BIDHU BHUSHAN RAY AND THE GLORIES

RAJINDER SINGH*

Bengal based physicist Bidhu Bhushan Ray/Bidhubhusan Ray/Bidhu Bhusan Ray or B.B. Ray is known for his researches in the field of x-ray spectroscopy. He started his carrier as a researcher under C.V. Raman's guidance. The less known fact is that B.B. Ray's D.Sc. thesis was in the field of meteorology. This short paper deals with his researches on light scattering and the theory of the glory.

Introduction

Bidhu Bhushan Ray is an unsung hero in Indian science. He is considered as one of the pioneers of the x-ray spectroscopy in India. The record of the University of Calcutta shows that the Board of Examiners of the University appointed G.C. Simpson, J.W. Nicholson and E.H. Barton to evaluate his D.Sc. thesis. On 1st November, 1922, they submitted the following report: "We have examined the thesis submitted by Mr. Bidhubushan Ray, M.Sc., and consider that the work described in the thesis is of sufficient merit to warrant the conferment upon Mr. Bidhubushan Ray of the Doctorate. The main thesis entitled "The scattering of light by liquid droplets and the theory of coronas, glories and iridescent clouds" deals with an interesting branch of meteorological optics and the results obtained by Mr. Bidhubushan Ray are new and valuable."[1]

To the best knowledge of the author†, there is no biography of B.B. Ray; however a few short articles provide glimpses of his life.[2,3,4,5] The present article is intended to high light his researches on light scattering, in particular the theory of glory, which is still being referred to in the scientific literature.

* Research Group: Physics Education and History of Science, Institute of Physics, University of Oldenburg, Germany. e-Mail: rajinder.singh@uni-oldenburg.de

† The statement was true when this manuscript was submitted for publication. In the meantime, a book entitled "Bidhu Bhusan Ray– A Pioneer of X-ray Spectroscopy" authored by the same author has been published by Shaker Publisher (German).

Bidhu Bhushan Ray's photograph one month before his death. (Credit: Mr. Subrata Roy, B.B. Ray's nephew)

B.B. Ray's Work on Light Scattering

Around 1500, Leonardo da Vinci suggested that the colour of the sky is due to the action of finely divided matter, rendering the atmosphere to a turbid medium.[6] In the second half of the nineteenth century, the experimental results of various scientists had shown that small particles scatter light of bluish colour and that scattered light is polarised.[7] In 1881, Lord Rayleigh (J. William Strutt) pointed out that the blue colour of the sky had nothing to do with the suspended particles in the atmosphere, but is due to scattering of light by the air molecules, which have dimension that of the wavelength of light.[8] He showed that scattering intensity is inversely proportional to the fourth power of the wavelength.[9] This means, the blue light with shorter wavelength scatters more than longer waves such as red and yellow. BBR improved Rayleigh's theory for particles, which have bigger size than the wave-length of the light.[10] For larger particles he formulated equations to calculate the numerical values of amplitude and phase of scattered light waves. It was a painstaking and extremely tedious work.[11] The equations were applied by C.V. Raman (Ray's mentor and research guide) and Ray to explain other phenomenon, to show the limit of Rayleigh's theory (detail below).

In 1914, B.A. Keen and A.W. Porter had observed that in the case of suspended sulphur particle in a weak solution of sodium thiosulphate and diluted sulphuric acid; the solution becomes turbid; and consequently the intensity of the transmitted light diminishes. After some time the colour of the solution becomes yellow, orange, red and in the end deep crimson-red. Finally, the solution becomes opaque. After a while, the colour of the solution becomes: at first indigo, then blue, blue-green, greenish-yellow and finally white. They also found that the diameter of the sulphur particle increases with time.[12] A part of the phenomenon could be explained by Lord Rayleigh scattering theory of selective scattering of blue light by particles; but not the reappearance of colours. Raman and Ray successfully applied Ray's numerical method (detail below) to explain the phenomenon.[11]

