and more than that he generated it in his students. Time in and time out, he would show by precept and example, that Ambition, Endeavour and Courage are the three qualities essential for good scientific work.

Only his students know his humanism. He would lend full support to the work carried out by his students. Any criticism of that work, he would answer with all his might. He was anxious that all the credit for the work should go to the students. As far as he was concerned, he had guided the student so completely, looked through every word of the final published paper, revised it five or six times sitting with the student, so that any distinction between his work and the student's work had ceased to exist. He would follow the career of his students even after they had taken up jobs elsewhere. They could always count on his support. I was often reminded of Vallathol's poem, "Student and Son". As with Lord Siva, the student took precedence over the son, in the case of Professor Raman also.

While I was leaving the Institute for a job in the India Meteorological Department, he gave me the following advice:

1. Do you know the secret of keeping good health ? It is keeping yourself warmer than what is necessary.
2. Since you are going to earn your livelihood through scientific work, never grudge buying books. You will find an investment in books and journals very rewarding.

I hope that I have indicated his method of guiding students. He inculcated in them a capacity for long hours of work and a self-confidence that they can and should pit their brains against the best brains of the world. Under his magnetic personality, these qualities lasted at least as long as the students were with him; but alas, many of them lost these qualities soon after they moved away from his proximity. However, whenever any of them went to him, he re-generated those qualities in them through a few minutes of conversation.

An *Acharya* of the stature of Professor Raman is rare in any country at any time. His intellectual brilliance was something unique. His brain was equal to that of three or four Nobel Laureates put together. It was a God-given gift. However, he had many qualities, which can be emulated with some effort. I have tried to recount some of the imitable qualities of Professor Chandrasekhara Venkata Raman, which, if emulated by teachers, will be rewarding to our nation, which is struggling under a "poverty-culture"—financial and intellectual.

PROFESSOR C. V. RAMAN AND THE COLOUR OF THE SEA

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1. Introduction

I HAVE selected this topic for two reasons. Firstly, Prof. Raman ushered in a new era of important research at Calcutta with his classical paper "On the Molecular Scattering of Light in Water and the Colour of the Sea" (*Proc. Roy. Soc.*, Sec. A, Vol. 101, 1922). Secondly, I had the privilege of assisting him in the urgent laboratory experiments at Calcutta which have been discussed in this very first paper by him on the topic referred to above.

The blue colour of the sea is a vast and beautiful phenomenon that sea-faring folk must have seen and admired from the earliest times. An intense love of Nature and the colourful beauties of natural phenomena was a very prominent trait of Prof. Raman's character and the deep blue of the Mediterranean Sea naturally attracted his scientific interest while he was crossing it during his return voyage to India after his first visit to Europe in 1921.

Lord Rayleigh who had so successfully explained the blue colour of the sky as due to the scattering of sunlight by the molecules constituting the gaseous atmosphere, when he discussed the colour of the sea had stated that *"the much-admired dark blue of the deep sea has nothing to do with the colour of water, but is simply the blue of the sky seen by reflection"*.* Prof. Raman would not accept the above conclusion of Lord Rayleigh. He intuitively felt that the matter needed a fresh

* See *Rayleigh's Scientific Papers*, Dover Publications, Inc., New York, Vol. 5, p. 540.

critical examination. Out in the open sea, the conditions are complicated by many variations due to the state of the sky, the state of the sea surface and the inclination of the solar rays. Nevertheless, to a keen mind like Professor Raman's, careful observation with the simplest of equipment, *viz.*, the eye aided by a Nicol prism, revealed the important fact that like the sky the ocean also is blue by virtue of its own capacity to diffract or scatter some of the incident solar radiation. To cite just one of his findings during this voyage, when he quenched the reflection on the sea surface of that part of the sky blue which was incident on the sea surface and reflected towards the observer at the Brewsterian angle, and so got rid of the reflection of the sky, he found the deep sea glowing with a deeper blue than that of the sky, evidently due to the scattering by the molecules of water constituting the sea. These and many other interesting observations made by him during the voyage convinced him that Lord Rayleigh's explanation was not altogether correct. Prof. Raman returned to Calcutta in September 1921 full of excitement and enthusiasm to test out his ideas under the controlled conditions of the laboratory by crucial but simple experiments, before publishing his results. Without the loss of a single hour he embarked on these experiments. The present writer had the unique privilege of watching his genius at work and of assisting him in this investigation. Instead of wasting valuable time in preparing vacuum-distilled pure samples of water (this was done in the immediately following investigations a few months later), Prof. Raman decided to examine readily available samples of water contained in carefully selected cleaned perfumery bottles of cut glass with uniform sides and square shape. An intense beam of light, about half-a-centimetre cross-section, was passed centrally through the water sample and its track observed in the transverse direction. A dark background was secured by coating the back of the bottle with dull black paint. Against this background it was easy to observe the intensity of the scattering by the water. Starting with tap-water which showed an intense whitish track with many motes and dust particles, attempts were made to precipitate the suspended matter by gelatinous precipitation rather unsuccessfully and it was not until we discovered some large bottles of distilled water lying stored away for many months if not years that the feeblest intensity of scattering could be found. The water from these bottles was carefully siphoned into the experimental containers and the track of scattered light became feebler on allowing time for any residual particles to settle. The track was then extremely feeble and of the azure colour of the sea. The intensity of scattering was compared with a rotating photometer with the blue track in saturated ether vapour. The comparative scattering of ether vapour and dust-free air had been studied by the younger Lord Rayleigh. It was soon estimated that the intensity of molecular scattering by liquid water was about 175 times that in dust-free air.

