Meghnad Saha: A Win for Science

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"…India is now passing through a critical stage in her history… It is necessary that at such a juncture the possible effects of the increasing application of discoveries in science to our national and social life, should receive very careful attention…"

- Meghnad Saha, *Science and Culture*, 1935

On 23rd August, Vikram, the landing module of Indian Space Research Organization (ISRO)'s latest Moon mission Chandrayaan-3, made a 'soft' landing near the Moon's south pole and sent waves of exhilaration throughout India and its diaspora. The landing was not only historically significant but also held the promise of lunar science hitherto unexplored[1]. However, to the millions watching ISRO's live broadcast with bated breath, it held a deeper message — science exploration was not restricted to an 'elite' few anymore, India has moved past its history of Western colonial oppression enough to enter a new era of decolonized scientific research. Decolonization[2] has been defined as 'a movement to eliminate, or at least mitigate, the disproportionate legacy of white European thought and culture in education.' ISRO's moon mission is being lauded as a 'win for science'[1]. An Indian physicist, oft forgotten in the discussion of reconstruction of post-colonial India and her present scientific prowess, even by Indians themselves, yet whose life reflects the upward mobility, both in professional prestige and social standing, that can be brought forth only by science, is Meghnad Saha.

Meghnad Saha's early hurdles and why science needs strong mentors

Perhaps best remembered for his ionization equation, one of the foundational works in developing the theory of stellar astrophysics[3], Saha wasn't predestined for a stellar scientific career. His precocity, as a child, and later, originality in scientific thought, were appreciated by well-intentioned individuals in positions of power, who enabled him to succeed in life despite all odds.

Born in the town of Seoratali in present-day Bangladesh to a family of grocers in 1893, his education would have ended abruptly in middle school, had it not been for a local medical practitioner who decided to assist him financially[4]. Misfortune struck soon after, when he got expelled from Dacca Collegiate School for staging a demonstration in protest of the 1905 partition of Bengal by the British Raj. However, that didn't stop him in his academic pursuits. In 1909, he ranked first (in East Bengal) in the entrance examination for Calcutta University and began his adventures in science at Dacca College under the tutelage of some renowned teachers[5]. He also started learning German from the Austrian scientist P.J. Brühl. This knowledge of German would play a significant role in his career later.

It's worth mentioning here that unlike other successful physicists who hailed from that era of Bengal Renaissance — Satyendranath Bose and C. V. Raman — Meghnad Saha was a *shudra*, the lowest class in the Hindu social order, and faced ostracization because of it. For example, in 1911, when he moved to Calcutta (present day Kolkata, India) to pursue a B.Sc. (and later an M.Sc.) degree in mathematics at Presidency College under Calcutta University, many of his fellow students refused to eat in the same dining hall with him[6]. However, armed with the friendship of other classmates like Bose and the mentorship of some of the best-known Bengali scientists (Figure 1) of the time, P.C. Ray, J.C. Bose and D. N. Mallik, Saha prospered, both in academics and his nationalist aspirations.