BBR wrote "on the colours of colloids in relation to the size of the dispersed particles," that (a) the gradual changes of colour of the light transmitted through colloidal solutions changes with the increase in the size of the suspended particles. (b) The intensity of the light passing through the medium changes due to the following two reasons: "(1) The decrease in the area, and consequently also of the resultant effect of the undisturbed portion of the wave front; and (2) The interference with this light of the light scattered in the direction of the primary wave by the particles lying in the wave front."[13] By combining the resultant effect due to (1) and (2) he got the following equation: $E = E_0\ e^{-(2\pi a^2 + (A\lambda^2)/\pi.\sin(2\pi/\lambda).\delta)nx}$; where A and δ are the amplitude and phase of the secondary waves which alter rapidly with the increase in the size of the particles. "a" is the radius of the particle. "Since the values of A and δ are functions of the λ, the transmitted light becomes coloured", wrote the author.[13] BBR's theoretical and observed values in the case of gold particles in water are shown in Figure 1.

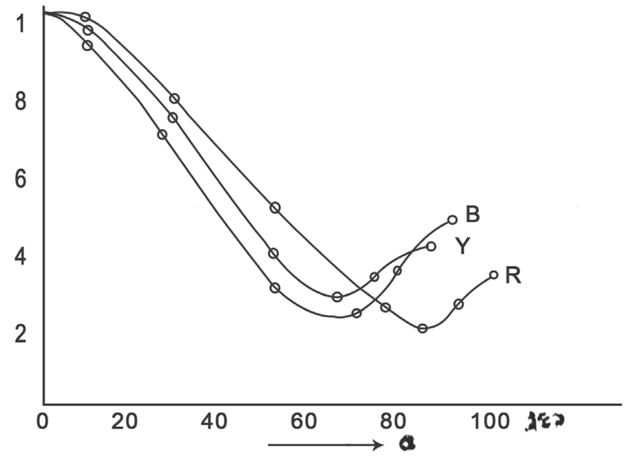

Figure 1: Abscissa "a" (radius of particle) and ordinate $e^{-(2\pi a^2 + (A\lambda^2)/\pi.\sin(2\pi/\lambda).\delta)nx}$. The theoretical values agree with the observations. As predicted by the theory, the colour of the transmitted light turns from red to yellow and finally blue.[13]

Ray's next two articles were intended to explain the phenomena like glories and iridescent clouds with his new theory of diffraction of light; as he was of the opinion that the exiting theories are erroneous.

Explaining the Glory

The glories, like rainbows intrigued the general public as well as scientific community for centuries. It was great challenge for scientists. Even today, its nature is not completely understood. One of the earlier scientific records about the observation of the phenomenon is from the year 1748, by a French scientist, who during a scientific expedition observed the phenomenon at the Pambamarca mountain, Ecuador.[14] Reinhard Mecke from Germany, in 1919, in his dissertation, investigated theoretically and experimentally, the appearance of wreath in the homogeneous mist.[15] Two years later he stated that there is hardly any scientific work on the scattering of light by the turbid medium; except that from R. Clausius (1849), Lord Rayleigh (1885), A. Schuster (1905) and H. Seeliger (1887). By considering the refraction in inhomogeneous particles he gave a general formula to explain the phenomenon like rainbow.[16] In 1923, B.B. Ray repeated R. Mecke's experiments and in a short article in "Nature", he gave his own views to explain the glory and rainbow.[17] The details of researches were published in the "Proceedings of the Indian Association for the Cultivation of Sciences." He stated that to understand the glories one needs to consider the light, which travels back to the source from the droplets. "This arises in two ways, (1) by reflection from the front surface of the droplets, (2) by two reflections and one internal reflection. When a plane wave falls on the spherical particles and is reflected wave-front is strongly divergent and as a result, it merely adds a little to the general illumination of the field and does not give rise to any notable diffraction effect. But wave-front (2) formed by internal reflection is not so divergent as (1) and is limited by a cusped-edge, at which it is doubled back" (Figure 2).[18]