2. The Einstein-Smoluchowski Formula for Scattering by Liquids at Their Critical State

By this time, Prof. Raman was convinced that the molecular scattering in liquid water was very much smaller than that indicated by the simple Rayleigh law of scattering where the individual molecules are assumed to be independent scattering centres owing to the large intermolecular distances. With characteristic, unerring intuition, Prof. Raman invoked the expression worked out earlier by Einstein and Smoluchowski, based on the theory of fluctuations to explain the very intense scattering of light by a liquid under the special conditions prevailing at the critical temperature. He felt sure that the same formula should hold good at all temperatures of the liquid state. The Einstein-Smoluchowski formula for the transverse scattering by the liquid at its critical temperature is:

$$\frac{\pi^2}{18} \cdot \frac{\beta}{\lambda^4} \cdot \frac{RT}{N} \cdot (\mu^2 - 1)^2 \times (\mu^2 + 1)^2$$

where λ is the wavelength, β is the compressibility of the substance, μ its refractive index and R, T, N have the usual significance attached to them in the kinetic theory. In the case of gases β is simply the reciprocal of the pressure and μ being nearly unity, the above expression reduces to the Rayleigh formula. Computing the intensity of the scattering by water in the liquid state according to the E.S. formula stated above, Prof. Raman showed that water at 30° C should scatter 159 times as strongly as dust-free air under standard conditions. This is of the same order of magnitude as the experimental estimate referred to above. It may be stressed that excepting for a modest correction to account for the anisotropy of the molecule, the E.S. formula has stood the test of time, in accounting for the intensity of scattering by liquids at all temperatures: a tribute to Prof. Raman's intuition in 1921.

3. Why the Sea has a Deeper Blue than the Sky?

Prof. Raman estimated from the above intensity ratio of 160 in round figures, that a layer of water 50 metres deep would scatter approximately as much light as 8 kilometres of the homogeneous atmosphere. For the case where the vertical sun is illuminating the sea, the upward scattering will be twice the transverse value B. If γ is the coefficient of absorption of light in water, the observed intensity of scattering from the deep sea will be:

$$\frac{2B}{\lambda^4} \cdot \int e^{-2\gamma x}\, dx$$

and for large depth x, this reduces to $B/\gamma\lambda^4$.

Using the available values of γ for wavelengths longer than 522 mμ, Prof. Raman estimated that the luminosity of the deep sea may be expressed in terms of the scattering by equivalent thicknesses of air as below:

Luminosity of deep-water

λ in mμ →	658	622	602	590	579	558	522	494	450	410
Equivalent kilometers of dust-free air	0·4	0·5	0·7	1·4	2·5	3·0	50	40	24	15

The scattering by the air column being itself blue, the diminution of intensity in the red, orange and yellow regions of the spectrum, in the case of water, shifts the centre of gravity of the colour of the sea towards the violet. The deeper blue colour of the sea as compared to the blue of the sky is thus readily accounted for. Attention may be drawn to the subsequent paper of Ramanathan, "On the Colour of the Sea" where he deals with the problem in some greater detail and shows how the above results are confirmed and how the presence of increasing amounts of suspended matter as one approaches the sea coast endow the sea with a greenish and later a whitish colour (*Phil. Mag.*: Vol. XLVI, Sept. 1923).

4. How the Study of a Natural Phenomenon, *viz.*, the Blue of the Sea, Leads to a New Epoch of Laboratory Research on the Constitution of Matter in all the Three States?

Immediately after sending away the paper discussing the above important results, Professor Raman lost no time in writing up his Memoir entitled, "The Molecular Diffraction of Light" in the several chapters of which, besides discussing results already obtained, he planned out the many further experimental and theoretical researches to be undertaken most urgently to investigate the molecular diffraction of light by matter in the gaseous, liquid and solid states, during the transitions from the gaseous to the liquid, and from the liquid to the solid state; in liquid mixtures in solutions and in relation to the shape and chemical structure of the molecule. In this remarkable and prophetic Memoir, Prof. Raman has discussed even the possible implications of the quantum theory. The Memoir was published by the Calcutta University Press in February 1922, indeed as rapidly as the author wrote it out. This momentous programme of work occupied him and successive bands of his pupils during the ensuing decades and led to no less than the discovery of the "Raman Effect" by 1928. This was immediately followed by Prof. Raman being awarded by 1930 the highest distinction of the Nobel Prize in Physics.

5. Concluding Remarks

In conclusion what we have to note is the important fact that the curiosity to study and explain observations out at sea brought the problem into the Laboratory and thereafter opened out an entirely new vista of impressive fundamental researches in Modern Physics and the interaction between Matter and Radiation.