THE PORTRAIT OF A SCIENTIST – C. V. RAMAN*

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1. RAMAN AND RAMANUJAN

WHEN one thinks of Indian science at its best, two names spring foremost to one's mind—the towering figures of Ramanujan and Raman, both of whom were born about a hundred years ago. And when they grew up, they did things that made the world sit up and take note. The first was one of the greatest mathematicians of the world, while the other was an experimental physicist *par excellence* who won for India a Nobel Prize. When the mathematicians of the world presented a copy of Ramanujan's bust to the Indian Academy of Sciences at Bangalore, the astrophysicist S. Chandrasekhar, incidentally Raman's nephew and also a Nobel Prize winner, wrote:

> As a companion to the bust of Raman so that the bust of the greatest physicist of India could be along with that of the greatest mathematical genius of our times who happened to be an Indian.

Nothing is so tedious as a twice-told tale, says Shakespeare. The story of Raman and the Raman Effect has been told all over India many times during this centenary year of his birth. I shall therefore have to fall back on the ancient tradition in India that the oftener one hears of the tales of the achievements of our great ones and heroes, the more merit does the listener acquire!

2. CALCUTTA AND THE "ASSOCIATION"

I am honoured that I have been invited to speak at this Raman Centennial held at the Indian Association for the Cultivation of Science. Raman's first posting as Assistant Accountant-General (when he was just eighteen) was in Calcutta, then the capital of the Indian Dominion. Within a few days of his reaching Calcutta, on his way to work one morning he saw a sign which said "Indian Association for the Cultivation of Science". It was then at 210, Bowbazaar Street. That evening, while going back from work, he sauntered in to find out what it was. It was just being locked up by Ashutosh Dey, subsequently known to all as Ashu Babu, who was destined to spend twentyfive years as Raman's assistant and the gentle tyrant ruling over his laboratory with an iron hand. Raman was told that Mahendra Lal Sircar had established this Institution in 1876 but that it had not prospered. Just before his death Mahendra Lal had said, "Younger men must come and step into my place and make it into a great place."

When Amrita Lal Sircar, the Secretary of the Association, met Raman, he knew that the young man his uncle had dreamt of had at last arrived. So he handed him the keys permitting him free use of the laboratory. Raman wasted no time in starting serious scientific research. He had a 10 a.m. to 5 p.m. job in the Finance Department and so work at the Association was always after "office" hours, even going late into the night. In one paper Raman thanks his assistants "for their working during hours when few institutions, if any, would even have remained open". He made the dying dream of Mahendra Lal Sircar a reality and the Association a great centre of research.

And on this occasion I also salute Calcutta, this much maligned but vibrant city, where things always seem to happen, where there is ever an intellectual ferment. India has had three Nobel Prize winners—the philosopher-poet Rabindranath Tagore, the experimental physicist Chandrasekhara Venkata Raman,

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Invited Lecture delivered at the celebrations of the Birth Centenary of C. V. Raman and the Diamond Jubilee of the Raman Effect held at the Indian Association for the Cultivation of Science, Calcutta.

and the gentle practical saint Mother Teresa. Is it not remarkable that it was this incredible city which provided each one of them the background and support for their work? I am of course afraid of suggesting to this great city or to its fathers that they reduce its din, its dirt and its smells, lest in attempting to do this Calcutta may also lose its glorious tradition of breeding Nobel Prize winners!

3. EARLY LIFE

C. V. Raman was a phenomenon. He had the eye of an artist and the vision of a poet. He could laugh like a child and rage like one possessed. When his intuition was at its best few could match him. He was for ever in the centre of a storm which, often, was generated by himself. He had elements in him which can easily make him a mythical figure. But I shall try my best in this presentation to avoid doing this. For Raman was really a man of flesh and blood. I shall try to paint him (as Cromwell told his portrayer to do) "with pimples, warts and everything".

There is no denying that there was some magic about Raman. He finishes school at the age of eleven, by which time he has read the popular lectures of Tyndall, Faraday and von Helmholtz. He joins the Presidency College, Madras, at thirteen, and is immediately spotted by his teachers, who exempt him from attending the usual lectures. He spends much of his time in the library consuming Lord Rayleigh's scientific papers, and bicycles twice a week to the Connemara Library, several miles away, to read the latest scientific journals. He learns from Helmholtz's *Sensations of Tone* what research really means, and ventures boldly into experimental research in a college laboratory which has had no previous tradition of research in physics. He works on acoustics and optics, and publishes original papers in *The Philosophical Magazine* and *Nature*. He corresponds with Lord Rayleigh, who was then the President of the Royal Society. To earn a living when he finishes college he sits for the Financial Civil Service examination and tops the list. He arranges his own marriage with Lokasundari, who is thirteen and a half years old. He is appointed Assistant Accountant-General in 1907 and is posted to far-off Calcutta, Nagpur, and Rangoon in Burma, where he earns a name in the Finance Department as one of its finest officers. In fact he acquires a reputation that he may even become the first Indian Member for Finance in the Viceroy's Council Sir C. D. Deshmukh, the first Governor of the Reserve Bank of India, said that its starting was based on a paper initiated by Raman in those early days. But all this was incidental to Raman.