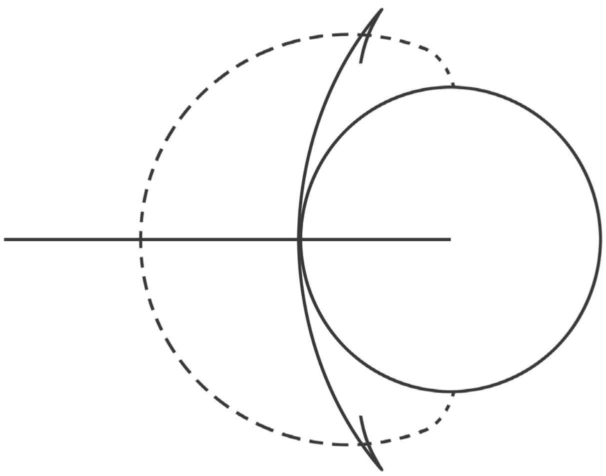

Figure 2: Wave-front (1) (see Text) is indicated by dotted and wave-front (2) by heavy lines.[18]

BBR gave an equation to calculate the position of maxima and minima of the illumination intensity. He showed that in the cases of Benzol (Table1) and water his experimental results were in agreement with his theory; if the experimental errors are taken into account.

TABLE 1

y	Observed	Culculated	Observed	Calculated
4π	$5^0.4$	$5^0.8$	$10^0.2$	$10^0.8$
5π	$9^0.2$	$8^0.8$	$11^0.5$	$18^0.2$
6π	8^0	$7^0.2$	$11^0.1$	$10^0.5$

The experimental and theoretical values of the position of maximum in Benzol and water. [18]

BBR concluded: "The glories or brocken-bows seen when a bank of cloud is viewed by reflected light are shown to be an independent phenomenon due to primary scattering of the sun's ray by the droplets and are not coronas due to secondarily scattered light as has been suggested by some previous writers. They are experimentally found to possess a character different from that of coronas. It is shown that they are due to the integrated effect of the whole wave-front having approximately the form of a spherical cap bounded by a cusped edge emerging after internal reflection at the rear surface of the droplets and the mathematical theory is worked out and shown to be in agreement with experimental results."[18]

Shortly after B.B. Ray's death, the Dutch scientist H. C. van De Hulst tried to explain the phenomenon with diffraction theory. He emphasized the importance of the measurement of light's polarisation.[19]

In the middle of the 1950s, W.E. Richardson, U.S.A., in the journal "Weather" reported his personal experience about the observation of the phenomenon. He wrote that in 1923 Bidhu Bhusan Ray has explained the "simultaneous occurrence of a glory and a fog bow. But much controversy is than suggested in the paragraph about the presence or absence of super-cooled water drop or crystals."[20]

In 2013, the Brazilian scientist H.M. Nussenzveig in renowned journal "Scientific America" discussed Ray's ideas. He wrote that in 1965 he started a research programme to give a full explanation of the formation of the glories. After about four decades he came to the conclusion that "…, three potential effects contend for primary contributors to the glory phenomenon: rays that hit the sphere, including Ray's geometric-optic axial backscattering edge rays, which involve the van de Hulst surface waves; and contributions from Mie resonances, arising from the tunneling of light…. The inescapable conclusion is that glories are a macroscopic light-tunneling effect."[21]

From the forgoing we see that even today, up to some extent, B.B. Ray's theory is valid.

Conclusions

B.B. Ray's life shows the importance in the history of science in Indian context. He is an unsung hero. In the literature, if his name appears at all, it is brought in contact with his work on x-spectroscopy. From the present communication we see that his theory of light scattering by particles having bigger size than the wave-length of the light; had far reaching consequences. It explained the results, where the theory of the "*gurus of optics*", like Lord Rayleigh failed. Not only that, even, in the 21st Century the term named after him "Ray's geometric-optic axial backscattering" appears in the scientific literature.

The details of the impact of his work as well as the reception by the scientific work in India and abroad will be published later.

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