The golden age of Calcutta physics: Difficulties in reconstructing the history

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Abstract

Classes started in the newly established Physics Department of Calcutta University Science College in 1916. Raman, Bose and Saha were three young members of the small physics faculty consisting of barely half a dozen faculty members. Within about one decade, three extraordinary discoveries came from these young men—Saha ionization equation in 1920, Bose statistics in 1924, Raman effect in 1928. However, fortunes of Calcutta University quickly got intertwined with India's freedom struggle led by Mahatma Gandhi exactly at the same time and the physics group got tragically disrupted. Indian physics never succeeded in reaching that height again. This paper discusses the difficulties in reconstructing a critical history of this Calcutta school of physics during the very short epoch of unmatched brilliance.

1 A look at an extraordinary epoch

We live in an age obsessed with ranking everything: from cinemas to washing machines, from tennis players to universities. Although India has one of the fastest growing economies in the world and is striving to find her place within the nations of the world, India's ranking remains poor in several important spheres of human activity. Apart from the poor showing in the Olympic games, one other area in which India's dismal record has become a huge embarrassment to India's intellectual class is the ranking of universities. No Indian university finds a place within the world's top 100.

Just about a century ago, for about one remarkable decade, an Indian university reached a height which no Indian university afterwards succeeded in reaching. It was Calcutta University under the leadership of the visionary Vice-Chancellor Sir Asutosh Mookerjee. That was a time when the world ranking

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of universities had not yet begun and we do not know what the rank of Calcutta University at that time would have been. However, judged by any reasonable yardstick, Calcutta University surely would have ranked among the world's greatest for a brief period of unmatched brilliance. Although Mookerjee managed to attract outstanding faculty in as diverse fields as philosophy, history and art, here we are concerned with the Physics Department of the University during the golden period. Mookerjee was a brilliant mathematician himself and, at a very young age, published a string of original papers in mathematics in leading journals, attracting international attention. As there was very little scope of a career in mathematics in India of that time, Mookerjee had to take up the legal profession before being appointed to head Calcutta University. Although Mookerjee could not pursue mathematics research in his later life, he maintained a lifelong interest in mathematics and physics. When Mookerjee took over the reins of Calcutta University, universities in India were primarily bodies for conducting examinations. Mookerjee wanted to create post-graduate departments where faculty members would carry on research. India was under the British rule and Mookerjee knew that financial support from the Government would not be forthcoming. He established the University Science College with donations from rich Indians, which enabled him to establish a few professorships.

An account of how Mookerjee built up the Physics Department of Calcutta University Science College almost reads like a fairy tale. He wanted to attract faculty who would teach modern topics in physics and simultaneously carry on research. There was no tradition of physics research in India at that time, apart from solitary workers like J. C. Bose at Presidency College (who was no longer working on physics at that time after his fundamental studies of radio waves). Mookerjee started looking for young people who had the potential for growing into outstanding physicists. He knew of a 26-year-old officer in the Finance Department, who was passionate about physics and had already published about a dozen papers in top international journals by carrying on research in his spare time. Mookerjee wanted to get him for the most prestigious chair of the fledgling Physics Department—the Palit Professorship. However, Mookerjee could offer him only Rs. 600 against his salary of Rs. 1100. Would he be willing to take up this professorship? The young man, C. V. Raman, jumped at the offer. Mookerjee also needed younger persons to man the department. As it happened, the batch which completed master's degree in the year 1915 was an exceptional batch. Mookerjee called three bright boys of that batch for a discussion[1]. Only one of them, Sailen Ghose, was a student of physics. Although the other two, Satyendra Nath Bose and Meghnad Saha, were students of mixed mathematics (what we would now call applied mathematics), Mookerjee knew that they were interested in physics. Mookerjee asked the three boys if they could teach the modern topics of physics which had never been taught in any Indian university. Saha was assigned to teach quantum theory and Bose was assigned to teach relativity. Sailen Ghose, who was a good experimenter, was given the job of designing the laboratory course and setting up the experiments.

Before classes started 1916, there was trouble. Although Sailen Ghose managed to acquire laboratory equipments and set up the laboratory, he could never formally join the department. He had connections with revolutionary groups fighting the British imperialism. Police found clues about this and raided his home when he was away. It appeared that he would be sent to the British penal colony of the Andaman Islands if caught. Ghose fled India in a ship bound for Philadelphia disguised as a Muslim crew member, thus putting down the curtain on what appeared to be a very promising career in physics. Ghose, however, later became a highly respected figure in the arena of international political activism. The short autobiography he wrote for the American magazine *Asia* in 1927 gives a fascinating account of the Calcutta academic world in his youth[2].

Bose and Saha were among the first to join the new Physics Department in 1916—at the monthly salary of Rs. 150. Raman joined about a year later when he had made up his mind to quit the Finance Department. The person to whom the other named chair (Rashbehari Ghosh Professorship) was offered—Debendra Mohan Bose—was in Germany when the First World War broke out. He was forced to stay there till the end of the War and could join Calcutta University only after the War ended. Raman, Bose and Saha were members of the small new Physics Department with barely half a dozen faculty members. Within about a decade, three spectacular physics discoveries emerged out of this group—Saha ionization equation in 1920, Bose statistics in 1924, Raman effect in 1930. Although Bose had shifted to Dacca University a little bit before his work on Bose statistics and, in that sense, that work should technically not be counted as a work from Calcutta University, Bose always had strong links with Calcutta University and eventually returned there again in later life. There were very few physics groups around the world—perhaps no group outside England and Germany—which could boast of three physics discoveries of this class in that decade. In many of the present-day surveys, Harvard University appears at the top. There was not even one physics discovery of this class made at Harvard University during the same period. Although the achievements of Raman, Bose and Saha dwarfed the achievements of their colleagues, it should be emphasized that some of their colleagues such as Sisir Kumar Mitra and Debendra Mohan Bose also made very important contributions to physics during the same period.

It seemed that this extraordinary decade heralded a new dawn for Indian physics. But that was not to be. That brilliant dawn quickly faded away and a fourth physics discovery of that class has not come out of India in the next 85 years! There were some obvious external reasons why academic activities of Calcutta University got derailed in a big way. Mahatma Gandhi returned to India in 1915 and the infamous Jallianwala Bagh massacre took place on 13 April 1919—exactly around the time when the fledgling Physics Department of Calcutta University was trying to find the ground under its feet. The golden age of Calcutta physics almost exactly coincided with the golden age of Indian freedom movement when the Muslim question still had not raised its ugly head and Indians were fighting together for their country. In fact, this coincidence

might not be accidental. Raman, Bose and Saha have all categorically stated on various occasions that patriotic fervour was one of the driving forces behind their science. They had to prove to the world that Indians could compete with white men in science. Saha had difficulties in getting a government job in his youth because he was perceived as a sympathizer of the revolutionary groups fighting the British Empire. Raman was found weeping when he received the Nobel Prize and gave a moving account of it himself:

> When the Nobel award was announced I saw it as a personal triumph ... But when I sat in that crowded hall and I saw the sea of western faces surrounding me, and I, the only Indian, in my turban and closed coat, it dawned on me that I was really representing my people and my country ... Then I turned around and saw the British Union Jack under which I had been sitting and it was then that I realized that my poor country, India, did not even have a flag of her own—and it was this that triggered off my complete breakdown.[3]

Although Mookerjee always expressed the opinion that students can serve their country best by excelling in their work and was against students boycotting classes, it was an open secret that he and many professors of the University were sympathetic to the national cause. The British administration decided to punish the University for its insubordination.

