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Famous Indian Scientists
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This article is under development.

An attempt is made here to acknowledge the world-leading contribution made by Indian scientists and to register our deep respect. The story weaved here so far relates to modern scientists : the first paper by JC Bose, the path-finding hero of this story, appeared in *Proc. R. Soc. Lond.* in 1895.

Indians are also indebted to the contribution made by social reformers like Rammohan Roy, Ishwar Chandra Vidyasagar and Swami Vivekananda, which created the social and cultural enlightenment that was necessary for inspiring and sustaining the objective scientific investigations of world-leading scientists like Jagadish Chandra Bose (1858-1937), Meghnad Saha (1893-1956), Satyendra Nath Bose (1894-1974) and CV Raman (1888-1970). Each one in this list of scientists was eminently worthy of the Nobel Prize; it is a tragedy for India that three of them did not receive it.

Bengal was then the centre of learning in India and all four have been nurtured by the exciting cultural environment of Bengal; all four have been associated with the University of Calcutta. It was the time of visionaries : Amrit Lal Sircar allowed CV Raman - then a civil servant - to carry out research at the Indian Association for the Cultivation of Science situated in Calcutta (IACS having been founded by Dr Mahendra Lal Sircar in 1876); Sir Ashutosh Mukherjee - the vice-chancellor of Calcutta University, having dual Masters degree in mathematics and physical sciences - appointed CV Raman as the Palit Professor there, and appointed Meghnad Saha and SN Bose as lecturers. Saha later became the Khaira, then the Palit Professor of Physics. SN Bose later moved to University of Dhaka but rejoined University of Calcutta as a Professor at the time of partition of Bengal and India. Jagadish Chandra Bose was already a Professor at Presidency College of University of Calcutta, and has been a teacher of M Saha and SN Bose who were class-mates. Prafulla Chandra Roy (1861-1944), a chemist of international reputation, taught at first at Presidency College, then he moved to the Science College of University of Calcutta as the Palit Professor of Chemistry. Like JC Bose, PC Roy was also an institution by himself under whose guidance modern Indian science grew. Like JC Bose, PC Roy too inspired generations of students. PC Roy also encouraged entrepreneurship - he himself founded the Bengal Chemicals and Pharmaceuticals, India's first such company. This was the golden period for science in Bengal and India.

Acharya Sir Jagadish Chandra Bose, FRS, (1858-1937)

Natural Science Tripos from Christ's College at Cambridge University.

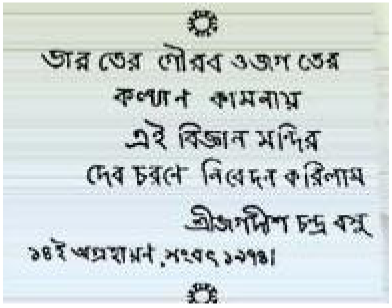
Jagadish Chandra Bose was one of the greatest and most versatile scientists that India has ever produced. He was a Bengalee polymath, a first-rate inventor. He worked as a professor of physics at the Presidency College of University of Calcutta. He had to overcome discrimination (under British rule), and lack of fund and equipment, to carry out pioneering research in several fields and laid down the foundation of modern experimental science in India. IEEE has recognised him as one of the fathers of radio science.

Physics:	• **Pioneering research on radio and microwave optics.** • **Discovery of millimetre-length electromagnetic waves. Research of remote wireless signalling.** • **Invention of the first wireless detection device. He was the first to use semiconductor junctions to detect radio signals.** • **2 years before Marconi, he gave a public demonstration of remote wireless signalling and detection.**

Biology, Biophysics:	• **Invention of crescograph.** • **Experiments on plant response to various stimuli including sound, wound, chemical agents and microwaves.** • **Electrical nature of transmission of various stimuli (rather than chemical nature).** • **Similarity of organic and inorganic matter in response to stimuli.** • **Theory of ascent of sap in plants involving electromechanical pulsations of living cells.**

