K S Krishnan as Co-discoverer of Raman Effect and as Independent Scientist

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Abstract

K S Krishnan worked in C V Raman's laboratory as a research associate and carried out experiments on light scattering in liquids and vapours. He was involved in the experiments that led to the discovery of the Raman effect. Afterwards Krishnan charted out his own path and initiated work on magnetism in solids, first in Dacca and then at the Science Association, where Raman created the Mahendra Lal Sircar Chair and invited Krishnan to it. Later Krishnan was Professor of Physics in Allahabad and then the Founder-Director of the National Physical Laboratory. He never worked on light scattering in liquids beyond the early days after the discovery of the Raman effect. He established a high reputation as a pioneer in the field of condensed matter physics.

Key words: C V Raman, K S Krishnan – diary, Raman effect, work on magnetism.

1. INTRODUCTION

I may be excused for beginning with a provocative remark: 'Raman Effect was actually discovered by K S Krishnan in 1925 and for whatever reason he never received the due credit for it.' In 1932, recommending Krishnan for a professorship at the Andhra University in Waltair, Raman wrote:

If the Nobel award for Physics made in 1930 had been based on the record of the year 1928 alone, instead of on the entire work on the scattering of light done at Calcutta from 1921 onwards, Krishnan would in justice have come in for a share of the Prize (Mallik and Chatterjee, 2012, p. 136).

But this statement conceals more than it reveals, since Krishnan had been involved with the scattering experiments right from the beginning, at least since 1923 when he formally joined Raman's laboratory at the Indian Association for the Cultivation of Science as a research associate. The paper I am referring to

appeared in 1925 in *Philosophical Magazine* (Krishnan, 1925).

Krishnan arrived in Calcutta in July 1920 just when the post-graduate classes in physics were about to begin. Raman insisted that he enrolled in M.Sc. physics and studied for two years as a preparation for launching into a research career. He never appeared for the M.Sc. examination but joined Raman in 1922 at the Science Association to start his research career.

2. DISCOVERY OF RAMAN EFFECT

In 1924, Raman was elected to the Fellowship of the Royal Society and soon after, he was invited to Toronto to attend a meeting of the *British Association for the Advancement of Science*. In that meeting, Arthur Compton was engaged in a lively debate with one William Duane on the Compton Effect in X-ray scattering. Here incident X-rays were scattered in a medium and

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the scattered beam had a lower frequency, as part of the energy was imparted to the ejected electron. Duane questioned Compton's interpretation of the phenomenon based on the quantum hypothesis. Surprisingly, Raman too sided with Duane. In the book *The Compton Effect turning point in physics*, the author Robert Stuewer quotes Raman saying to Compton: 'You are a good debater, but the truth isn't in you' (Stuewer, 1975, pp. 268-69).

Raman was against the interpretation of the effect based on quantum hypothesis and was of the view that the wave theory of light was adequate to explain the phenomenon observed by Compton. But the fact that radiation of a different wavelength than the incident one was seen in a scattering process had stirred Raman's imagination and he wanted to see the same effect in light scattering.

During Raman's absence in 1924, Krishnan had embarked on an elaborate experimental study of light scattering in a large number of liquids. He studied more than 60 dust-free liquids, determining in each case the properties of the scattered light in blue, green and orange regions of the spectrum. He found that some of the liquids were 'feebly fluorescent'. The blue region of the spectrum excited 'fluorescence' in the green. In discussing the results on these liquids, Krishnan noted the following:

To see how this would influence the polarisation, let us, for example, consider the case where the blue region of the spectrum excites a fluorescence in the green. With the blue filter in the path of the incident beam, the scattered light would be mixed up with the fluorescent light, and if we may assume that the fluorescent light is mostly unpolarised, the light observed would show an abnormal imperfection of polarisation. On transferring the blue filter to the path of the scattered beam, however, the imperfection would become normal. If instead of a blue filter, we use a green filter, normal polarisation would be observed when the filter is in the path of the incident beam, and an abnormally high polarisation when in the path of the scattered beam.

This implies that the so-called 'feeble fluorescence' was polarised! The paper was communicated by Raman to *Philosophical Magazine* in 1925 and appeared in October of that year (Krishnan, op. cit.).

