Indian Journal of History of Science, 53.4 (2018) T68-T73 DOI: 10.16943/ijhs/2018/v53i4/49527

How Costly was Raman's Equipment for the Discovery of Raman Effect?

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(Received 23 March 2018; revised 9 May 2018)

Abstract

In 1928 C V Raman and his students found out that when monochromatic light is scattered by a transparent media, the scattered light contains not only the original colour, but also other colours; which give information about the molecular structure of the scattering substance. For this work on light scattering, known as Raman effect, Raman, the first Asian, received the Physics Nobel Prize in 1930. That the discovery worth a Nobel Prize costs only a few hundred rupees is seen with awe and in circulation for quite some time in the country. An analysis of the price of total number of instruments (including associated components) required by Raman for this discovery has been made and presented in this paper. It shows that the actual cost of the instrument is far more than that is commonly believed.

Key words: C V Raman, K S Krishnan, Nobel Prize, Raman effect, Scientific instruments.

1. Introduction

Scientific inventions and discoveries are the result of hard work of many years; and can not be measured by the amount of money spent, especially for any path-breaking discovery like winning a Nobel Prize. Same is true for Raman and the discovery of the Raman effect.[1] C V Raman[2], who initially started research on acoustics in the beginning of the 1920s, diverted his attention to observe the scattering of light. In a monograph '*Molecular diffraction of light*', he reviewed the work in this field (Raman, 1922). From 1922 onwards, the hard work done by Raman and his students from 1922 till 1928, led to the discovery of the Raman effect. After India's independence in 1947, mythical stories regarding the cost of instruments Raman used for the Nobel winning discovery started appearing. For example, according to '*The National Herald*' of Nov. 14, 1948 issue, Raman's instruments costed 400 Rupees. Just a week earlier, on Nov. 7, 1948, '*The Indian News Chronicle*' quoted the same price. The newspaper '*The Bharat Jyoti*' on Jan. 15, 1950, quoted Raman as follows: 'The apparatus costed me exactly 300 Rupees!' In 1970, Raman said: 'When I got my Nobel Prize, I hardly spent 200 Rupees on my equipment' (Bhavan Journal, 1970, pp. 73-75; Brand, 1989, pp. 1-25). This cost exploration continued for quite some time mainly by Raman's students. For instance, A Jayaraman wrote: 'It is of particular significance that the equipment which Raman employed for the discovery was very simple and amounted to a total cost of 500 Rupees at the time' (Jayaraman, 1989a, pp. xix-xxviii). According to R S Krishnan and R K Shankar: '…, the total cost did not exceed $ 25' (Krishnan & Shankar, 1981, pp. 1-8).

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[1] This article is based on chapter "Instruments for the discovery of the Raman effect", in Singh (2018).

[2] For various aspects of Raman's life see, Keswani (1980); Sen (1988); Venkataraman (1994); Jayaraman (1989); Singh (2004); Parmeswaran (2011); Biswas (2013); Banerjee (2014).

In the following we shall see that the price given by Raman and his students is far from the true cost when cost of all associated equipment used for the discovery is taken into account. Raman did not use just one spectroscope (Fig. 1) for the discovery; but many more instruments to take spectrum to determine the wavelength and polarization of the scattered light (Fig. 2).

Fig. 1. Spectroscope used by C V Raman for the discovery of the new effect. (Credit: Indian Association for the Cultivation of Sciences, Calcutta.

To start with, we need to discuss, when the discovery of the Raman effect began and when it ended.

2. Initial Papers on the Discovery of the Raman Effect and Instruments therein

On Feb. 16, 1928, Raman and K S Krishnan[3] sent a paper entitled: 'A new type of secondary radiation.' It was published on March 31, 1928, in the British journal *Nature*. Thereafter the authors reported the observation of a new effect, that is, a modified scattered radiation of degraded frequency, in the case of dust free liquids and gases (Raman & Krishnan, 1928a, pp. 501-502). They argued that it is not fluorescence, which is also an effect associated with change of wavelength, because: (i) the effect is feeble. (ii) the polarisation of the scattered light is quite strong and comparable with the polarisation of the ordinary scattering.

This paper cannot be seen as discovery, because Peter Pringsheim, Berlin; argued that: (i) by lowering the concentration of a substance, the intensity of the fluorescent can be made small, (ii) from Raman's own work and others, it is well known that the radiation is very often depolarised up to 50% in the direction of observation due to anisotropy of the molecules, (iii) apart from that under various other conditions, the fluorescence light might be polarised (Pringsheim, 1928, pp. 597-606).

