INTRODUCTION

The background

Volume VI of the *Scientific Papers* contains the work C V Raman did in the last decade of his life. It also contains the monograph he wrote entitled *The Physiology of Vision.*

As the previous volumes of these collected papers show, his major research interests continually changed over the years—acoustics (1910–1920), optics and scattering of light (1920–1930), ultrasonic diffraction and the application of Brillouin scattering to liquids and Raman scattering to crystals (1930–1940), diamond and vibrations of crystal lattices (1940–1950) and optics of minerals (1950–1960). Clearly a change seemed due in the early sixties and it came with his renewed interest in vision.

The process by which light is perceived by the human eye must have always intrigued Raman. It was the visual impact of the blue of the Mediterranean which provoked his entry into the field of molecular scattering with such success. Yet he knew that blue was by no means the most luminous part of the spectrum of the light scattered by the sea. He suspected that the eye was endowed with the strange property of enhancing certain regions of the spectrum and suppressing some others in the presence of a slight excess of blue light.

Again his recent involvement with gems brought out that the beauty of a gem is assessed by the precise shade and depth of the hue that it displays, i.e. by what one *perceives* of it. And so the characteristics of human vision, which plays such a vital role in this perception, would therefore be as important in deciding the quality of a gem or mineral as its optical properties.

In 1959 he delivered the first Gandhi Memorial Lecture on October 2nd, the birthday of the Mahatma, and he chose as his subject *Light, Colour and Vision.* As with most of his popular lectures, it was delivered extempore and it was also rather different from the later written version. The lecture was a masterly survey of how the eye functions as an optical instrument but he also became aware that there were many important questions still to be answered in regard to the perception of colour by the human eye.

The retina and vision

Raman realised that if one were to understand human vision one must explore the retina. He could not put a probe into the eye so he devised a simple method by

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which one could actually view one's own retina. The observer views a brilliantly illuminated screen, holding before his eye a colour filter (which absorbs completely a limited region of the spectrum while transmitting the rest of it). When the filter is suddenly removed, he sees a highly enlarged view of his own retina (that too in colour) projected on the screen, displaying the response of different areas of it to the incident light. By using a series of filters transmitting different wavelengths, Raman could explore the behaviour of *his* retina under various spectral excitations.

Raman also studied in detail a remarkable but not widely known faculty—namely that the unaided eye is not only able to recognise polarised light but can also locate its plane of polarisation. Sky-light exhibits a high degree of polarisation when observed in a direction transverse to the rays of the Sun. When one views this region of the sky one sees the image of a cross, a dumb-bell shaped bluish brush along the direction of maximum polarisation, and a bright yellow brush of light perpendicular to it. Raman investigated this phenomenon by looking at the spectrum from a diffraction grating with a polaroid in front of it. From the direction of the brush and its response to colour, the orientation and the optical characteristics of the dichroic molecules in the visual pigments were deduced.

Raman did a series of experiments (some of them a repetition of earlier ones) and found that the eye could discriminate colours corresponding to wavelengths differing by as little as 10 Å. Younger eyes could perceive the difference in colour between the *D*1 and *D*2 lines of sodium which are separated by just 6 Å. This established that the transference of radiational energy to the sensing mechanism is a very rapid process not greatly influenced by the thermal agitation of the medium. (If it were, he reasoned that the discrimination could not be finer than 20–25 Å in the yellow).

Raman was interested in the relationship of brightness and colour. He was familiar with the appearance of nebulae as viewed by a seven-inch telescope which was available to him in Calcutta—faint indistinct patches of light with no colour. During a visit to California, he viewed the same objects through the 60-inch and 100-inch telescopes of Mt Wilson Observatory near Pasadena. He recounted vividly that the Ring nebula in Lyra exhibited flaming colours changing progressively from the external edge of its ring to its inner margin while the great nebula in Orion was a blazing area of variegated colour determined by the line emission of the gases of which it is composed. Obviously, the total energy of the light beam which is perceived not only increases the brightness but also considerably affects the sensation of colour. He did set up some simple experiments to demonstrate and measure the intensity at which the colour perception is lost for different colours.