All government funds to Calcutta University were drastically cut. There was a period when the University was unable pay the salary of its faculty for several months. At the height of the crisis, in a Senate meeting on 8 December 1922 to discuss a financial offer from the government with humiliating conditions, Mookerjee spoke stirringly: "If you give me slavery in one hand and money in the other, I despise the offer ... Our post-graduate teachers would starve themselves, rather than give up their freedom ... I call upon you, as members of the Senate to stand up for the rights of your University ... Freedom first, freedom second, freedom always: nothing else will satisfy me." In a letter dated 26 March 1923, Mookerjee turned down the offer of another term of Vice-Chancellorship with humiliating conditions. Then he suddenly died on 25 May 1924 at the age of 59. In the meeting at Calcutta University to condole his death, Lord Lytton, Viceroy of India who was also the Chancellor of Calcutta University, said: "Let each of us severally resolve that this cherished creation of his life shall not suffer because he has left us ... let all differences be forgotten, all mistakes forgiven, let us resolve to build over his ashes a temple of reconciliation."[4] However, it was already too late. Although Mookerjee hoped that the "post-graduate teachers would starve themselves", many of them had already left Calcutta for greener pastures by the time of his death. Bose left for Dacca University in 1921 and Saha for Allahabad University in 1923. Calcutta University could never regain its lost glory.

Saha was abroad at the time when the financial crisis had first struck Calcutta University. Saha must have been aware of this crisis and applied for a

grant to the British High Commissioner of India for his research on his return to India. The mood of the period can be gauged from the letter dated 9 February 1921 that Mookerjee wrote to Saha at that time:

> I wish you had applied to your Alma Mater and not to the High Commissioner. We are in great financial crisis here on account of Non-Cooperation movement, but you may rest assured that so long as it is practicable, your Alma Mater will not be slow to help you ... I trust you will not hesitate to serve your Alma Mater when you return. I was deeply grieved to hear that Dr. Jnanendra Ghosh had decided to give up his Alma Mater and accept service in Dacca University. When will the children of our Alma Mater realise that it is absolutely necessary for all of them to stand by Her at the most critical period of the history of Her development?[5]

While reading this letter, we can almost hear the anguished voice of that proud visionary who built Asia's most outstanding university of that time and then saw the creation of his dreams crumble before his own eyes. Physics research in India could never reach the height that it reached during the extremely short golden period of Calcutta University!

Whenever I have discussed this extraordinary history with my non-Indian friends, many of them wanted to know if there exists a coherent account of this history that I could recommend to them. I did not know of any book that covers the history of this extraordinary epoch of physics research in Calcutta comprehensively. There are authoritative biographies of Raman, Bose or Saha, some of which I shall list later in § 3. However, most of these biographies have been written specifically for Indian readers. For example, a scholarly biography of Bose begins by referring to Bengal, Calcutta and Dacca in the opening paragraph. An Indian reader would be expected to know that Bengal was a province of the British Indian Empire comprising roughly of present-day Bangladesh and the state of West Bengal in India, and that Calcutta and Dacca were the first and second largest cities of that province. A non-Indian reader who does not have this background of geography and history would be quite a bit lost. Also, one can have a full picture of that extraordinary epoch only from a study focussing on that epoch rather than from individual biographies, setting that epoch as a landmark in modern India's search for self-expression against the backdrop of the freedom movement. To the best of my knowledge, no such study focussing on this epoch that would be easily accessible to non-Indian readers exists.

Apart from the dramatic way in which the Physics Department of Calcutta University rose and fell, there are other elements of high drama connected with our history. I give two examples. The first example concerns Raman, who hailed from the Tamil country in the deep south of India and had come to Calcutta in 1907 with a job in the Finance Department. While on his way back from work by tram one day, he noticed the signboard of Indian Association for the Cultivation of Science, which was started by Mahendra Lal Sircar, a successful

medical doctor, about a quarter century earlier for the 'cultivation of science', but remained a dormant place in which, to Sircar's great disappointment, nobody took any interest. Raman discovered this sleepy place stocked with various kinds of scientific instruments where nobody was working, and Amrita Lal Sircar, the son of Mahendra Lal Sircar who had passed away by then, was believed to have risen to embrace Raman with the words "All these years we have been waiting for a person like you", and made all the facilities available to him. It was the Indian Association for the Cultivation of Science where Raman carried out his initial research at weekends and in the evenings that attracted the attention of Asutosh Mookerjee and brought the offer of Palit Professorship. The second example is about the way Bose's famous work got published. When Bose had difficulty publishing his epoch-making paper in *Philosophical Magazine* where he had already published three papers, he sent the paper to Einstein with a covering letter. Einstein immediately understood the revolutionary nature of the paper, himself translated it into German from English and arranged for its publication in *Zeitschrift für Physik*. Later on, Einstein extended Bose's analysis for photons to particles with mass.

Certainly Raman, Bose and Saha belong to the whole world and not just to India. Their story ought be told in a way that is accessible to readers outside India. Even though the history of the physics community in Calcutta at the time of the establishment of the Science College is so rich in human drama, the important question before us is whether we can reconstruct that history reliably and critically with the help of materials available to us at the present time. We look at this question in this paper.

2 The role of our epoch in the growth of modern science in India

Raman, Bose and Saha occupy a peculiar place in the history of the growth of modern science in India. They were certainly not the first Indian scientists to receive international attention. That honour should go to the physicist J. C. Bose and the chemist P. C. Ray—both teachers at Presidency College in Calcutta—who rose to scientific eminence towards the end of the nineteenth century. Then, just around the time when the Physics Department of Calcutta University was being planned, Srinivasa Ramanujan dazzled the world of mathematics like a brilliant short-lived comet. All these scientists depended on the West in very crucial ways for their creativity. (J. C.) Bose and Ray had their initial training in research in London and Edinburgh respectively. Although Ramanujan wrote his first paper before leaving India, his genius blossomed only when G. H. Hardy got him to Cambridge. Compared to them, Raman, (S. N.) Bose and Saha were completely self-made. None of them ever had a proper research 'supervisor'. All of them figured out on their own what they wanted to do. The famous

discoveries of Saha and Bose were made before they ever stepped out of India. While Raman had been abroad after his early research made his reputation, that international exposure was probably not too crucial in shaping his subsequent research path leading to the discovery of the Raman effect.