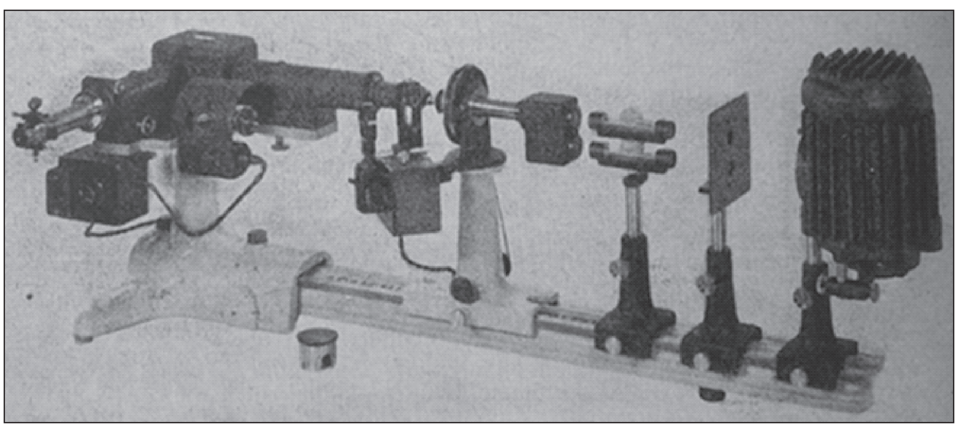

Fig. 2. All the individual parts (from left to right – constant deviation spectroscope, Nutting polarisation photometer, filter and mercury arc lamp) are fixed on a heavy massive iron bench as they should be in a laboratory (Brode, 1943, pp. 165-166)

[3] For Krishnan's description on the discovery, see, Mallik, 2000.

The next paper, signed by Raman alone, sent on March 8, 1928, was published in *Nature* on April 21st, 1928. In it, Raman wrote:

> The preliminary visual observations appear to indicate that the position of the principal modified lines is the same for all substances, though their intensity and that of the continuous spectrum does vary with their chemical nature (Raman, 1928a, p. 619).

Here we see, that Raman draw wrong conclusion regarding the position of the modified lines. Other paper, dated March 22, 1928, entitled 'The optical analogue of the Compton effect' was sent by Raman and Krishnan to *Nature*. It contains the spectrogram of toluene with modified lines of longer wavelength and the incident mercury vapour lines (Raman & Krishnan, 1928b, p. 711). This was the first spectrogram published by Raman in a western journal. Therein Raman corrected his results by stating 'It is found that the shift of wavelength is not quite the same for different molecules, …'(Raman & Krishnan, 1928b, p. 711).

In his lecture at the South Indian Science Association, Bangalore, on March 16, 1928, Raman presented Fig. 3. The lecture was published in the *Indian Journal of Physics* (Raman, 1928b, pp. 387-398).

In all the above stated articles, Raman reported the observation of modified lines of longer wavelength as in the case of Compton effect.

From the theoretical work of the Austrian scientist A Smekal (1925, pp. 241-244); and H A Kramers and W Heisenberg (Kramers & Heisenberg, 1925, pp. 681-708), Raman knew that scattered light also has shorter wavelength than that of the incident light. In their article of May 7, 1928, Raman and Krishnan reported for the first time the observation of such lines (Raman & Krishnan, 1928c, pp. 399-419).

Raman's experimental results confirmed the correctness of the theory. Obviously, Raman's discovery was complete only after the qualitative results were given.