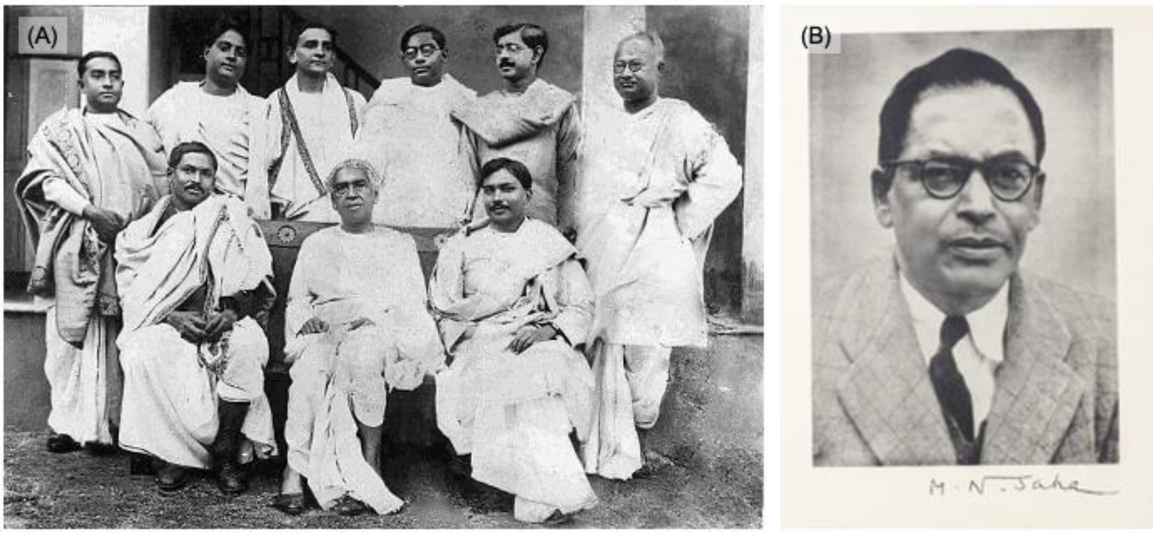

Figure 1: (A) Meghnad Saha (seated, left) with other Bengali intellectuals in the 1910s, including polymath Jagadish Chandra Bose (seated, middle) and physicist Satyendranath Bose (standing, second from left). SNBCBS archives[5] (B) Saha in his later years[7]

Even though the extent of his involvement with Bengali revolutionary groups like Anushilan Samity remains unknown, Meghnad Saha's sympathies for the Indian freedom movement made the British government mistrustful of his intentions. Despite securing top ranks in his B.Sc. and M.Sc. exams, he was barred from writing the Indian Finance Service exam in 1915. It was Sir Ashutosh Mukherjee, an esteemed Bengali mathematician and the vice-chancellor of Calcutta University who invited Saha (and Bose) to join the newly established University College of Science as a maths lecturer. Soon after, an untenable relation with the maths department head resulted in Bose and Saha being transferred to the physics department. Thus, at the age of 22, Meghnad Saha, an anomaly in terms of his circumstances, began his career as a physicist.

Dynamic beginnings: Foundational stages of Saha's research career

While teaching postgraduate courses in the physics department and leading the Heat laboratory, Saha became well-versed in physics topics like thermodynamics and spectroscopy[7]. Upon reading Agnes Clerke's popular science books on astronomy, he got to know more about the major themes of astrophysics research at that time. His knowledge of the German language played a crucial role as he learnt about the works of Western physicists like Planck, Nernst, Bohr and Sommerfeld. Soon after the First World War, together with Bose, he prepared an English translation of Einstein's work on the theory of relativity, which was published by the University of Calcutta. His earliest research[8,9] dealt with developing a better understanding of Maxwellian electromagnetic theory through discussions on radiation pressure and the dynamics of relativistic point charges.
Saha's first significant work[10] in the realm of astrophysics was in attempting to explain phenomena like tails of comets and solar prominences, which are formed by particles being repelled from the Sun. This repulsion could not be completely understood from the wave theory of light. Previous works by Schwarzschild, Nicholson and Koltz had suggested that the pressure due to solar radiation on particles of molecular sizes should be negligible but the

experimental findings of Lebedew had shown otherwise. Saha sought to resolve this by employing the quantum theory of light where absorption of a 'pulse' of light of frequency ν by a particle of mass m would result in a 'kick' or an impulsive momentum of $(h\nu/c)$ on the particle, resulting in a velocity of $(h\nu/mc)$ where h is the Planck's constant and c is the velocity of light in vacuum. Saha postulated that it is an accumulation of these 'kicks' of light, similar to those discussed in Einstein's photo-electric theory, that results in the radiation pressure leading to tails of comets, for example. The novelty of such ideas might be lost to the reader: after all, it has been more than a century since the inception of quantum mechanics. However, these discussions predate the inelastic scattering experiments between charged particles and X-ray photons performed by Compton in 1922-23 and demonstrate the originality of Saha's thoughts. Perhaps[5] it was because they were geographically far removed from the traditional scientific philosophies of the West, that scientists like Saha and Bose were more open-minded to the newly emerging ideas of quantum physics and perceptive to their consequences. Saha was awarded the Doctor of Science degree in 1918 by the Calcutta University, based on his work on electromagnetism and selective radiation pressure.