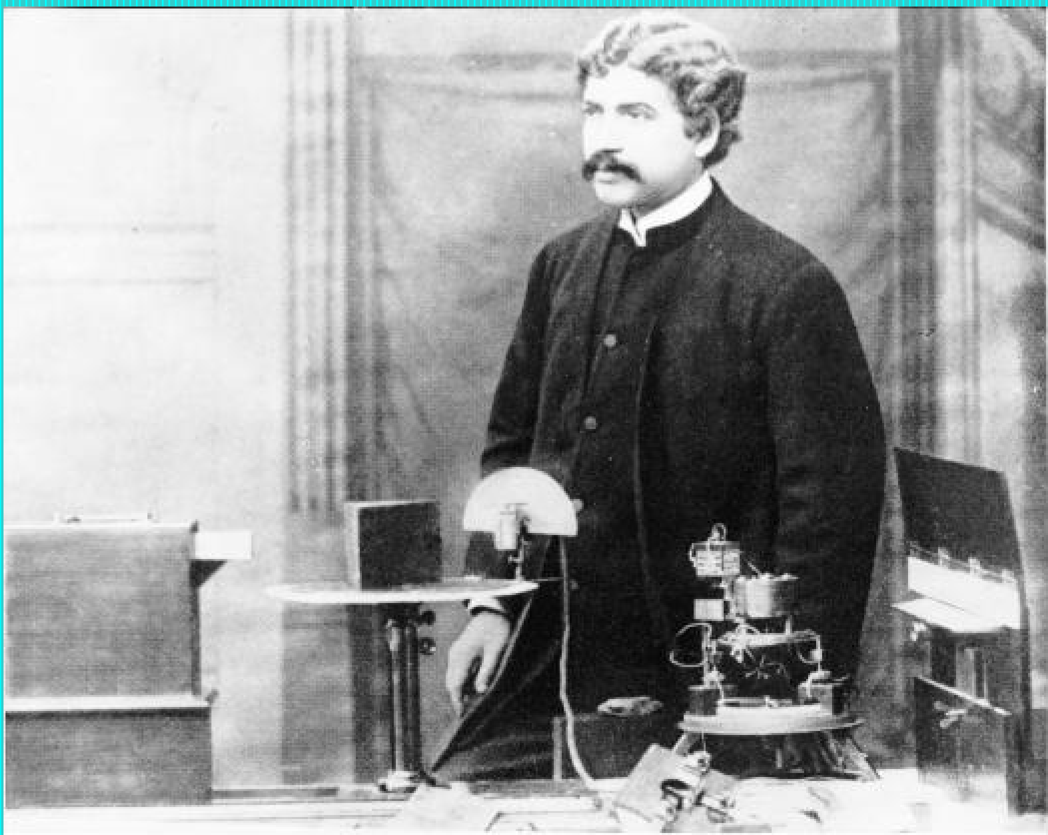
A list of his research papers and books is compiled by Abhijit Guha. According to the literature search by the present author, JC Bose wrote at least 32 articles in prestigious journals - 14 articles in *Proc. R. Soc. Lond.*, 5 articles in *Proc. R. Soc. Lond. B*, 1 article in *Phil. Trans. R. Soc. Lond. B*, 9 articles in *Nature*, 3 articles in *Proc. R. Soc. Med.* -, among others. Most of his research articles were single-authored. He wrote several science monographs (books) - 18 have been included in the list. He also created the genre of Bengali science fiction. It is an astonishing and awe-inspiring list of contribution.

JC Bose was against patenting inventions, it was Swami Vivekananda who arranged to file a Patent on behalf of JC Bose, "Detector for electrical disturbances, 1904, US Patent 755840" - the first US patent by an Indian.