Scintillation of stars

Perhaps the most intriguing observation he made during this period concerned a new type of "twinkling" of stars due to the statistics of photons striking the retina. It would not be possible to perceive a star steadily as a point of source of light unless the stream of light corpuscles reaching the particular spot on the retina is continuous and of sufficient strength. Failing this one can expect to perceive the star only by fits and starts depending on the statistics of the arrival of the photons. This picture of fluctuating luminosity would be exhibited most clearly by the fainter stars which are just on the borderline of visibility and would be less evident as the star goes up in the scale of luminosity. This quantum scintillation is altogether different from the well-known phenomenon of the scintillation of stars which has its origin in the local variations of refractive index in the atmosphere. This classical effect is exactly the same for bright and faint stars though naturally more easily observed in the former case. Further the elevation of the star from the horizon has a noteworthy influence. Raman made observations on stars high up in the sky on clear calm nights when the brighter stars in that vicinity did not exhibit variations in intensity. The fluctuating intensity was most obvious when two or more very faint stars fairly close together were viewed and their relative luminosities constantly compared. He found that these were continually changing and attributed this to photon statistics.

In this connection, it may be mentioned that Raman clearly set out in qualitative terms the presently accepted ideas on the conventional scintillation or twinkling of stars. He was convinced that only by invoking wave optical principles could this phenomenon be explained. The plane wave-front of light coming from a distant star gets randomly corrugated by the changes of refractivity accompanying density variations in the atmosphere. According to Raman one has to consider the diffraction effects of this ever-changing randomly corrugated wave front to understand the scintillation and other associated phenomena completely.

While considering the deceptively simple question as to why one was able to see the Milky Way in the sky with the naked eye, Raman set up many experiments to illustrate some strange characteristics of human vision. For example, when a wire mesh was held at the distance of distinct vision and viewed against a bright background, the apertures in the mesh through which the light passes can be perceived—well-defined and clearly separated. As the illumination is progressively decreased a stage is reached when the independent aperture areas cease to be visible and the entire mesh appears as a uniform field—but exhibiting a noticeable enhancement of fluctuations in the brightness over its area. These fluctuations increase conspicuously as the illumination is further reduced.

Raman had devised many such beautiful experiments and evolved many empirical theories to explain the perception of light and colour. He personally felt that his contributions to this field were important—as important as those he had made to light scattering. But other workers in this very complicated field were of a different view. Experimenters had introduced sophisticated microprobes into the eyes of living animals and combined these with very clever electronics to investigate the visual process. They felt, quite justifiably, that Raman's elementary experiments, however basic they appeared, were too simplistic for this complex field. Thus, his work remained largely unnoticed. Nevertheless many of Raman's simple observations may not yet have found a satisfactory explanation.

The years of depression

The remarks made so far describe Raman's scientific preoccupations in the last decade of his life. But they do not give a full picture of either his internal or external circumstances to which we now turn.

Many things happened at this time in his Institute and in the country which affected Raman greatly. The half a dozen graduate students whom he had handpicked to work at his Institute began to leave. By 1960 all of them had gone, and he chose not to take any more and (except for two assistants) he was almost all alone. It was then that Raman became a recluse, literally isolating himself by building high walls round his Institute discouraging visitors. He passed through a period of deep depression. He appeared to be in agony, to say the least.

Much of his torment must have sprung from his view of things happening in the country. It seemed to him that scientific administrators, not believing that there was sufficient strength in the country for science to grow, looked more and more outside for inspiration. The policy seemed to be that expenditure (however indiscriminate) would automatically further the progress of science and technology. He felt that the universities, which till then identified and generated talent, were denuded and desertified by the exodus of scientists and teachers to better paid positions in large, impersonal Government laboratories. Quantity appeared to be mistaken for quality. His attitude towards everyone—especially the Government—became one of suspicion and cynicism. But there were undoubtedly other causes for his depression at a much more personal level. Was it that once his students had left, he lacked the stimulation of discussing science with the young? Or was it because he finally sensed the decline of his creative powers? Or was it just the physiological process of ageing? One does not know.