Although the Western influence was so important in moulding the careers of (J. C.) Bose, Ray and Ramanujan, they were often perceived by their contemporaries as the culmination of the Indian tradition. Both (J. C.) Bose and Ray were generally referred to as *Acharyas*—an epithet for great teachers in the Indian cultural tradition. In the case of J. C. Bose, after his early brilliant work on radio waves, when he shifted to studying responses in plants, it became easy to connect him to the Indian tradition which perceived a unity in nature. Although Ray's chemistry research could not be connected to the Indian tradition that way, Ray also carried out pioneering research on the history of Hindu chemistry. In Ramanujan's case, the lack of importance he often attached to mathematical proofs could easily be ascribed to his incomplete training in mathematics in his formative years[6]. However, since mathematical proof was historically given less importance in the Indian mathematical tradition compared to the Greek tradition, one could connect the peculiarities of Ramanujan's genius to his Indian heritage. Ironically, although Raman, (S. N.) Bose and Saha were the first modern Indian scientists whose careers were not shaped by their interactions with the West as in the case of their predecessors and, in that sense, they were more indigenously Indian, they were the first generation of Indian scientists who were generally not viewed as being connected with the Indian tradition. They were simply regarded as international scientists belonging to the global tradition of science.

After these comments on how Raman, Bose and Saha stood in relation to their predecessors, we come to the more important question: how do they stand in relation to their successors? The short brilliant burst of scientific creativity with which they had been associated did not lead to the establishment of a school of physics research. It is vitally important for us to address the question why this extraordinary phase of scientific creativity disappeared as suddenly as it appeared. Was it that conditions in India at that time were such that it was not possible for such a creative phase to continue for too long? Or do we have to 'blame' Raman, Bose and Saha in some way that, in spite of their extraordinary achievements, they did not provide the right kind of leadership for the growth of Indian physics? Since Raman, Bose and Saha have been icons of science in India, it has been almost a taboo to raise such a question. Nearly all the Indian authors who wrote on them refrained from analyzing this issue. Now that we can view them from a historical distance, perhaps it is time to analyze this vital issue objectively.

Amal Kumar Raychaudhuri, the most outstanding physicist to come out of Calcutta in the next generation, is remembered for the Raychaudhuri equation which played a crucial role in proving the singularity theorems in general relatively. Raychaudhuri, who had seen Bose and Saha closely, wrote:

> The present writer passed out of the University in 1944. I remember how those who were a few years senior discouraged me about taking up research. The feeling was that one should take up any job whatsoever that he may be able to get rather than enter into a field where prospects were simply dismal. To make matters worse an idea went around that scientific research is the business of supermen like Bose and Saha and an ordinary Indian should not be foolish enough to aspire after doing anything worthwhile. Strangely neither Bose nor Saha did anything to counter such absurd ideas—I wonder whether they actually relished it![7]

Note that Raychaudhuri is referring to the year 1944—only slightly more than a decade after the glorious era of Calcutta physics when many of the heroes of the glorious era were still very much around. How could the mood change so much in such a short time? We have to keep in mind that the national mood as a whole was much gloomier and darker at that time compared to the forward-looking 1920s. That was the time of the Second World War. Bengal was recovering from the terrible man-made famine of 1943. Communal riots between Hindus and Muslims started becoming a frequent occurrence. Still we get a feeling that this societal mood does not fully explain Raychaudhuri's pessimistic outlook. Even at the darkest of times, human spirit has an urge to conquer the circumstances and rise above them. Could it be that Raychaudhuri was a natural pessimist and his view did not really reflect the view of his generation? Raychaudhuri himself and many of his contemporaries had been my teachers in Presidency College in the 1970s. With several of them, I had detailed conversations about their student days. I can assert with confidence that the quotation from Raychaudhuri quite accurately reflects the mood of his generation.

If there is a sudden burst of scientific creativity in a country which did not have a tradition of scientific research, there are opposing examples of that leading to the establishment of a school of research and also that *not* leading to the establishment of a school of research. Let me give two such contrasting examples. In the second half of the nineteenth century when America was in the backwaters of scientific research, Josiah Willard Gibbs, a solitary genius working at Yale University, made very deep and profound contributions to theoretical physics. He was an intellectual recluse who did not leave followers behind him and his influence did not give rise to any school of physics research in the USA. Contrast with this the case of the Russian physicist Lev Landau, a few years younger than Raman, Bose and Saha. Although there had been some earlier Russian physicists who made important contributions to theoretical physics, it was the charismatic personality of Landau, through his teaching and research mentorship, that inspired the whole next generation of Russian physicists and established a very strong school in theoretical physics. If we want to compare the Indian situation with the Russian situation, we have to keep one important factor in mind. It was not easy for a Russian physicist to travel abroad. So the

brightest people stayed in the country and produced their best science there. On the other hand, brain drain had a serious impact on the growth of Indian science as countries like the USA became more welcoming to scientific emigres. This, however, does not explain the mood of despondency expressed in the quotation from Raychaudhuri.

When would we expect that a sudden burst of scientific creativity would lead to the establishment of a vibrant scientific tradition? I would like to humbly propose the following answer. Only when there is a community of many active competent scientists, we expect that a few of them may make spectacular discoveries, giving rise to a strong scientific tradition. In a given population, there may be a small handful of unusual geniuses who would rise to scientific eminence even under the most adverse circumstances. Presumably Raman, Bose and Saha, as well as Raychaudhuri in the next generation, belonged to this class. But one cannot have a school of science only with such unusual individuals. There would be a much larger number of persons in the population who have the intrinsic ability to become competent scientists, but who blossom into competent scientists only if they receive appropriate guidance and encouragement in their formative years. A community can have a strong school of scientific research only when this second category of persons are able to realize their full potential. When we consider the generation after the generation of Raman, Bose and Saha, we clearly perceive it as a generation of missing physicists. I can only talk about that generation in Calcutta, because I am not sufficiently familiar with that generation elsewhere in India. Those of us who had the privilege of being taught physics by Shyamal Sengupta, Rashbehari Chakrabarti and Hemendra Nath Mukherji in Presidency College in the 1960s and 1970s would unanimously agree that they had the potential to become outstanding physicists if circumstances were different in their youth. Their command over physics would easily surpass that of many professors in India's top physics departments today. In spite of the spectacular achievements of Raman, Bose and Saha, why did Calcutta not have an intellectually stimulating atmosphere for physics in the following years? Why many would-be physicists never really blossomed into successful researchers? What caused this generation of missing physicists?