JC Bose founded the Bose Institute in Calcutta on 30th November 1917. On this occasion, he delivered an address entitled "The Voice of life" and dedicated the institute to the nation. JC Bose wrote in Bengali (see the picture on the right) a sentence while dedicating the Bose Institute that encapsulates his Rishi-like attitude towards science, which is utterly inspirational for all of us. The sentence may be translated as :"I am dedicating this temple of science at the God's feet for the glory of India and the benefit of the world". The Bose Institute has a museum where some of the experimental apparatus developed by JC Bose are on display. The ingenuity displayed is awe-inspiring - one of the polarizers is made of twisted jute, another consists of a book (Bradshaw's Railway Timetable) interleaved with tinfoils; countless similar examples reinforce that internal inspiration, not material resources, is the first ingredient for attaining excellence.

Since 1993, INSA and The Royal Society have been jointly organizing the annual Blackett Memorial Lecture (in India) and Sir JC Bose Memorial Lecture (in UK).



In 1895 JC Bose gave a public demonstration in Calcutta on remote wireless signalling and detection. The Daily Chronicle of England reported this public demonstration in 1896: "The inventor (J.C. Bose) has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel." Being invited by Lord Rayleigh, JC Bose travelled to England in 1897 and gave lectures on his millimetre-wave research at the Royal Institution, London and other societies. The picture above is of JC Bose with his apparatus at the Royal Institution in January 1897.

Meghnad Saha, FRS, (1893-1956)

Saha Equation, Thermal Ionization, Astrophysics, Stellar Spectroscopy.

Saha worked with A. Fowler at Imperial College London and worked for one year at Nernst's Laboratory in Germany.

Meghnad Saha published 17 papers in *Philosophical Magazine*, 4 papers in *Physical Review*, 2 in *Proc. R. Soc. Lond.*, 25 in *Nature*, 1 in *Astrophysical Journal*, 1 in *Z Phys*, 7 in *Proc. Nat. Inst. Sci. Ind.*, among others. He wrote a famous book entitled *A Treatise on Heat*.

Note that Meghnad Saha lived for 63 years only (as compared to 79 years for JC Bose, 80 years for SN Bose, 82 years for CV Raman). This fact should be considered to appreciate fully the achievements of Meghnad Saha, both in the quality and amount of his published work and in the tremendous organizational efforts needed to establish so many institutes of distinction (see below).

The Saha Equation for a gas of single atomic species is generally written as:

$$\frac{n_{i+1}\, n_e}{n_i} = 2\frac{G_{i+1}}{G_i}\frac{(2\pi m_e kT)^{3/2}}{h^3}\exp\left(-\frac{\chi_i}{kT}\right)$$

Where, two ions, "*i*" (i.e. with *i* electrons removed) and "*i*+1", of the same element are considered. The number densities of the two types of ions and free electrons are n_i, n_{i+1} and n_e respectively. χ_i is the ionization potential of state *i* (to reach state *i*+1), ground to ground level. G_i and G_{i+1} are respectively the partition function of the ionization state *i* and *i*+1. m_e is the mass of an electron. T is the temperature, k is the Boltzmann constant and h is the Planck's constant.

Saha published his first paper (single-authored) in 1917 in *Physical Review* at the age of 24. Between the years 1917 and 1927, he published 3 papers in *Physical Review*, 16 papers in *Philosophical Magazine*, 1 in *Proc. R. Soc. Lond.*, 5 in *Nature*, 1 in *Z. Phys.*, 1 with *Royal Astronomical Society* - an amazing decade of outstanding output. Saha wanted to verify his theory of Thermal Ionization, for which high-temperature experimental facility was needed. This is why he went to the laboratory of the Nobel Laureate Nernst and spent a year there. The deduction of the now famous Saha Equation is given in one of his 1920 paper: Meghnad Saha, "Ionization in the solar chromosphere", *Philosophical Magazine* Series 6, vol 40, issue 238, October 1920, 472-488. Saha published this celebrated paper, which strongly influenced the development of modern astrophysics, when he was only 27 years old, working in isolation in Calcutta, India, which had barely any scientific facility (such as a good library). One year later Saha published another paper in the Proceedings of the Royal Society, that included his work conducted in India as well as his work (of about four months) at the Imperial College London, incorporating A Fowler's new data. Saha wrote "I had the advantage of Professor Fowler's criticism, and access to his unrivalled stock of knowledge of spectroscopy and astrophysics". We quote the following excerpt from this 1921 paper:

M.N. Saha, "On a physical theory of stellar spectra", *Proc. R. Soc. Lond. A.*, 1921, vol 99, 135-153, doi: 10.1098/rspa.1921.0029.