Flowers and children

It was at this juncture that Raman rediscovered as it were the marvels of flowers and children. It was his interest in colour that made him look at flowers again—

for what better material was there which displayed such incredible variations of colour and hue to delight the human eye? Raman was always ardently interested in gardens and gardening. He personally planned, supervised and planted hundreds of flowering and avenue trees at the Indian Institute of Science for which it is now justly famous. When he set up an Institute of his own, the land had not a blade of grass on it and no water was available. He contoured the land so that not a drop of rain drained out and made it a veritable garden by planting many beautiful trees and flowering bushes. He had 168 rose plants in his Institute which he tended with personal care. He studied the spectra of the petals and extracts of hundreds of species of flowers. His Institute became a riot of colour and his laboratory exuded the aroma of a perfumery. When any lady visited him, he presented her with a magnificent bunch of flowers (on which he had experimented) and she thought that the Grand Old Man of Indian Science had chosen her specially for this honour! Twice every year—on January 26th and August 15th—he was at the historic Lal Bagh at the flower show examining the exhibits with his famed pocket direct vision spectroscope—himself attracting a greater crowd than the flowers!

And then he invited children to come. First there was a trickle, then almost everyday he was seen taking school children and college students round his Institute—regaling them with stories, teaching them science, making them observe things in nature, chiding them for not recognising the familiar objects that surrounded them—be they trees, plants, minerals or rocks—pointing out to them the exquisite beauty of each, showing them his precious gem and mineral collections, demonstrating many acoustical and optical phenomena so familiar to him, testing them for colour blindness, using their young eyes for spectral discrimination experiments. He asked smaller groups to visit the Institute in the evening and after nightfall he showed them the haloes of the moon, and through his 5-inch telescope, the mountains of the moon, the rings of Saturn, the moons of Jupiter and of course the great Orion nebula. The Institute was filled with the laughter of children, following old Raman from place to place. His spirits revived, his joy in doing science was restored and the verve he always felt as a teacher came back to him.

The end

On 2nd October 1970, he gave his last Gandhi Memorial Lecture *On the cochlea and the perception of sound* – (was he thinking of changing his field again?). For the first and only time in his life he asked of his large audience permission to answer their questions sitting down. At the end of October he collapsed in his laboratory, the valves of his heart having given way. He was moved to hospital and the doctors gave him four hours to live. He survived and after a few days refused to stay in hospital as he preferred to die in the gardens of his Institute surrounded by his flowers. When he was told that there was little chance that he could lead a

normal life and that he might have to spend it in bed, he refused medication since he would not care to live in the horizontal position.

On the 19th of November, two days before he died, he told a former student who was present, "Do not allow the journals of the Academy to die, for they are the sensitive indicators of the quality of science being done in the country and whether science is taking root". He then gave his vision of the future of his Institute:

"This Institute was created by me in 1948 to provide a place in which I could continue my studies in an atmosphere more conducive to pure research than that found in most scientific institutions.

"To me the pursuit of science has been an aesthetic and joyous experience. The Institute has been the haven where I could carry on my highly personal research.

"This personal character of the Institute should obviously change after me. It must blossom into a great centre of learning embracing many branches of science. Scientists from different parts of India and all over the world must be attracted to it.

"With its beautiful gardens, large libraries, extensive museums, I feel that the Institute offers a perfect nucleus for the growth of a centre of higher learning.

"Science can only flower out when there is an internal urge. It cannot thrive under external pressures. Fundamental science cannot be driven by instructional, industrial, governmental or military pressure. This is the reason why I decided as far as possible not to accept money from Government.

"I have bequeathed all my property to the Institute. Unfortunately this may not be sufficient for the growth of this centre of learning. I shall therefore not put it as a condition that no governmental funds should be accepted by the Institute. I would however strongly urge taking only funds that have no strings attached."

The same evening he held a meeting of the Board of Management of the Institute, conducted the proceedings from his bed, and when it concluded he dictated the minutes. He died peacefully early in the morning of the 21st of November, 1970.

S RAMASESHAN