I now do a fast forward to February 1928 and under February 7, 1928, Krishnan's Diary says (Mallik, 2000, pp. 75-76):

Incidentally discovered that all pure liquids show a fairly intense fluorescence in the visible region, and what is much more interesting all of them are strongly polarised. ... In fact the polarisation of the fluorescent light seems in general to run parallel with the polarisation of the scattered light, i.e. the polarisation of the fluorescent light is greater the smaller the optical anisotropy of the molecule. When I told Professor about the results he wouldn't believe that all liquids can show polarised fluorescence and that in the visible region. When he came into the room, I had a bulb of pentane in the tank blue with violet filter in the path of the incident light, and when he observed the track with a combination of green & yellow filters he remarked "you don't mean to suggest, Krishnayengar all that is fluorescence?!" However when he transferred the green yellow combination also to the path of the incident light he couldn't detect a trace of the track. He was very much excited and repeated several times it was an amazing result. One after another the whole series of liquids were examined and every one of them showed the phenomenon without exception. He wondered how we missed discovering all that five years ago.

We too wonder and the question why this was not pursued with intensity in 1925 itself remains unanswered. In 1928, they termed it 'modified scattering' and knew that this was the effect predicted theoretically by Kramers and Heisenberg (1925). It is not clear when Raman and/or Krishnan saw the Kramers-Heisenberg paper. Two years had gone by and Krishnan's attention had been diverted to other problems in the meanwhile.

In 1927, Compton won the Nobel Prize in physics and this spurred Raman on to prompt action. He asked S Venkateswaran to study light

scattering in glycerine and the latter found that the scattered beam of sunlight was of intense green colour instead of blue as it should have been. Raman asked Krishnan to follow this up. Krishnan confirmed the result, and found the scattered light to be highly polarised. He continued experimenting with other organic liquids. On February 16, 1928, Raman and Krishnan (1928) wrote up the first of the four discovery papers with the title 'A new type of secondary radiation' and sent it to *Nature*.

On February 28, Raman and Krishnan decided to

examine the influence of the wavelength of the incident light on the phenomenon. Used the usual blue violet filter coupled with a uranium glass, the range of wavelengths transmitted by the combination being much narrower than transmitted by the blue violet filter alone. On examining the track with a direct vision spectroscope we found to our great surprise the modified scattering was separated from the scattering corresponding to the incident light by a dark region. This encouraged us to use mono-chromatic incident light (Krishnan's Diary Mallik, 2000, p. 78).

They used a mercury arc. By a suitable filter arrangement they eliminated all radiation redward of the prominent 4358 angstrom line and watched the scattered radiation through the spectroscope. They were thrilled to notice the appearance of faint additional lines in the red in the scattered beam. It was late afternoon when the *Raman Effect* was discovered. Raman asked Krishnan to photograph the spectrum of the scattered beam. This needed some ingenuity and enormous patience, since the weakness of the 'modified' lines required long exposures to be taken. The first liquids examined were benzene, toluene and pentane and in each case the 'modified' lines were seen. Next day, February 29, 1928 the news of the discovery was released to the Associated Press.

3. THE DISCOVERY PAPERS

During the span of twelve months, February 1928 to January 1929, Raman and

Krishnan wrote no less than fourteen original papers on the Raman Effect. Of these, eight were jointly authored by them; Krishnan wrote another four under his sole authorship. The remaining two appeared under Raman's sole authorship. The first of these, which came to be known as **the Discovery Paper**, with the title 'A change of wavelength in light scattering' was sent to *Nature* by Raman without Krishnan's knowledge (Raman, 1928a). Krishnan learnt about this paper later when the proofs arrived. The other one was a written version of Raman's talk at Central College in Bangalore, where he spoke on March 16, 1928, and which eventually appeared in the *Indian Journal of Physics*, which Raman edited (Raman, 1928b).

All the descriptions of the history of the discovery have been based on three sources — (1) Raman's paper in the *Indian Journal of Physics* (Raman, 1928b), (2) Raman's speech at the Nobel Award ceremony and most importantly, on an elusive document known as (3) *Krishnan's Diary* (Mallik, 2000). The Diary relates day-to-day events in February 1928 but ends abruptly in the middle of a sentence on February 28 which says — 'this encouraged us to use monochromatic incident light ...'. Krishnan told Subrahmanyam Chandrasekhar that he had kept a diary from January to April which he wished to deposit at The Royal Society Archives. Obviously, he did not do it. Only a few pages have been found among the Krishnan papers kept with his family.