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The equation of the reaction-isochore for calculating the equilibrium is*

$$\log \frac{x^2}{1-x^2} \mathrm{P} = -\frac{\mathrm{U}_1}{2{\cdot}3\,\mathrm{RT}} + \frac{5}{2} \log \mathrm{T} - 6{\cdot}5. \qquad (5)$$

Where x = fraction ionised, P = total pressure.

Calculations for the ionisation of Ca, Sr, Ba, Mg, Na, K, Rb, Cs, H, He, will be found in the papers A and B.

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4. *Theory of Second-step Ionisation.*

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neutral Ca-atoms is vanishingly small, we can put $x+y = 1-\epsilon$, where ϵ is a small fraction. The equation (8) then takes the form

$$\log \frac{\mathrm{P}y^2}{(1-y)(2+y)} = -\frac{\mathrm{U}_2}{2{\cdot}3\,\mathrm{RT}} + \frac{5}{2} \log \mathrm{T} - 6{\cdot}5. \qquad (8')$$

* M. N. Saha, "Ionisation in the Solar Chromosphere" (A), 'Phil. Mag.,' October, 1920; "Elements in the Sun" (B), December, 1920; "On the Temperature-Radiation of Gases" (C), February, 1921; "On Electron-Chemistry and its Application to Problems of Radiation and Astrophysics" (D), 'Journ. Ind. Ast. Soc.,' July, 1920.

Other than establishing the physics of Thermal Ionization, Saha also pioneered the idea of Selective Radiation Pressure in one of his article in *Nature* (1925), the idea was later expanded by Milne. Saha was also the first to convert the Harvard Scale of Alphabets for stellar spectra into a temperature scale based on the spectral information. This idea was later expanded by RH Fowler and Milne. Saha's contribution on this aspect is contained in his 1921 paper in *Proc. R. Soc. Lond.*, in conclusion of which he wrote: "The work thus corroborates Russell's view that the continuous variation of stellar spectral types is mainly due to the varying values of the temperature of the stellar atmosphere, and the classification B, A, F, G, K, M, which has been adopted by the Harvard Astrophysicists, as the result of long years of study and observation, are therefore seen to acquire a new physical significance."

Meghnad Saha founded the National Academy of Sciences, India (NASI) in Allahabad in 1930.

He founded the National Institute of Sciences, India, in Calcutta in 1935. In May 1946, the headquarter was shifted to New Delhi, and in 1970, the name was changed to Indian National Science Academy (INSA).

He established the Institute of Nuclear Physics in 1947 in Calcutta; the institute has later been renamed after him as the Saha Institute of Nuclear Physics (SINP).

Satyendra Nath Bose, FRS, (1894-1974)

Bose-Einstein Statistics.

SN Bose, "Plancks Gesetz und Lichtquantenhypothese", *Zeitschrift für Physik* 26:178-181 (1924). (The German translation of Bose's paper on Planck's Law and the Hypothesis of Light Quanta).

Bose worked for one year in France with Marie Curie, one year in Berlin with Einstein.

The Bose-Einstein Statistics determines the statistical distribution of indistinguishable bosons over energy states at thermal equilibrium.

$$n_i = \frac{g_i}{\exp((\varepsilon_i - \mu)/kT) - 1}$$

Where, $\varepsilon_i > \mu$, n_i is the number of particles in an energy state *i*, g_i is the degeneracy of state *i*, ε_i is the energy of the *i*-th state, μ is the chemical potential, k is the Boltzmann constant and T is the absolute temperature.

The Bose-Einstein statistics is applicable when quantum effects are important; like the Fermi-Dirac statistics (applicable to fermions), the Bose-Einstein statistics reduces to the classical Maxwell-Boltzmann statistics at high temperature or low concentration.