Stellar findings: Saha's theory of thermal ionization and its consequences in astrophysics

"Although Bohr must thus be considered the pioneer in the field [atomic theory], it was the Indian physicist Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory… The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas."

- S. Rosseland (1936) [3]

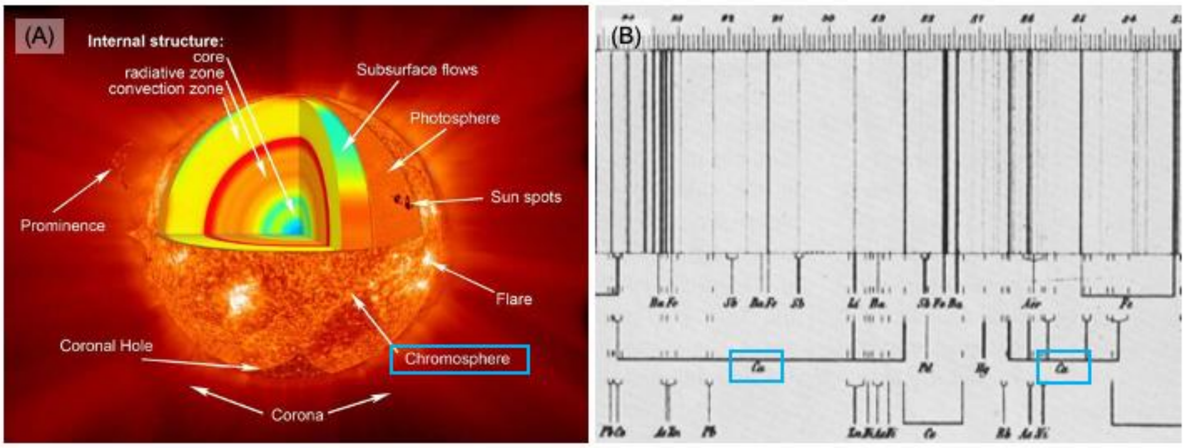

Figure 2: (A) Chromosphere is a ~2000 kms thick layer of the solar atmosphere sandwiched between the inner photosphere and the outer corona. Temperature rises in the chromosphere from 6000°C to about 20,000°C as one goes radially outwards. (NASA/Goddard) (B) Part of the solar spectrum published in 1863 by Kirchoff showing the absorption spectral lines corresponding to various chemical elements, calcium spectral lines highlighted in blue. (Paul Charbonneau's website, University of Montreal)

In 1920, in a paper[11] submitted to the British journal *Philosophical Magazine*, Saha sought to answer a question haunting astrophysicists at that time — why does the spectrum for the upper levels of the solar atmosphere show the existence of heavier atoms like calcium (Ca), barium (Ba) or strontium (Sr). Assuming the chromosphere to be a gas of particles at different levels of ionization in thermal equilibrium and building on previous work by Nernst and Eggert on thermal ionization, Saha demonstrated, using his 'equation of the reaction-isobar for ionization', that the degree of ionization for any element is dependent on the pressure (P) and the temperature (T) of the charged gas as well as the ionization energies. For example, considering the ionization of Ca: $Ca + \mathrm{U} \rightleftharpoons Ca^+ + e^-$ where U is the ionization energy, Saha derived for calcium,

$$\log \frac{x^2}{1-x^2} \mathrm{P} = -\frac{\mathrm{U}}{4.571\,\mathrm{T}} + 2.5\log\mathrm{T} - 6.5 \qquad \dots (1)$$

Here x denotes the fraction of Ca atoms that are ionized. Saha said that the ionization potentials can be directly calculated using the quantum relation $\mathrm{U} = h\nu/e$. Thus, knowing the temperature and pressure of any region of a gaseous stellar mass, it would be possible to predict the degree of ionization of different chemical elements there. He also realized how ionization is enhanced not only by increasing temperature but also by lowering the pressure. This, he reasoned[11,12], is why heavier atoms like Ca or Ba can ionize in the chromosphere, because of the decreased pressure. In subsequent papers, he studied the ionization levels of different elements in the Sun[13,14].