4. DACCA: 1928 - 1933

In July 1928, the University of Dacca advertised the post of a Reader in Physics. S N Bose, who headed the Department of Physics, was making a serious effort to build a competent experimental group. Raman was on the Selection Committee and he urged Krishnan to apply. Krishnan had a very high regard for Bose and knew proximity to a theorist of his stature would be beneficial to his own growth. Krishnan also

felt that although his contribution to the great discovery was recognised by Raman and others in the Science Association, in the public eye he was still playing the second fiddle. Raman was extremely possessive of the discovery and he was not really ready to share the credit of it with anyone else. That the paper 'A change of wavelength in light scattering' was sent to *Nature* under Raman's sole authorship without Krishnan's knowledge bothered Krishnan. He was also aware that Raman was in correspondence with some eminent physicists in Europe seeking nomination for himself for the 1929 Nobel Prize. Krishnan felt that to establish his own reputation as an independent scientist, he had to get out of Raman's orbit.

In September 1928, Krishnan sent in his application to Dacca. It was accompanied by testimonials from Raman, D M Bose, S K Mitra and P N Ghosh. In due course Krishnan was appointed to the Reader's post. He arrived in Dacca in December 1928.

In Dacca, Krishnan turned his attention to magnetism. He decided to explore the relationship between the magnetic properties of minerals and solids and the inherent structural properties of the crystals that made them. For the better part of the next twelve or thirteen years Krishnan and his students worked intensely in this field. There were two broad themes to their research — diamagnetic anisotropy measurements to provide clues to molecular orientations in crystals and magnetic properties of paramagnetic salts. Their experimental work provided the required quantitative base to test the new theories of magnetism in solids which were being developed by Bethe, Van Vleck and others.

Krishnan's major collaborators in the work on crystal magnetism were students from Dacca. They were Bhagawati Charan Guha who later taught magnetism in the post-graduate classes in Calcutta to generations of students, and Santilal Banerjee, Asutosh Mookherjee and Akshayananda

Bose. Later in 1937/38, Akshoy Bose and he designed and built the first cryostat in the country and they were able to make measurements of magnetic susceptibility down to the temperature of liquid oxygen, 90K. Bose later distinguished himself as a low-temperature physicist and founded the Cryogenic Council of India.

The results on crystals of a great variety of materials were published in a series of six long papers in the *Philosophical Transactions of the Royal Society*. According to Lonsdale and Bhabha (1967), 'The papers were the foundation stones of the modern fields of crystal magnetism and magneto-chemistry'.

Krishnan's seminal contribution to these fields won him international acclaim and established him as one of the leading authorities in the field of magnetism. In 1940, Krishnan was elected to the fellowship of The Royal Society and he thus became a member of an exclusive club which had only three other names on it at that time — C V Raman, M N Saha and Birbal Sahni.

5. MLS PROFESSOR OF IACS: 1933 - 1942

In early 1933, Krishnan put together a set of preprints and reprints of his work done between 1927 and 1933 and submitted them along with a thesis titled *Magnetic susceptibilities of crystals in relation to crystal structure* to the University of Madras supplicating for the D.Sc. degree. He was awarded the degree later in the year. He was thinking of taking a two-year study-leave to go to Cambridge, England to pursue more intensely his research on magnetism. He applied for a Carnegie Fellowship tenable in UK for the purpose. But his plans were totally derailed by a new initiative planned by his mentor C V Raman and Krishnan had to return to his old institution, the Indian Association for the Cultivation of Science as a Professor in the newly created chair named after Mahendra Lal Sircar. Raman was to leave the institution shortly as he had accepted the post of Director at the Indian Institute of Science,

Bangalore. The move by Raman to have Krishnan back in Calcutta as the MLS Professor was perceived by many as a deliberate attempt on Raman's part to retain control of the institution through his student. Raman paid no attention to the rumours doing the rounds that he only favoured students and scholars from the South and ignored those from Bengal, nor did he take any step to dispel the lurking fears among the people that he wanted full control of the Science Association even after he moved to Bangalore.