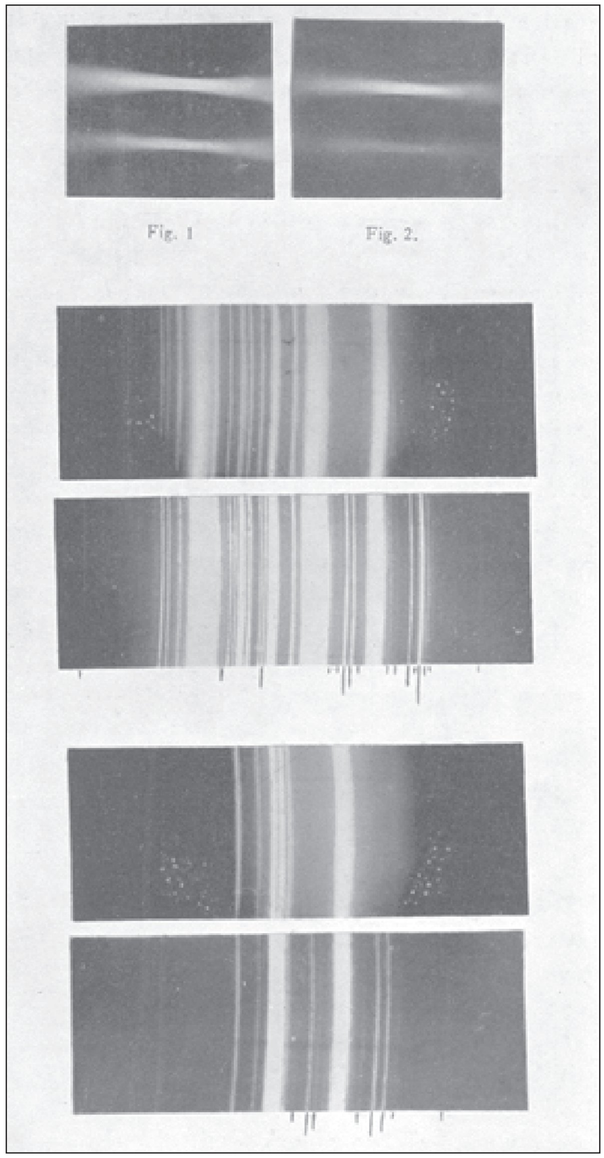

Fig. 3. Top: Polarisation of scattered light in toluene for incident light (Fig. 1) and scattered light due to Raman effect (Fig. 2). Middle-upper: Mercury arc light filtered through a blue glass with transmission range from 350 to 440 Nanometer. Middle-lower: Scattered spectrum of benzene with additional lines. Bottom-upper: Mercury arc incident light filtered with potassium permanganate solution. Bottom-lower: 'Raman' Scattered spectrum. Courtesy: IACS.

What we see from the forgoing discussion that neither the first nor the second paper can be seen as 'the discovery', as wrong conclusions were

Table 1. Various parts of apparatus mentioned in the first four articles on the discovery of the new effect.[4]

Article No.	Instruments/Apparatus used
1. 'A new radiation' (Raman, 1928b, pp. 387-398)	Sources of light: Sunlight, a quartz mercury arc lamp. Other instruments – Heliostat, 7-inch telescope objective, and a lens of short focal length. Direct vision spectroscope, a small Hilger quartz spectroscope. Polarisers - A double image prism. 80 liquids/vapours/gases/crystals either in 'glass-bulbs' or in 'steel vessel.' Filters: Corning glass G. 586, blue, violet, green; solutions of potassium permanganate and quinine sulphate.
2. 'A new type of … radiation' (Raman & Krishnan, 1928a, pp. 501-502)	Sunlight, a telescope objective of 18 cm aperture and 230 cm focal length, a second lens of 5 cm focal length, 60 liquids, and filters: blue-violet and green-yellow.
3. 'A change of wavelength in the light scattering' (Raman, 1928a, p. 619)	Sunlight, mercury arc lamp, filters, polariser, a steel vessel, (chemicals') vapours, and a direct vision spectroscope.
4. 'A new class of spectra … Part I.' (Raman & Krishnan, 1928c, pp. 399-419)	3000 C P (candle power) quartz mercury vapour lamp; 8-inch glass condenser; glass bulb; chemical studied – benzene, toluene, pentane, ether, methyl alcohol and water; glass filters; direct vision spectroscope; constant deviation spectrometer; Adam Hilger E2 quartz spectrograph; Ilford-Iso-Zenith photographic plates; Adam Hilger travelling micrometer; Nutting photometer.

drawn; and also the observations were only visual; which could hardly be verified by others. The third article based on Raman's lecture contains polarisation as well as the new lines as written by Raman in the first two papers; however, in the paper, neither qualitative nor quantitative results, which match with theory, were given. This was done in a publication in the beginning of May 1928, as the article by Raman and Krishnan indicates (Raman & Krishnan, 1928c, pp. 399-419).

In Table 1 instruments mentioned by CVR and KSK in the four 'discovery' publications are given. The order of the articles is according to the date of publication. The paper 'The optical analogue of the Compton effect' has not been considered in the table, because it did not give new information regarding the instruments.

Details of the above mentioned instruments, as well was instruments made by Raman for the study of liquids; and vapours under normal and high pressure are given elsewhere (Singh, 2018, pp. 17-46). In order to study the spectra of the scattered light, spectroscopes were necessary. Raman had different type of spectroscopes such as direct vision spectroscope, constant deviation spectroscope, small size spectroscope, Quartz Spectrograph E2 and Quartz Spectrograph E1.

Raman's publication from the year 1909 shows that the IACS had facilities for photography and photometric measurements. In order to photograph spectra Raman took Ilford Iso-Zenith photographic plate of the type 700 HD (Singh, 2018, pp. 33-36). In order to determine the position of the unknown lines in spectrum, comparator or micrometer eyepiece were required. Fig. 3 shows the first spectrogram with new lines taken by Raman. For the quantitative results, it was necessary to estimate the wavelength of the lines. One of Raman's students Sukumar Chandra Sirkar recalled that Raman did not took iron arc comparison spectrum on the spectrogram. He was asked by Raman to evaluate the plates with the Adam Hilger comparator which was available in the laboratory (Sirkar, 1988, pp. 54-58). The micro-photographic record of liquid benzene was

[4] Table taken from Singh, 2018, p. 16.

