elected to Fellowship in the Royal Society in 1940.

Bhabha was vacationing in India at the outbreak of World War II in 1939. Unable to return to Cambridge, he accepted a readership in physics at the Indian Institute of Science in Bangalore and in 1942 was appointed professor of cosmic-ray physics.

The institute had been founded in 1909, largely through a donation by Sir Jamshediji Tata, a Bombay industrialist who, like several of his Calcutta contemporaries, believed that modern science held the key to India's self-reliance. In 1933, as I have mentioned, the institute lured C. V. Raman away from his Palit Professorship in Calcutta. With Raman's support and through his own Tata connections, Bhabha used his position in Bangalore to argue forcefully for development of a scientific and technological infrastructure for India.

In March 1944 he proposed to the Tata Trust the establishment of an institution that would be devoted to advanced research and teaching in mathematics and physics, particularly cosmic-ray and nuclear physics. He conceived of the institute as both a world-class center for basic research and an incubator for new types of industrial enterprises. The Tata Institute for Fundamental Research was

M. N. Saha (1893–1956), seated at center, in middle row, with his students at Calcutta University. Saha also taught at the universities in Dacca and Allahabad. He worked on nuclear physics, astrophysics and statistical mechanics.

founded at Bangalore in June 1945 with Bhabha as its first director, and set up temporary quarters in Bombay in December of that same year.

Bhabha was a strong advocate of a nuclear-power electrical system. When the Indian Atomic Energy Commission was established in 1948, Bhabha was made its chairman. The commission conducted most of its early research and development work at the Tata Institute. In 1954 the commission was reorganized as the Department of Atomic Energy, with Bhabha as its secretary; that same year Bhabha was appointed director of the Atomic Energy Research Center, construction of which was just getting under way at Trombay, a Bombay suburb.

Bhabha, a staunch advocate of international cooperation in science and technology, concluded agreements with the United Kingdom, Canada, France and the United States for assistance in developing the Indian atomic-energy program. He was the unanimous choice for the position of president of the First International Conference on Peaceful Uses of Atomic Energy, held in Geneva in 1955. He became a governor of the International Atomic Energy Agency at Vienna (established as one result of the Geneva conference) and a member of the Scientific Advisory Committee to its secretary-general. He died in January 1966 when an airplane carrying him to a meeting of that committee crashed on Mount Blanc.

Bhabha conducted research until he became Secretary of the Department of Atomic Energy, authoring or coauthoring more than 60 papers in cosmic-ray physics, nuclear physics and meson theory between 1933 and 1954. Although he engaged in formal teaching only during his years in Bangalore, his influence on his contemporaries and younger colleagues at the institutions he established was enormous and lasting. He also had considerable influence with Nehru, who came to rely heavily on his scientific advice.

Bhabha had a deep aesthetic attachment to both music and art. As a boy he had learned to appreciate Western classical music by listening to the extensive record collections of his grandfather and aunt, and he refined that appreciation and knowledge during his years in Europe. Upon his return to India he began to immerse himself in the study of Indian classical music, and later he became a patron of contemporary Indian art. He personally selected the permanent sites of the Tata Institute and of the Trombay Atomic Research Center, and worked closely with the architects in designing both complexes.

Physics and development

While it is hazardous to generalize from six cases, three conclusions suggest themselves:

- Basic research conducted in less developed countries, under far from optimal conditions, can contribute significantly to international scientific progress.
- Basic-research activity can also make substantial contributions to the less developed country itself.
- The contributions to the country most frequently do not flow directly from the results of the research.

For example, the results of J. C. Bose's research on centimeter-wavelength radiation were certainly applicable to the radio communications industry. But neither Bose nor any other Indian scientist was involved significantly in the development of that industry, even though some of Bose's critical results probably anticipated Marconi's. Likewise, a 1930 prediction by Rutherford that Raman scattering would become a powerful analytical tool turned out to be correct, but India reaped no direct economic benefits from it.

Of course there is nothing particularly novel or unusual about the fact that Bose's and Raman's results were exploited elsewhere and after a considerable lapse of time. But it does suggest that the value of basic research to a less developed country—or to any country—cannot be assessed in terms of how well that country succeeds in capturing for commercial purposes the results of the basic research conducted within its borders. The ability of a less developed country to capture basic-research results that originate elsewhere may be a far better measure of its scientific capabilities. And as Bhabha persuasively argued and later demonstrated, training in basic research can provide the breadth and flexibility required to recognize promising scientific leads, wherever they arise.

Of all the physicists I have discussed, perhaps the least influential was S. N. Bose. Despite Einstein's favorable impression of his early research, he made no obvious direct contributions to the development of India's science-and-technology infrastructure, possibly because he largely remained isolated in Dacca except for the two years he spent in Europe in the mid-1920s. In that respect his career bears at least some superficial similarities to the earlier career of Josiah Willard Gibbs, whose profound contributions to thermodynamics while he was a professor at Yale remained largely unrecognized in the United States during his own lifetime. Indeed the case of Bose (and that of Gibbs before him) provides a graphic illustration of the plight of the isolated scientist in a less developed country—a general point made repeatedly by Salam.