SN Bose published only a few papers in his life - 14 of them could be traced while writing this article: of these 1 in *Z. Phys.*, 2 in *Philosophical Magazine*, 1 in the *J. Lond. Math. Soc.*, 1 in *Annals of Mathematics*, 4 in French journals (*Bulletin de la Société Mathématique de France*, *Journal de Physique et le Radium*), 2 in *Sankhya*, 3 in IACS publication.

Meghnad Saha and Satyendra nath Bose were approximately of the same age, they were class-mates, both were taught by JC Bose and PC Roy. M Saha and SN Bose wrote only one paper together ("Intelligence and miscellaneous articles on the equation of state", *Philosophical Magazine*, vol 39, issue 232, April 1920, p 456) - this was the first publication of SN Bose. (By this time Saha had published several articles in prestigious journals.) The biggest breakthrough came to SN Bose in 1924.

SN Bose developed the mathematical expression for the statistical distribution of photons over energy states and, with this, deduced Planck's blackbody radiation hypothesis. The manuscript was however rejected by the *Philosophical Magazine*. Being unable to publish his work on Planck's law in a good journal, Bose in desperation sent his manuscript to Albert Einstein. A historical connection was made as Einstein himself translated the manuscript in German and arranged to publish it (with Bose as the sole

author) in the *Zeitschrift für Physik* which was a very renowned journal at that time. This author found it interesting to note that in the published paper Bose's name appears as just "von Bose" without the first name or any initial. The paper was written when Bose was at University of Dhaka which was then part of Bengal and India.

Copy of the last few lines of Bose's famous 1924 paper translated in German by Albert Einstein is reproduced below:

$$S = k\left[\frac{E}{\beta} - \sum_s A^s \lg\left(1 - e^{\frac{h\nu^s}{\beta}}\right)\right],$$

woraus mit Rücksicht darauf, daß $\frac{\partial S}{\partial E} = \frac{1}{T}$, folgt, daß $\beta = kT$. Setzt man dies in obige Gleichung für E ein, so erhält man

$$E = \sum_s \frac{8\pi h \nu^{s^3}}{c^3} V \frac{1}{e^{\frac{h\nu^s}{kT}} - 1} d\nu^s,$$

welche Gleichung Plancks Formel äquivalent ist.

(Übersetzt von A. Einstein.)

Albert Einstein added the following note at the end of Bose's 1924 paper:

Anmerkung des Übersetzers. Boses Ableitung der Planckschen Formel bedeutet nach meiner Meinung einen wichtigen Fortschritt. Die hier benutzte Methode liefert auch die Quantentheorie des idealen Gases, wie ich an anderer Stelle ausführen will.

Albert Einstein subsequently extended Bose's idea for massless photons to atoms, which have mass, in two papers of his own. This led to the concept of Bose-Einstein Condensation.

In 1986 S.N. Bose National Centre for Basic Sciences was established in Calcutta by an act of Parliament, Govt of India.

In honour of SN Bose, the particles that obey the Bose-Einstein Statistics are called "Bosons" which have integer spin. Bosons do not obey the Pauli Exclusion Principle. Bosons can be of the elementary type (e.g. photons) or composite type (e.g. mesons). A meson is made up of a quark and an antiquark. [The other type of particles is called Fermions (Quarks and Leptons) which have half-integer spin, and follow the Fermi-Dirac Statistics and the Pauli Exclusion Principle. The well-known electron is a lepton. The proton is composed of two up quarks and one down quark, the neutron is composed of two down quarks and one up quark.]

Sir CV Raman, FRS, (1888-1970)

Acoustics and Vibration (musical instruments); structure and property of diamond and iridescent substances; Raman Effect.

Nobel Prize in Physics 1930.

Until 1934 Raman's research was based at the Indian Association for the Cultivation of Science situated in Calcutta and the University of Calcutta. He then moved to Bangalore, first to the Indian Institute of Science, then to RRI.