Table 2. Instruments and their price

Instruments/Apparatus/Chemicals	Price £-s.-d.	Approximate price in Rs.
Direct vision spectroscope (Adam Hilger, 1921, unpaged)	Minimum 2	20
Small quartz spectroscope (E6) (Adam Hilger, *ibid*).	48	480
Constant deviation spectroscope – Large model (D19) without Camera.[5]	211-13-9	2110
Adam Hilger E2 spectroscope (Adam Hilger, 1921, "current price, June)	145-0-0	1450
Hilger-Nutting photometer (Adam Hilger, 1931, p. D2) (H56) + Stand for Tube (H57) + 2 Tubes for liquids (H58)	77-0-0 + 5-7-6 + 3-19-0	860
Microphotometer (Adam Hilger, 1921, pp. L1-L3) ("Photo measuring micrometer") L1	115-0-0	1150
Heliostat (L7) (Adam Hilger, 1921, p. L7)	62-0-0	620
Thermopile, etc., and wavelength drum calibrated (Adam Hilger, 1931, p. D2) to 2.0μ (F430)	57-0-0	570
Broca galvanometer (F91) (Adam Hilger, 1931, p. D2) + Scale on stand (F93)	19 + 4	230
Combined spark holder and arc lamp (F449) (Adam Hilger, 1931, p. D2)	14-10-0	140
Total cost		7630

taken by Raman using Nutting photometer (Fig. 2). Raman also required spectroscope and polarizer with a special mount, for the determination of polarization (Fig. 3).

Table 2 shows the cost of some of the instruments. Raman got Rs. 3000 to buy E1 spectroscope, which cost 311 pounds. This would suggest that one pound was equivalent to about Rs. 10. In the Table 2, we take 1 pound equivalent to only Rs. 10 to find out the cost of Raman's instruments (Singh, 2018, p. 46).

So, we see that the total amount is Rs. 7630. This does not contain the costs of Adam Hilger comparator, condenser (lens from telescope), 80 chemical probes and 80 cells, 36 double-bulbs (AR-IACS, 1925, pp. 126-127), mercury arc lamp (Hewittic), cross-tubes for gases/vapours, Ilford-Iso-Zenith photographic plates[6], chemicals used for photography and a set of 7 monochromatic Wratten glass filters (which cost about 20 US Dollars).[7]

Also, we have not considered the cost of manpower. For instance, in 1927 in Raman's laboratory at the IACS, there were 36 research workers. Out of them 23 were whole time workers (AR-IACS, 1927, p. 291). In the year of discovery, that is, 1928, there were 32 research workers. Out of them 21 were full-time (AR-IACS, p. 435).

3. Conclusions

The fact is, Raman made a Nobel winning discovery using instruments costing between 200 to 500 Rupees is not correct. Such an impression was created because the complete experimental set-up required by Raman for the discovery had never been considered in the past. The statement like: 'The apparatus used by Raman for the discovery consisted of a mirror for deflecting sunlight, a condensing lens, a pair of complementary glass filters, a flask containing benzene and a pocket spectroscope, …'(Krishnan & Shankar, 1981, pp. 1-8) is an understatement.

[5] The total cost in Pounds: spectrometer + levelling screw + mahogany case + camera = 211-13-9 + 3-11-9 + 9-7-6 + 22-0-0 = 245-33-4. (Adam Hilger, 1921:unpaged).

[6] The price of plates in October 1940 - The largest plates, 38cm x 30.5cm were £3 9s 9d for 12 plates. Fisher Maurice to Singh R., July 21, 2017. (Private communication).

[7] Mercury vapour lamp monochromatic filter - Set of 3 - yellow, green and violet. Price 4 Dollars. Single filter 1.35 Dollars. (Eastman Kodak Company, 1919).

Any path-breaking discovery can not be measured by the amount of money spent on the programme and it is not the purpose of the paper to belittle either Raman or his discovery. The amount of money spent even when converted to present valuation is awfully insignificant. It was Raman's deep knowledge in physics, innovative mind and devotion to work that helped him to get the Nobel using such an insignificant money.

Acknowledgements

I am thankful to Prof. S C Roy, Editor-in-Chief, *Science and Culture* for correcting the early version of this paper. Archivists, librarians and curators of the following institutions are thanked for helping me in collecting materials referred to in this paper: Science Museum London; Adam Hilger Archive London; University of Calcutta; and Indian Association for the Cultivation of Science, Kolkata. Last but not the least, I thank Prof. Arnab Rai Choudhuri and Prof. Deepak Kumar for editorial work.

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