In a letter dated November 21, 1932 to the Science Association President Rajendranath Mookerjee, Prafulla Chandra Ray expressed his displeasure with several things that were happening in the Association. In response, Rajen Mookerjee wrote:

In regard to the Indian Science Association, I am only nominally the President. I lent my name at the request of Raman, in order to enable him to secure financial support from the Government. I do not think I attended more than one meeting a year during the period I have been the President and only on the occasion of the last meeting I enquired of Raman about the long intervals at which Committee meetings were called. I have also heard the complaints about the non-admission of Bengalee students, but I hadn't seen the press agitation until you sent me the file. But the President or the Committee have not been functioning and the entire blame must rest with Raman (Chakrabarti, 2009, p.318).

The press agitation that Mookerjee refers to is a series of articles that came out in the *Ananda Bazar Patrika*, a widely circulated daily in Calcutta, and they were severely critical of Raman. One of Raman's former students, C M Sogani, who was then a Professor of Physics at the Benares Hindu University, published a letter refuting some of the charges and produced a list of some twenty Bengalee students who had worked or were still working with Raman at the Science Association (Sogani, 1932). The letter produced no effect among the dissenters. As far as Raman was concerned, he went ahead with his plans.

It is significant that Acharya P C Ray was unhappy, for until quite recently he had been an admirer and a friend of Raman. In the speech that Raman had given at the felicitation function by the Calcutta Corporation when he had returned with the Nobel Prize, he had mentioned his gratitude to the Late Sir Asutosh Mookerjee and his happiness to have Acharya P C Ray as a colleague.

In a meeting on May 20, 1933 of the Managing Committee of the Association chaired by its Vice-President Sudhangshu Banerjee, Raman formalised the institution of the Mahendra Lal Sircar Chair and Krishnan's appointment to it. At the outset, Banerjee read out a letter from the President Sir R N Mookerjee who wanted to resign from that position. This was accepted. Raman had already co-opted his wife and his elder brother C Subrahmanyam Ayyar as members of the M. C. and they were present. C S Ayyar and one Rama Pai proposed Raman's name as the new President and Raman then proposed Krishnan as the new Secretary. These suggestions were accepted without a note of dissent. But a little later when the names of Syama Prasad Mukherjee, Rama Prasad Mukherjee and the chemist J N Mukherjee were proposed for new membership, the proposal was voted down. At this point two members of the Managing Committee left the meeting in a huff (Mallik and Chatterjee, 2012, p.139).

Krishnan formally joined the Science Association as the first MLS Professor on December 21, 1933. He continued with the magnetic work. The Association laboratories had all the necessary infrastructure. His hands were full with administrative work and work related to the *Indian Journal of Physics* which he and Raman edited. But this situation did not last long.

Raman wanted further changes in the Statutes of the Association and these had to be endorsed by the General Body of the Association. Several months had passed and in the intervening

period a lot of bad blood was created by Raman's founding the Indian Academy of Sciences (April 30, 1934) in Bangalore pre-empting the move by the Indian Science Congress Association under the leadership of M N Saha, S P Agharkar, and L L Fermor to create an all-India academy in Calcutta. On June 19, 1934, in a General Body Meeting of the Association, the changes in the Statutes proposed by Raman were rejected. Syama Prasad Mukherjee wrested the control of the Science Association from the hands of Raman who was forced to resign. The eminent doctor, Nil Ratan Sircar, took over as the President of the Association and S K Mitra became the Secretary. Krishnan was relieved of his administrative duties and editorial responsibilities but retained his Professorship. Raman left the Association altogether and resigned from the Palit Professorship.

Shorn of his administrative and other responsibilities, Krishnan could now devote his entire attention to research. However, the work environment in the Science Association had undergone a big change and it did not take Krishnan long to discover that the new management was not favourably disposed towards him. He was looked upon as a remnant of the Raman legacy and his presence was a reminder of the past that the new dispensation wanted to forget.

At the meetings of the Managing Committee of which he was still a member, things were made difficult for him and attempts were made to disrupt the smooth course of his research. In a letter to Chandrasekhar dated May 3, 1935, he said:

At the Assocn. things are getting quite unpleasant, and had it not been for old memories and associations of the laboratory I should have left it long ago. I am quite tired of fighting against a crowd in every meeting. The only redeeming feature is that the Govt of India, which finance us, are very friendly, and extending their grant for another term of five years (Mallik and Chatterjee, Chapter 10, p.156)

The situation improved after Walter Jenkins came on the Board of Management as a Government nominee. Jenkins, who had started the Physics Department in Dacca, knew Krishnan well, and was supportive of his research needs and arranged for adequate funds from the Government.