We now come back to the question whether we have to 'blame' Raman, Bose and Saha for this. Since we are mainly talking about Calcutta now and Raman left Calcutta in 1933 to take up the Directorship of Indian Institute of Science in Bangalore, let us leave Raman out of our reckoning right now. Although Bose and Saha spent several years in Dacca and Allahabad respectively, both of them eventually came back to Calcutta University—Saha in 1937 and Bose in 1945. There was a period of about seven years (1945–1952) when Saha and Bose were both in the physics faculty of Calcutta University. Many of our outstanding teachers in Presidency College went through Calcutta University exactly during this period. As I have already pointed out, there have been supremely great physicists like Gibbs who simply did not have the type of personality to inspire the next generation that Landau could do. If Bose and Saha also like Gibbs

did not have the right type of personality, then we can feel sorry that physics did not take root in Calcutta in a way we would have liked, but we can hardly blame Bose or Saha for not being Landau! We should blame them only if they did something that was detrimental to the growth of physics in Calcutta. The quotation from Raychaudhuri obliquely hints that Bose and Saha indeed have to be blamed, to some extent at least, for what was happening (or rather what was not happening) in the physics world of Calcutta.

There is now a genre of biography-writing which is essentially slinging mud at great persons. The biographer digs out all kinds of unknown negative secrets in the life of a great man to cut him down to size. I personally have never been an admirer of this genre of biography-writing. But uncritical iconography is not the viable alternative. Raman, Bose and Saha were scientific giants of such colossal stature that even if our analysis shows that they have to be blamed for their negative impact on the growth of Indian physics, that will not diminish the brilliance of their extraordinary achievements. However, an objective analysis of this should have much broader implications for the whole subject of history of science. Such an analysis would enable us to understand better the circumstances under which a tradition of scientific research may develop and flourish, as well as what may stifle such a tradition. The important question is whether we have sufficient source materials available to us at the present time to reconstruct a history of the glorious epoch of Calcutta physics in sufficient detail to make a proper objective analysis possible. We now take stock of the available source materials and address this question.

3 In search of source materials

Since less than a century had elapsed after the epoch in which we are interested and many persons who had seen Raman, Bose and Saha in flesh and blood are still alive, one may think that reconstructing a history of that epoch should not be too difficult. But as I started looking for source materials, I quickly realized that this is a much more challenging job than what I initially expected. The scientific papers of all three are easily accessible, since their important papers appeared in standard journals and the collected papers of all of them have also been published[8–10]. Saha had written a considerable amount apart from his scientific papers. These writings also have been collected[11]. The collected Bengali writings of Bose and Saha have also been published[12–13].

We do know the broad outlines of the major events in the lives of our three protagonists—Raman, Bose and Saha. Soon after their deaths, short sketches of their lives appeared in *Biographical Memoirs of the Fellows of the Royal Society* written by persons who knew them well and knew about their science (D. S. Kothari wrote on Saha[14], S. Bhagavantam on Raman[15], J. Mehra on Bose[16]). The primary sources of information about the lives of Bose and Saha are the short biographies penned by Santimay Chatterjee, a Calcutta-based

physicist, and his writer-wife Enakshi Chatterjee[17–18]. Santimay Chatterjee had done research under Saha's supervision and had known both Bose and Saha personally. Although the biographies were written after the deaths Saha and Bose, Chatterjees got quite a lot of their information from the family members of Saha and Bose. Afterwards Santimay Chatterjee, in collaboration with others, prepared a fuller biography of Bose on the occasion of his birth centenary[19]. The most detailed account of Raman's personal life can be found in the biography by Uma Parameswaran[20], who was the granddaughter of Raman's elder brother. She got much of her information from family members—especially from Raman's wife Lokasundari, who lived for several years after Raman's death and whom Parameswaran knew intimately. S. Ramaseshan, Raman's nephew who carried on research under Raman's supervision, also wrote several articles on Raman as scientist and man[21]. A monumental scientific biography of Raman was written by G. Venkataraman[22], who also wrote excellent short scientific biographies of Bose[23] and Saha[24]—describing the scientific achievements of all of them against the backdrop of physics of their time. Venkataraman has been much more critical than a typical biographer of an Indian cultural icon. An account of Raman's scientific work at Calcutta was prepared by S. N. Sen[25], the doyen of history of science research in India, who also edited a volume on Saha's life and works on the occasion of his 60th birthday[26]. Since Saha himself went through this material, the account given in this volume can be taken to be the authorized account of Saha's life and works as he would have liked to be passed on to posterity. Finally, Rajinder Singh has written a study on the discovery of the Raman effect and its international impact, leading to the Nobel Prize[27].

As I have pointed out, our interest is to reconstruct the history of an extraordinary epoch rather than of individuals. One may naively think that we merely take the materials from the above-listed biographies pertaining to the epoch of our interest and combine these together to reconstruct the history of this epoch. A quick perusal of the biographies listed above shows that this will not do—one simple reason being that most of these biographies have only very limited amount of material concerning the questions of what made this extraordinary epoch possible and why it faded away so quickly. For example, in Venkataraman's biography of Raman running to more than 500 pages[22], only about 20 pages are devoted to events during Raman's golden years when he was working in Calcutta (1907–33). In the cases of many famous persons (including Jesus Christ), it is much easier to get information about them after they became important public figures. It is much harder to gather information about early stages of their lives before they became famous. I should mention that there are some valuable studies which cover the later lives of our protagonists. Robert Anderson has published a detailed and thorough study of Saha as an institute-builder by comparing him with the other institute-builders of India of that time (Bhabha, Bhatnagar)[28]. Just like this study, an interesting study of Raman and Saha from a feminist viewpoint by Abha Sur[29] also focuses on the later phases of their lives when they were public figures.

Biographies of famous persons are secondary source materials. Do we have enough of more primary source materials on which we can rely in order to reconstruct our history? To understand intellectual creativity, often an account of the external events is not sufficient. We need to know how the creative person responded to various influences and what might have been going through his mind to enable him to be so creative. Unless we have a record of what a great man thought at a certain time, we have to guess what might have gone through his mind based on the available data. The personal papers of the great man—private and official letters, memoirs, recorded speeches—often constitute the primary source materials that allow us a glimpse into the great man's mind and give us a key to understanding the creative process. Reminiscences by contemporaries constitute another valuable primary source material. Do we have such source materials for Raman, Bose and Saha available to us? Thanks to Saha's children, his personal papers have been preserved. Saha himself was an organized man and kept all his personal papers systematically arranged. At one stage a few years after his untimely death, his children had to decide what should be done with these personal papers. They decided to deposit the personal papers in the archive of Nehru Memorial Museum and Library, New Delhi, after making two copies of the entire set of papers—one set of which is kept at the Saha Institute of Nuclear Physics in Calcutta and the other set at the home of Saha's daughter Chitra Roy. Each set consists of a few thousand pages. To the best of my knowledge, there has been only one detailed study of Saha's personal papers (in Bengali) by Atri Mukhopadhyay[30]. Not much of the material in the Saha archive has ever been published. Unfortunately Bose was the extreme opposite of Saha and never kept his personal papers systematically. Very little of his personal papers seem to have survived. However, in his old age, Bose was quite fond of reminiscing about his youth. He never wrote a long coherent autobiographical account. But his reminiscences are scattered through many pieces—mostly in Bengali. A few of these pieces were translated into English on the occasion of Bose's birth centenary. But one has to browse through Bose's collected writings in Bengali[12] for the other autobiographical clippings. Perhaps the fate of Raman's personal papers is the most intriguing. There is enough evidence that Raman also kept his personal papers organized very systematically—just like Saha. What happened to his personal papers? Nobody seems to know an answer to this question! I have personally enquired at the five organizations with which Raman had been associated—Indian Association for the Cultivation of Science, Calcutta University, Indian Institute of Science, Raman Research Institute, Indian Academy of Sciences. Apart from some stray documents, none of these organizations has a substantial systematic collection of Raman papers. Unfortunately, in India, for a long time there was no awareness that such materials are of inestimable historical value and should be preserved properly. I wonder if this is due to our Vedantic view that life is a transitory illusion! Every historian knows that records of ancient India are much sparser compared to the records of other ancient civilizations. Only within the last