In 1919, Saha was awarded a scholarship by Calcutta University that enabled him to travel abroad for two years, working first in Alfred Fowler's spectroscopy lab at Imperial College London and later in Walther Nernst's laboratory in Berlin.

Saha's theory laid the foundations for subsequent works by astrophysicists like Cecilia Payne who, during her doctoral years at Harvard College Observatory characterized multiple stellar absorption spectra to determine their chemical composition. Saha's equation was further refined by Fowler and Milne from a viewpoint of statistical mechanics to eventually lead to the form by which its more familiar today.

$$\frac{n_{i+1}}{n_i} = \frac{g_{i+1}}{g_i} \frac{2(2\pi m_e k_B T)^{3/2}}{h^3 n_e} \exp\left(\frac{-(\epsilon_{i+1}-\epsilon_i)}{k_B T}\right) \qquad \dots (2)$$

where n_i, g_i and $\epsilon_i$denote the density of atoms in, degeneracy of and the energy required to create an i-th level of ionization respectively.

"The humanizing influence of science" [15]: Saha's role in the reconstruction of India

After returning to India in 1923, Saha joined the University of Allahabad as the Head of the physics department where he devoted a large part of his time to teaching, but continued research on topics ranging from active modification of nitrogen and high-temperature dissociation of molecules to ionospheric propagation of radio waves[7]. Under his leadership, University of Allahabad became a premier research institute in the country and played an important role in training a new generation of Indian scientists.

If the revolutionary activities of his youth had put him at odds with the British colonialists, Meghnad Saha's scientific accomplishments now ushered in respect and recognition from the international scientific community. In 1927, he became a Fellow of the Royal Society. The next few years saw several trips to the West, including a solar eclipse expedition in Norway and working with Shapley at the Harvard College Observatory.

In 1938, after returning to Calcutta University, Saha became increasingly involved in administrative work. He played a major role in revamping the Indian Association for the Cultivation of Science, laid the foundations for several scientific societies within the country, and in 1948, soon after India's independence, helped establish the (Saha) Institute of Nuclear Physics in Kolkata.

However, Saha's contribution to the Indian reconstruction wasn't limited to only academic administration. He cared deeply about making scientific research accessible to the wider public and recognized the importance of science, industrialization and systematic planning in developing India's national identity. In 1935, he founded the journal *Science and Culture,* which, deviating from the contemporary political or technical journals, published articles written in simpler language addressing a variety of social and scientific issues, ranging from distribution of electricity in India to communications between scientists on the newest theories. Saha's humanist approach to conducting scientific research is apparent in his writings on the various natural calamities in colonial India in the early twentieth century, Saha stressed[15] on the need for an improved railway engineering system in India. British engineers designing a railway plan for Bengal, sitting in Britain, he explained, hadn't considered the river system unique to Bengal, which led to a poor drainage system and subsequent floods. As a member of the National Planning Committee, Saha served on various committees for power, fuels, rivers, and irrigation. Saha prepared the original plan for Damodar Valley Project, the first multipurpose river valley project in India[7].

Meghnad Saha's life is, in a way, emblematic of the post-colonial science trajectory of his country. Neither his family's financial background nor the systemic exclusion his social caste has historically endured (and continues to endure[16]) held the promise for a better future. Science, with its ability to transcend discrimination, resulted in the upward mobility of his life. In the discussion on decolonizing science, Saha's life serves a case study — the need for inclusivity and objectivity in science, the role of mentorship in making a science career accessible and the increasing social responsibility of scientists in the face of the challenges of the 21st century.

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