In 1942, at a crucial stage in his career, Krishnan was forced to leave Calcutta due to some extraneous circumstances. The city was under threat from a Japanese attack and the Association management had decided to close down the laboratories and shift the equipment to a remote location in Bengal to secure their safety. Krishnan's persuasive arguments to prevent this fell on deaf ears.

6. FINAL COMMENTS

In the K S Krishnan Birth Centenary Special issue of *Current Science*, the sociologist Shiv Visvanathan (1998) titled his article as 'The tragedy of K S Krishnan : A sociological fable'. He began with the statement that 'A lot of Krishnan has been hidden in the crevices of the Raman myth. It is time to tease him out.' I do not know how far Chatterjee and I have succeeded but we tried to do this with our book on Krishnan which came out in 2012 (Mallik and Chatterjee, 2012).

Beyond the decision to join Raman's Laboratory in 1920, when he was only 22 years old, Krishnan was never given a choice where he wanted to work. He left the Science Association and went to Dacca as a Reader in Physics, partly due to Raman's insistence. Raman wanted him back in Calcutta in 1933 and his unflinching loyalty to his guru won over his desire to pursue a more exciting research programme at the Mond Laboratory of the University of Cambridge. In Calcutta he was exposed to a huge turmoil caused largely by Raman. Krishnan did suffer but his outward behaviour and his research activities give

no indication of it. In 1942, much against his own wish, just when his research work was heading in a very important direction, which could perhaps have led to the discovery of semi-conductors a few years ahead of the actual discovery made in the US, he was forced to leave Calcutta for Allahabad to occupy the chair vacated by Meghnad Saha four years earlier.

In Allahabad, with wartime restrictions and in a department that was in disarray after four long years of neglect, Krishnan could make no progress in his experimental work as he had to concentrate on reviving the department first. He turned to theory and while he, along with his student Avadh Behari Bhatia, was deeply involved in research on Electrical Resistivity of Liquid Metals, he was dragged by Nehru at the instance of S S Bhatnagar to Delhi to head the National Physical Laboratory, a place very different from a university. According to Visvanathan (1998), this was a disastrous move because Krishnan was hardly the right person to head an industrial laboratory. He was a quintessential university man and his heart was in pure research.

In Delhi he started two major initiatives – he succeeded in starting Low-temperature Physics in India but he failed to start Radio astronomy, which had to wait till Bhabha took it up in the early 1960s in TIFR. By that time K S Krishnan was dead. Krishnan lived his life with great dignity and unquestionable integrity, rare among today's scientists. In each of the messy situations that he landed, he managed to keep his calm and composure, he never lost his sense of humour and he let his science speak.

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BIBLIOGRAPHY

- Chakrabarti, S. *Oitijhya Uttaradhikar O Bijnani Prafullachandra*, 2009.
- Kramers, H and Heisenberg, W. On the scattering of radiation through atoms, *Zeitschrift für Physik*, 31 (1925): 681.
- Krishnan, K S. On the molecular scattering of light in liquids, *Phil. Mag.*, 50 (1925): 679.
- Lonsdale, K and Bhabha, H J. Kariamanikkam Srinivasa Krishnan, *Biographical Memoirs of the Fellows of the Royal Society*, 13 (1967): 244.
- Mallik, D C V. The Raman Effect and Krishnan's Diary, *Notes and Records of the Royal Society of London*, 54 (2000):67.
- Mallik, D C V and Chatterjee, S. *Kariamanikkam Srinivasa Krishnan: His Life and Work*, Universities Press, Hyderabad, 2012.
- Raman, C V. A change of wavelength in light scattering, *Nature*, 121 (1928a): 619.
- Raman, C V. A new radiation, *Indian J. Phys.*, 2 (1928b): 387.
- Raman, C V and Krishnan, K S. A new type of secondary radiation, *Nature*, 121 (1928): 501.
- Sogani, C M. The Advance, December 15, 1932.
- Stuewer, Robert H. *The Compton Effect Turning Point in Physics*, Science History Publications, New York, 1975, pp. 268-269.
- Visvanathan, S. The Tragedy of K S Krishnan: A sociological fable, *Current Science*, 75 (1998): 1272.