few years, several Indian organizations have at last started building archives to preserve their historical records. In fact, people in all the organizations with which Raman had been associates are now looking for Raman materials. We can only hope that the Raman papers are still gathering dust in some unknown shelf of a storeroom in one of these organizations and will be discovered in the near future. Right now, we have to proceed with the assumption that the personal papers of Raman are largely lost.

There is one other extremely valuable source for reconstructing the history of our extraordinary epoch that has so far been explored very superficially—the records of the Syndicate and the Senate of Calcutta University. In the early years of the twentieth century, Calcutta University used to keep these records in unbelievable detail. Very often, minutes of important meetings would include very detailed statements of the persons who spoke at these meetings. For example, the records of the year 1924 alone run to a whopping 3550 pages!!! It is certainly not easy to dig out the material you are interested in from these records. Recently Calcutta University has taken the initiative to put these records on the Internet. In his study of Raman's scientific work at Calcutta, S. N. Sen[25] quotes a few extracts from these reports describing discussions in which Raman took part. These extracts quickly dispel the general perception that Raman was so involved with his work at the Indian Association for the Cultivation of Science that he did not take much interest in the affairs of Calcutta University. For example, Raman strongly argued in support of those who wanted to introduce Bengali at the highest levels of Calcutta University, although Raman himself could not speak or understand Bengali. I know of only one scholar who has made extensive studies of the records of Calcutta University—Dinesh Chandra Sinha, who retired as the Deputy Registrar of the University. A number of articles he wrote on various aspects of Calcutta University (written in Bengali, though various documents are quoted in the original English) have been collected together in a book[31]. This book has two articles on Saha and Raman, quoting several fascinating official letters between them and the University. I have already quoted the letter from Mookerjee to Saha on the financial crisis of Calcutta University[5]. This letter is given in full in Sinha's book. Sinha must have obtained these letters from files kept in some office of Calcutta University. Most of Sinha's articles were written more than two decades ago. Clearly these files existed at that time. Even after making several enquiries at Calcutta University, I have not been able to find any information where these files are kept now or if they still exist. When I tried to find contact details of Sinha in order to meet him personally, I discovered to my regret that he had passed away just a few months earlier. Although Sinha wrote two articles on Saha and Raman reproducing several official letters to and from them, Sinha unfortunately did not write a similar article on Bose. When Santimay Chatterjee was preparing the biography of Bose on the occasion of his birth centenary in 1994, he visited Dacca University in search of source materials. He found several official letters between Bose and Dacca University neatly filed. Some of these letters

are quoted in the biography of Bose prepared for his birth centenary[19]. We do not find similar official letters between Bose and Calcutta University quoted in that biography. My guess is that Chatterjee must have looked for such letters and could not find them. So, already in 1994, Bose's file at Calcutta University was not accessible to scholars. Again, with the increased awareness about the value of such materials, we can only hope that the files of Raman, Saha and Bose, as well as the files of other famous professors of Calcutta University of that period, will be discovered some day from some godown and will thereafter be preserved carefully for posterity.

Raman joined the Physics Department of Calcutta University in 1917 and Saha left for a tour of Europe in September 1919. By the time he returned, Bose had already left for Dacca University. So probably only two or three batches of MSc students during the years 1917–1919 had the privilege of being taught by Raman, Bose and Saha simultaneously. All three of them were young men who still had not made their famous discoveries and students probably could not guess that one day these three would be legends of physics. What was it like to be an MSc student in the small Physics Department of Calcutta University at that time? Who taught what? Was the teaching exciting? What were the examinations like? Can we reconstruct the intellectual atmosphere of the Department at that time? From the documents I have so far looked at, I could not even find out how many students were there in each batch. We would like to know the names of the students in these first batches, whether some of them turned out to be professional physicists and what the others did after MSc. As the Physics Department of Calcutta University is approaching its centenary, I find that a few colleagues are interested in finding answers to these questions. There is a plan of searching the records of Calcutta University in the next few months and hopefully we shall have at least partial answers to some of these questions. If we could have a reminiscence of the Physics Department of Calcutta University in those early years, that would be wonderful. While I am not aware of anybody who wrote such a reminiscence, it will probably not be easy to trace such a reminiscence even if somebody had written it. I have already mentioned that Sailen Ghose, who built the MSc physics laboratory and then could not join the faculty because of his connection with the revolutionaries, wrote a reminiscence for the magazine *Asia*[2]. All my efforts of finding this reminiscence anywhere in Calcutta failed, although it was reprinted in Calcutta in 1992 in the *Sailendranath Ghosh Birth Centenary Commemoration Volume*. Usually such volumes are not kept and catalogued in libraries. Ultimately I came to know that Vivek Bald of Massachusetts Institute of Technology, who was studying immigrants to America from the Indian subcontinent, was interested in Sailen Ghose as an eminent immigrant. On contacting Bald through e-mail, he told me that he managed to get those old rare copies of *Asia* through great difficulty and kindly sent me a scanned soft copy of the Ghose reminiscence. While discussing reminiscences, I shall mention another unusual document. Raman's student K. S. Krishnan, who was involved in the discovery of the Raman effect

and about whom many feel that more credit should have gone to him, kept a diary describing the work done in the laboratory. The mysterious thing about the diary is that several pages starting from the day on which the Raman effect was discovered have been torn out. Nobody knows what happened to these missing pages. A detailed biography of Krishnan has been written by D. C. V. Mallik and S. Chatterjee[32].

It appears that chemists have been more interested in writing reminiscences than physicists. The great P. C. Ray—who taught at Presidency College in Calcutta (where Bose and Saha were his students) and then joined Calcutta University as the Palit Professor of Chemistry at the invitation of Asutosh Mookerjee—wrote a fascinating autobiography both in English and in Bengali[33]. This invaluable autobiography gives a detailed account of the establishment of the Science College of Calcutta University and the subsequent difficulties it faced from an insider's point of view. Another interesting reminiscence in Bengali is by P. C. Rakshit[34], who was a student of Jnanendra Ghosh (whom Mookerjee mentioned in his letter to Saha quoted earlier[5]) in Dacca and has given an intimate portrait of Bose during his Dacca years.