The research about "new radiation" by light scattering was published by Raman, with KS Krishnan as the co-author, in *Nature* (1928), *Indian Journal of Physics* (1928), *Proc. R. Soc. Lond.* (1929).
In the Letter entitled "A new type of secondary radiation", published in *Nature* 121, 501—502 (31 March 1928) doi:**10.1038/121501c0, CV Raman and KS Krishnan wrote:**

"IF we assume that the X-ray scattering of the 'unmodified' type observed by Prof. Compton corresponds to the normal or average state of the atoms and molecules, while the 'modified' scattering of altered wave-length corresponds to their fluctuations from that state, it would follow that we should expect also in the case of ordinary light two types of scattering, one determined by the normal optical properties of the atoms or molecules, and another representing the effect of their fluctuations from their normal state. It accordingly becomes necessary to test whether this is actually the case. The experiments we have made have confirmed this anticipation, and shown that in every case in which light is scattered by the molecules in dust-free liquids or gases, the diffuse radiation of the ordinary kind, having the same wave-length as the incident beam, is accompanied by a modified scattered radiation of degraded frequency.

The new type of light scattering discovered by us naturally requires very powerful illumination for its observation. In our experiments, a beam of sunlight was converged successively by a telescope objective of 18 cm. aperture and 230 cm focal length, and by a second lens was placed the scattering material, which is either a liquid (carefully purified by repeated distillation in vacuo) or its dust-free vapour. To detect the presence of a modified scattered radiation, the method of complementary light-filters was used. A blue-violet filter, when coupled with a yellow-green filter and placed in the incident light, completely extinguished the track of the light through the liquid or vapour. The reappearance of the track when the yellow filter is transferred to a place between it and the observer's eye is proof of the existence of a modified scattered radiation. Spectroscopic confirmation is also available.

Some sixty different common liquids have been examined in this way, and every one of them showed the effect in greater or less degree. That the effect is a true scattering, and secondly by its polarisation, which is in many cases quire strong and comparable with the polarisation of the ordinary scattering. The investigation is naturally much more difficult in the case of gases and vapours, owing to the excessive feebleness of the effect. Nevertheless, when the vapour is of sufficient density, for example with ether or amylene, the modified scattering is readily demonstrable.

210 Bowbazar Street
Calcutta, India
Feb, 16"

The Nobel Prize-winning work was conducted in Calcutta. The Nobel Prize was awarded to CV Raman alone (KS Krishnan did not receive it), with the citation "for his work on the scattering of light and for the discovery of the effect named after him". AH Compton, the scientist named in the 1928 publication in *Nature* by Raman and Krishnan reproduced above, had received the Nobel Prize in Physics in 1927 for discovering the Compton Effect. The Raman Effect is the optical (ordinary light) analogue of the Compton Effect observed for X-rays. For Compton effect, one can derive the change in wavelength ($\Delta\lambda$) as a function of scattered angle ϕ : $\Delta\lambda = (h/mc)(1-\cos\phi)$, where m is the mass of an electron, h is Planck's constant, c is the speed of light and the term (h/mc) is called the "Compton wavelength".

Spontaneous Raman scattering is typically weak. Thus an important challenge of Raman spectroscopy is to separate the weak inelastically scattered light (Raman scattering) from the intense, elastically scattered laser light (Rayleigh scattering; the intensity of the scattered light varying inversely with the fourth power of the wavelength, $I_{Rayleigh} \propto 1/\lambda^4$).

Raman spectroscopy has found many applications in chemistry, biology and medicine, including fingerprinting of molecules, chemical imaging and microscopic analysis.

Raman is the only Indian scientist with Indian citizenship to receive the Nobel Prize; three other scientists of Indian origin have received the Nobel Prize after India became independent but they were naturalized citizens of other countries at the time of the award. Raman was the second Indian to receive the Nobel Prize, Rabindranath Tagore having won the Nobel Prize in Literature in 1913.

CV Raman founded the Raman Research Institute (RRI) in 1948 and the Indian Academy of Sciences in 1934, both in Bangalore. He established a chemical company in southern India.

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