Physics and culture

The careers of all the scientists I have discussed demonstrate the aptness of Needham's metaphor likening science to a great river that has re-

AIP NEILS BOHR LIBRARY

H. J. Bhabha (1909–1966) was instrumental in establishing India's atomic-energy program. An advocate of international cooperation in science, he presided over the conference that established the International Atomic Energy Agency.

ceived contributions from the separate streams of many different cultural traditions. Modern science thus need not conflict with the cultures from which those other scientific contributions sprang, but rather should reinforce the liberating cultural traditions of any society. Perhaps the connection between what these six men saw as the value of basic research and the necessity of basing modern science in India on Indian cultural traditions is simply this: At its best basic research aims to satisfy human curiosity. But curiosity is among the most innate and universal of human characteristics, so its systematic and disciplined pursuit need not do violence to any culture. On the contrary, it should harmonize with the best of that culture.

If this proposition has any merit, then perhaps the encouragement of basic research in a less developed country is a necessary precondition for the establishment of a stable basis for a modern technology. Sircar emphasized[16] this point in one of his earliest appeals for support for the Indian Association for the Cultivation of Science:

> We are so constituted that we must either go forward, or be driven backward; we cannot remain stationary. There is an immense difference between the civilized man and the man happening to live in civilized times. Such incidents of birth will never endow us with the privileges of the times in which we live, unless we render ourselves worthy of the same.

More than three centuries earlier, at the very birth of modern science in Europe, Francis Bacon concluded[17] the preface to his *Novum Organum* with a stern warning to those who aspired to pursue his vision of a new experimental philosophy:

> Lastly, I would address one general admonition to all; that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of mind, or for contention, or for superiority to others, or for profit, or fame, or power, or any of these inferior things; but for the benefit and use of life; and that they perfect and govern it in charity.

Nehru, at one with the visionaries and pioneers who laid the foundations for modern science in India, believed that his country was particularly well equipped to heed Bacon's admonition to "perfect and govern [knowledge] in charity." In view of the vital importance that science has now assumed throughout the world, the ways in which India struggled and still struggles with the problem are worth pondering. But one may still ask, why pursue basic research in a less developed country? J. C. Bose's friend Tagore gave[18] an answer:

> Whoever wishes,
> May he sit in meditation
> With eyes closed
> To verify if the universe be true or false.
>
> I, in the meanwhile,
> Shall sit with insatiate eyes
> To see the universe
> While the light lasts.

This article is adapted from a paper presented at a symposium entitled From Ancient Traditions to the 21st Century: The Development of Science in India, *held at the Chicago Museum of Natural History on 10 August 1985.*

References

1. M. G. K. Menon, Current Science, 20 January 1982, p. 77.
2. A. Salam, Minerva **4**, 461 (1966).
3. A. K. Biswas, *Science in India*, Mukhopadhyay, Calcutta (1969).
4. W. A. Blanpied, Jpn. Studies Hist. Sci., No. 12, 128 (1973).
5. S. D. Collet, *The Life and Letters of Raja Ram Mohun Roy*, Sadharan Brahmo Samaj, Calcutta (1900).
6. M. Sircar, Calcutta J. Med. **2**, 286 (1869).
7. For biographical information on J. C. Bose, see: C. Susskind, in *Dictionary of Scientific Biography*, vol. 2, Scribner's, New York (1970), p. 325; P. Geddes, *Life and Work of Sir J. C. Bose*, Longmans, Green, London (1920); M. Gupta, *Jagadish Chandra Bose, A Biography*, Bharatiya Vidya Bhavan, Bombay (1944); M. N. Saha, Obit. Not. Fellows R. Soc. **3**, 3 (1939–41).
8. For biographical information on P. C. Ray, see: ref. 3; V. V. Raman, in *Dictionary of Scientific Biography*, vol. 11, Scribner's, New York (1975), p. 318.
9. For biographical information on C. V. Raman, see: J. Mehra, in *Dictionary of Scientific Biography*, vol. 9, Scribner's, New York (1975), p. 264; S. Bhagavantum, Biog. Mem. Fellows R. Soc. **17**, 565 (1971); S. Ramaseshan, ed., *The Scattering of Light: The Scientific Papers of Sir C. V. Raman*, Indian Academy of Sciences, Bangalore (1978).
10. C. V. Raman, Proc. R. Soc. London, Ser. A **101**, 64 (1921).
11. C. V. Raman, *The Physiology of Vision*, Indian Academy of Sciences, Bangalore (1958).
12. C. V. Raman, *The New Physics*, Philosophical Library, New York (1951).
13. For biographical information on S. N. Bose, see W. A. Blanpied, Am. J. Phys. **40**, 1212 (1972).
14. For biographical information on M. N. Saha, see: W. A. Blanpied, Pacific Affairs **50**, 91 (Spring 1977); D. S. Kothari, Biog. Mem. Fellows R. Soc. **5**, 217 (1960).
15. For biographical information on Homi Bhabha, see: W. A. Blanpied, Pacific Affairs **50**, 91 (Spring 1977); J. Cockcroft, Proc. R. Inst. G. B. **41**, part IV, 411 (1966); M. G. K. Menon, Proc. R. Inst. G. B. **41**, part IV, 423 (1966).
16. M. Sircar, Calcutta J. Med. **4**, 1 (1871).
17. R. Bacon, *The New Organon*, Bobbs–Merrill, Indianapolis (1960), p. 15.
18. R. Tagore, *Our Universe*, I. Dutt, translator, Jaico, Bombay (1969). □