In order to put the brilliant epoch of Calcutta physics in proper historical context, we need to know how modern science grew in India. A brief account of how Western science started in India has been given in the seminal work on the history of Indian science by Bose, Sen and Subbarayapppa[35]. Fuller accounts are given by Pratik Chakrabarti[36] and Chittabrata Palit[37]. J. Lourdusamy studied the four pioneers[38]—Mahendra Lal Sircar, Asutosh Mookerjee, J. C. Bose, P. C. Ray. Detailed studies of Mookerjee and Ray in Bengali have been carried out by Shyamal Chakrabarti[39−40]. The authorized biography of J. C. Bose was by his maverick friend Patrick Geddes[41]. See also a recent volume with three long critical essays on Bose[42]. Ashis Nandy carried out an interesting study of Bose and Ramanujan from a psychoanalytical point of view[43].

Lastly, I should mention the institutional histories. Calcutta University was established more than half a century before Mookerjee started the Science College. On the occasion of the centenary of Calcutta University in 1957, a group of scholars produced a history of the University[44]. Before the establishment of the Science College at Calcutta University, there were two serious efforts of starting organizations for scientific research: Indian Association for the Cultivation of Science in Calcutta (which was discovered by Raman from a tram on his way home) and Indian Institute of Science in Bangalore (of which Raman became the first Indian Director in 1933. A history of the first organization was compiled at the time of its centenary[45], whereas a history of the second organization has been written by B. V. Subbarayappa[46]. Just as the first organization was a dormant sleepy place in its first few decades, the second organization also had an undistinguished start. In fact, the failure of Indian Institute of Science to produce any worthwhile science in its first years was a matter of concern when Mookerjee was planning the Science College in Calcutta. The primary reason for the failure of Indian Institute of Science was that the British rulers of India

were using it as a parking place for second- and third-rate British academics who could not find any positions in Britain. To avoid this from happening in Calcutta University, Mookerjee always insisted that the donors whose donations created the various named chairs put the condition that these chairs can only be offered to Indians. This was another reason behind the wrath of the British rulers against Calcutta University.

In this survey of source materials, while listing secondary source materials, I have mainly restricted myself to the most important book-length studies. There have also been numerous articles and essays in many journals and magazines that throw important light on our topic. Since Raman, Bose and Saha are icons in Indian science, there have also been many short descriptive books on them—written specially for children and young people. I have primarily cited those books which appeared to me to be historically sound and critical in a scholarly way.

4 Can we reconstruct the history?

After this survey of source materials, let us come to the question whether we can adequately reconstruct the history of the glorious period of physics research at Calcutta University. Certain documents which would have been of inestimable value in reconstructing this history are not available to us—the most important being the personal papers of Raman and Bose, as well as the official files of Raman, Bose and Saha with Calcutta University. There is a small chance that some of these documents may be discovered in the coming years. However, since we are not certain of this, we should make an attempt at reconstructing the history as best as we can, on the basis of what we have available to us today. Since we can now view Raman, Bose and Saha from the distance of a few decades and most of the persons who had been involved in close scientific interactions with them are no longer alive, we can now analyze many events connected with them objectively without hurting the feelings of any living persons. One thing is clear. If we treat Raman, Bose and Saha as faultless supermen that many of their biographers would like us to believe, then we shall never be able to address certain important questions—such as why the brilliant epoch of physics research did not lead to the establishment of a strong tradition of physics research in India. To analyze this issue adequately, we have to treat them as intellectual giants who nevertheless had many human failings.

A few persons who had known Raman, Bose or Saha intimately are still alive. One important question is whether we can obtain valuable data for reconstructing our history by interviewing them. I believe that what we can learn from such interviews is not only of limited value for our study, but can actually be quite misleading. These still living persons have all seen these great men in the twilight years of their lives. We know that all living beings change with age. In the cases of all three of our protagonists, there seem to have been some crit-

ical phase transitions in their personalities—approximately in the early 1930s in all the cases. So the three elderly men whom the still living persons knew were entirely different persons from the three young men who revolutionized physics. If we try to interpret the events of 1920s on the basis of the impression we gather from people who have seen these great men in the 1950s and 1960s, then we shall be mistaking apples for oranges. One simple example will suffice. Although I have never come across detailed and objective accounts of the teaching of Bose and Saha in their younger years, there is evidence to suggest that they were dedicated and inspiring teachers in their younger years. Perhaps the biggest support in favour of this is Saha's extraordinary textbook on thermal physics[47], presumably the best physics textbook ever written from India. Having myself written two critically acclaimed textbooks, I personally know what is involved in writing a textbook and I cannot believe that a person who was not completely dedicated in teaching could have written the textbook that Saha wrote. However, a few persons who have been taught by Bose and Saha when they again returned to Calcutta University are still alive. Over the years, I had detailed discussions with at least half a dozen of them (including some who are not alive today). I got the uniform opinion that attending lectures by Bose or Saha was an extremely disappointing experience. They both taught in a way as if they had lost all interest in physics and teaching was an onerous burden in which their heart was not there. Bose and Saha, who taught at Calcutta University in the years immediately preceding their retirement, were totally different persons from the young men who took up the teaching of newest developments in physics as a challenge thrown to them by Asutosh Mookerjee!

In Indian society, writing anything negative about somebody who had become a cultural icon is often considered a taboo. Without exception, all the persons who told me about Bose's and Saha's unsatisfactory teaching made it clear to me that they would not like their statements to be recorded or would not want to be quoted with their names. In scholarly writing, the standard practice is to provide any information only with full details about the source of that information. Although it is still possible to gather anonymous data about Bose's or Saha's teaching in their later years from persons who are still alive, it is not easy to prepare a scholarly account of their teaching with proper accrediting. The same difficulty arises when we try to obtain any negative information about the personal lives of these great men. Often negative developments in personal life affect a person's intellectual creativity at a deep level and a knowledge of such developments is often important to explain the patterns of creativity. I give an example to demonstrate how difficult it is to obtain such negative information about a famous person. Raman's elder son Raja fell out with his father, because both of them had dominating but incompatible personalities. During his adulthood, Raja never had any contacts his father, though I have heard that his mother secretly used to help him with money. Except Uma Parameswaran[48], none of the other biographers of Raman even acknowledged Raja's existence! One gentleman who was close to the Raman family told me the following about

Raja:

> He was a very intelligent man and the sharpness of his mind would be apparent even in casual conversation. He never married. He became a communist in his youth. Since Raman hated communists, that was the beginning of the breakup of his relation with Raman. Afterwards Raja converted to Islam. Although he lived in the Muslim neighbourhood in a Bangalore locality called Kodigehalli, he and Raman never saw each other during Raman's final years. I often used to visit Raja in his last few years. He told me that I could visit him only on one condition: I should never disclose his family connections to his neighbours. Once when I went to his house, I found it locked. On enquiring with the neighbours, I came to know that he had passed away about a week ago. None of the neighbours knew anything about his family and could not contact any family members. He was buried in an unmarked grave in the nearby Muslim graveyard.

When I asked this gentleman if I could quote him with his name in scholarly writing, he told me that he would disown ever making such statements to me if I quoted him with his name!

When Bose and Saha returned to Calcutta after their innings in Dacca and Allahabad respectively, they were legends in Indian science. Calcutta has been known for a long time as a city where some of the brightest students were interested in physics. One would have expected some of these brightest students to flock around Bose and Saha to learn physics from them and to work under their guidance. Something like this does not seem to have happened. Purnima Sinha, who did her PhD thesis under Bose's supervision and worshipped Bose as a demi-god, gave a very bizarre explanation of why the brightest students did not work with Bose:

> He never tried to establish a school by gathering the best students around him. After all, the best students can always find their own paths. But who will look after the less capable students? The great savant therefore took upon himself the job of guiding such students[49].

I am aware of only one frank depiction of the atmosphere of the Calcutta physics community in the 1940s and 1950s—written by none other than Amal Raychaudhuri of the Raychaudhuri equation fame. It is an extremely frank 30-page autobiographical note (in Bengali) written when he was convalescing from a serious illness. Although he lived for three years after this note was written, it was never published during his lifetime. After his death, his daughter decided to publish it[50]. Over the years, I had heard many of these things written in the autobiographical note directly from Professor Raychaudhuri. He used to tell

us that he wanted promising physics students of the next generation to know of this history, but he could never think of having this history published. We are fortunate that we now have this valuable document. It gives a grim and unflattering portrait of the Calcutta physics world when Bose and Saha were the living icons. We are quite shocked to know of the way Bose and Saha would interact with young budding physicists of that time. While Bose never tried to build a research group around himself, Saha had a thriving research group at Allahabad and several members of this group became respected physicists afterwards. We feel extremely saddened to read the account of Raychaudhuri—especially when we contrast with it several accounts that we have of Saha's extraordinary kindness to his students in Allahabad. How could an idealistic man who was so inspiring and charismatic in his younger days change so much?

When several persons of exceptional intellectual ability are put in the same place, two opposing things can happen. On the one hand, interactions amongst them can create a vibrant intellectual atmosphere and enhance the creativity of everybody around. On the other hand, if resources—laboratory space, funding, positions—are too limited for several extraordinary individuals to grow together, that can also lead to a Darwinian struggle for existence. Both of these things happened within the Calcutta physics community. Although Bose and Saha were rivals in the BSc and MSc classes, they were extremely intimate friends in their youth and interacted closely. Apart from writing a joint paper (Bose's first paper), they together prepared the first English translation of Einstein's papers on relativity, barely three years after the publication of Einstein's famous work on general relativity[51]. Apparently Bose's famous work on Bose statistics done in Dacca was also triggered by Saha, who had come to Dacca for some official work and discussed some recent papers, making Bose interested in the problem of energy distribution of photons[52]. Although Bose and Saha never fell out with each other, the intensity of friendship diminished considerably in their later lives. When I asked Saha's daughter Chitra Roy whether Bose sometimes visited Saha at his home or Saha visited Bose at his home when they were both in Calcutta in their later years, Chitra Roy could not recollect any such visits.

To collect reliable information about the conflicts amongst scientists is much more difficult than to collect information about their cooperation. Both Raman and Saha had strong dominating personalities. It is clear that each man admired the other for the other's physics contributions. However, there was a clash of egos between these two titans in the early 1930s that had a disastrous consequence for Indian science. I have mentioned about the drastic changes in the personalities of Raman and Saha. These changes more or less coincide with this clash, making us wonder whether this unfortunate clash was a major contributor in the changes of their personalities. It is not easy to find reliable information of exactly what happened. Some biographers have squarely taken the side of their biographees. For example, Uma Parameswaran[20], the biographer of Raman, would like us to believe that Raman was a faultless person of childlike simplicity who was not to be blamed for any conflicts he was involved in. On the

other hand, Atri Mukhopadhyay[30], who studied Saha's private papers, projects Saha as an innocent victim of the conspiracies hatched by others against him. I find G. Venkataraman to be the *only* author who has been impartial and made the following perceptive comment:

> Clashes between strong personalities are not uncommon and they are to be found everywhere and at all times. But in the academic world, one seldom witnesses events such as those which occurred in Calcutta. The basic problem there was that there was not enough room for both the giants. If only the country had been rich enough to afford several faculty and student positions, this conflict might never have gone beyond minor skirmishes[53].

But even Venkataraman reconstructed events "based on conversations with persons who had first-hand knowledge" and not on the basis of proper documentation. According to Venkataraman, Saha was interested in a professorship created at the Indian Association for the Cultivation of Science and requested the support of Raman, who was the Secretary of the Association. Raman, who wanted this position to be offered to his former student Krishnan, wrote back saying that "lately Saha had not been much concerned about research; what the Association needed was an active young man on his way up rather than one who had reached a plateau"[54]. These letters between Saha and Raman have not been found! Atri Mukhopadhyay dismissed this version as a story fabricated by Raman's supporters. Perhaps the account of the events in a fateful meeting at the Indian Association for the Cultivation of Science that Mallik and Chatterjee[55] have given is as much as we can now establish on the basis of documentary evidence. But what Saha wrote in a letter to P. C. Ray indicates that there were more things happening and the version of Venkataraman may have some truth. Saha's language in the letter is quite shocking:

> Prof. Raman will have to know that if he does not leave the Science Association to Bengal, he will have to meet with determined opposition from me. Ten years administrative experience at Allahabad have not been in vain. He will find a Tartar in me, and you may drop him a hint that is not my only trick. I have got many other obstructive tactics up my sleeve. This time I placed my cards on the table, but next time, I shall not give him even this chance. I will confront him with the difficulties on the spot and make him dance[56].

While these conflicts rose to a crescendo in the early 1930s, there were tussles for scarce resources as soon as the Science College of Calcutta University was established. J. C. Bose and Raman were the two outstanding experimental physicists of that era. It is unfortunate that they fell out with each other very soon. S. N. Bose, who had seen this encounter from a close distance, reminisced many years later:

> when we were students, the professors used to hold on to their mechanics as some of the most precious possessions ... there was a mechanic with Sir J C Bose and he did very fine work—indeed to his amazement. Because Sir C V Raman had cast his jealous eyes on this mechanic ... he grew furious ... this Sir J C Bose wouldn't forget and wouldn't forgive[57].

In fact, J. C. Bose was so furious that he wrote an angry letter to the Vice-Chancellor of Calcutta University, complaining that Raman was trying to lure away this mechanic by offering a much higher salary[58]. While this might have been acceptable in the American academic world, this was certainly unacceptable behaviour in India of that period. Given the fact that J. C. Bose was not employed at Calcutta University, his writing a letter to the Vice-Chancellor clearly shows how disgusted he was. Several years later, when Raman was felicitated by the Mayor of Calcutta on receiving the Nobel Prize, all the important persons in the Calcutta scientific world were there, except J. C. Bose. While there could be other simple explanations for this absence (illness, not being in Calcutta on that day), it appears that the relationship between J. C. Bose and Raman always remained strained. However, when Sommerfeld visited India, J. C. Bose accompanied him for a visit to Raman's lab[59]. Clearly J. C. Bose did not want a distinguished scientist from abroad to know of their differences.

Abha Sur has written about a seminar at Harvard in 1998:

> [The] speaker showed a group photograph of scientists and went about identifying all the European and American scientists in the picture. In cases where the speaker did not know the identity of the scientist, the audience was asked for help. There was C. V. Raman right in the middle of the front row of the picture in his big turban, conspicuous in his difference from the rest of the scientists, but the speaker's pointer simply slid over his imposing personality without a pause, without any hesitation whatsoever. The otherwise alert and inquisitive audience seemed not to mind the omission[60].

Although every physicist around the world is expected to know of the famous works of physics connected with the names of Raman, Bose and Saha, the extraordinary story of how they created their physics fighting against all odds remains largely unknown and untold to the international physics community. This story needs to be told, even if we do not have all the source materials to reconstruct the full history. While this is an uplifting and dramatic story of how the human spirit can conquer many obstacles, this is also a story of great sadness: a story of how the human failings of the extraordinary individuals who created this glorious epoch of physics—all fiercely patriotic and idealistic in their youth—coupled with forces in the colonial setup that was beyond their control, finally extinguished the light that shone with such brilliance for a short epoch.

Notes

1. This meeting has been described by S. N. Bose in an autobiographical article written in Bengali: *Satyendra Nath Basu Rachana Sankalan* (Bangiya Vijnan Parishad, Calcutta, 1980), pp. 226–227. Asutosh Mookerjee's tenure as Vice-Chancellor ended in 1914, though he was again appointed Vice-Chancellor a few years later. Most probably this meeting took place in 1915 when Ghose, Bose and Saha completed their MSc. Then Mookerjee was not the Vice-Chancellor exactly at that time, although he was still very much giving shape to the new activities initiated at Calcutta University.

2. Sailendra Nath Ghose, "An Indian Revolutionary", *Asia*, Part I: p. 586 (July 1927); Part II: p. 671 (August 1927); Part III: p. 737 (September 1927).

3. S. Ramaseshan and C. Ramachandra Rao, *C. V. Raman: A Pictorial Biography* (Indian Academy of Sciences, Bangalore, 1988), quote at pp. 15–16.

4. *Sir Asutosh Mookerjee: A Tribute* (University of Calcutta, 2013), quote at p. 198.

5. Dinesh Chandra Sinha, *Prasanga: Kolkata Biswabidyalay* (University of Calcutta, 2007), quote at p. 250.

6. A fascinating account of Ramanujan's life has been given by Robert Kanigel, *The Man Who Knew Infinity: A Life of the Genius Ramanujan* (Washington Square Press, 1991). This book portrays the academic environment in another region of India at the beginning of the twentieth century.

7. Amal Kumar Raychaudhuri, "A century of progress" (unpublished manuscript). Courtesy: Subinay Dasgupta.

8. S. Ramaseshan (editor), *Scientific Papers of C V Raman*, in 6 volumes (Indian Academy of Sciences, Bangalore, 1988).

9. *S N Bose: The Man and His Work. Part I: Collected Scientific Papers* (S N Bose National Centre for Basic Sciences, Calcutta, 1994).

10. *Collected Scientific Papers of Meghnad Saha* (Council of Scientific and Industrial Research, Government of India, New Delhi, 1969).

11. Santimay Chatterjee (editor), *Collected Works of Meghnad Saha*, in 4 volumes (Orient Longman, 1982–1993)

12. *Satyendra Nath Basu Rachana Sankalan* (Bangiya Vijnan Parishad, Calcutta, 1980).

13. Santimay Chatterjee (editor), *Meghnad Rachana Sankalan* (Orient Longman, 1986).

14. D. S. Kothari, "Meghnad Saha 1893–1956", *Biographical Memoirs of Fellows of the Royal Society* **5**, 217 (1959).

15. S. Bhagavantam, "Chandrasekhara Venkata Raman 1888–1970", *Biographical Memoirs of Fellows of the Royal Society* **17**, 564 (1971).

16. Jagdish Mehra, "Satyendra Nath Bose 1 January 1894-4 February 1974". *Biographical Memoirs of Fellows of the Royal Society* **21**, 116 (1975).

17. Santimay Chatterjee and Enakshi Chatterjee, *Satyendra Nath Bose* (National Book Trust, New Delhi, 1978).

18. Santimay Chatterjee and Enakshi Chatterjee, *Meghnad Saha* (National Book Trust, New Delhi, 1984).

19. "S N Bose: Life", in *S N Bose: The Man and His Work. Part II: Life, Lectures and Addresses, Miscellaneous Pieces* (S N Bose National Centre for Basic Sciences, Calcutta, 1994).

20. Uma Parameswaran, *C. V. Raman: A Biography* (Penguin Books India, 2011).

21. Several of S. Ramaseshan's articles on Raman, though not all of them, are collected in S. Ramaseshan and C. Ramachandra Rao, *C. V. Raman: A Pictorial Biography* (Indian Academy of Sciences, Bangalore, 1988).

22. G. Venkataraman, *Journey into Light: Life and Science of C. V. Raman* (Indian Academy of Sciences, Bangalore, 1988).

23. G. Venkataraman, *Bose and His Statistics* (Universities Press, Hyderabad, 1992).

24. G. Venkataraman, *Saha and His Formula* (Universities Press, Hyderabad, 1995).

25. S. N. Sen, *Prof. C. V. Raman: Scientific Work at Calcutta* (Indian Association for the Cultivation of Science, Calcutta, 1988).

26. S. N. Sen (editor), *Professor Meghnad Saha: His Life, Work and Philosophy* (Meghnad Saha Sixtieth Birthday Committee, Calcutta, 1954).

27. Rajinder Singh, *Nobel Laureate C. V. Raman's Work on Light Scattering: Historical Contributions to a Scientific Biography* (Logos Verlag, Berlin, 2004).

28. Robert S. Anderson, *Nucleus and Nation: Scientists, International Networks, and Power in India* (The University of Chicago Press, Chicago, 2011).

29. Abha Sur, *Dispersed Radiance: Caste, Gender, and Modern Science in India* (Navayana, New Delhi, 2011).

30. Atri Mukhopadhyay, *Abinash Meghnad: Bijnan Samaj Rashtra* (Anushtup, Calcutta, 2012).

31. Dinesh Chandra Sinha, *Prasanga: Kolkata Biswabidyalay* (University of Calcutta, 2007).

32. D. C. V. Mallik and S. Chatterjee, *Kariamanikkam Srinivasa Krishnan: His Life and Work* (Universities Press, Hyderabad, 2012).

33. P. C. Ray, *Life and Experiences of a Bengali Chemist*, 2 volumes (Chuckervertty, Chatterjee and Co., Calcutta, 1932 and 1935).

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