4. HIS MOTIVATIONS

But during those ten years, 1907–1917—rain or shine, Nagpur or Rangoon—he did experimental research at home under the most adverse and trying conditions or at the Association when he was in Calcutta. Colonial India was noticed by the scientific world because of his activities. The Vice-Chancellor of Calcutta University Asutosh Mookerji—the Tiger of Bengal—also noticed him and suggested he leave government service to join the University as a professor. To the horror of some and the amazement of all Raman accepted the professorship on a salary of about half of what he was getting.

What were the motivations of this strange man? He wrote a few years later:

> In my case strangely enough it was not the love of science, nor the love of Nature [both of which he had in abundance], but an abstract idealization, the belief in the value of the Human Spirit and the virtue of Human Endeavour and Achievement. When I read Edwin Arnold's classic *The Light of Asia*, I was moved by the story of the Buddha's great renunciation, of his search for truth, and of his final enlightenment. It showed me that the capacity for renunciation in the pursuit of exalted aims is the very essence of human greatness.

Lokasundari Raman.

5. LOKASUNDARI RAMAN

But before I start seriously on Raman himself let me pay tribute to one without whom he might not have done half the remarkable things he did in science. I refer to his wife, the gracious Lokasundari Raman.

We were all, in a sense, not sorry that he died before her; for what would he have done without her? Her devotion to him was what we read of in our epics. But she was a tough character; yes, she had to be tough to be his wife. She was never afraid of telling him when he was wrong and was ever advising him on what he should *not* do or have done. She had, by choice, married a hurricane and she tried to keep it under control for sixtythree years but never really managed. And when the hurricane died she was left all alone.

6. SOME ATTITUDES

Raman was typically Indian. He never gave up his old traditional hairdo. In public he always sported a turban. "How else" he quipped "could Lord Rutherford have recognized me in that crowded Cavendish lecture hall?" Unlike most Indians he was not at all superstitious and he despised rituals. On the night of his death, his wife asked him to take the name of God. He was dying but he said, "I believe only in the Spirit of Man", and talked of the Mahatma, the Christ and the Buddha and then made a request, "Just a clean and simple cremation for me, no mumbo-jumbo please."

7. THE RAMAN EFFECT

The discovery of the Raman Effect is a saga of a single-minded man pursuing the holy grail with a stamina and persistence never before or since seen in this country. On his first voyage to Europe in 1921 the visual beauty of the Mediterranean bewitched him. Lord Rayleigh was of the view that this blue was due to the reflection of the sky in the water. Raman disproved it by a simple experiment he did on board the ship. He quenched the sky's reflection with a nicol prism at the Brewster angle and found that the blue colour "far from being impoverished by suppression of the sky reflection was wonderfully improved thereby". He showed thus that the blue is due to molecular scattering and established quantitatively that the Smoluchowski–Einstein fluctuations were its basic cause. He then wrote the celebrated monograph *The Molecular Diffraction of Light* in 1922.

From a thought experiment, imagining scattering to take place in a black-body enclosure, he obtained the result that Rayleigh scattering must be a discontinuous process caused by photon collisions. He argued how this can be reconciled with Maxwell's electromagnetic equations and ended by saying, "Rather the Maxwell's field equations must be altered to introduce the quantum of action." A concise statement of the basic goal of quantum electrodynamics to be developed much later by Dirac, Heisenberg and Pauli. Max Born told Nagendra Nath later, "It was astounding to

know that Raman realized as early as 1922 that the field equations themselves have to be quantized." No wonder Born stated, "Raman's mind leaps over mathematics."

Intuitively Raman concluded that the interaction of the photon with a molecule must reveal itself by a change in colour. Even the first experiment (with K. R. Ramanathan) in 1923, using sunlight filtered through a colour filter and observing the scattered light track with a complementary filter, revealed this change of colour. Ramanathan thought that this "weak fluorescence" was caused by impurities. Raman refused to accept this impurity hypothesis as the track exhibited polarization. In 1925 the attempt to record the spectrum of this "weak fluorescence" track by S. Venkateswaran failed.

A European scientist visiting the California Institute of Technology recalled that he met a scientist from India who imagined that he was going to discover a quantum effect in light scattering which would win for India the Nobel Prize*. "I thought that he was crazy. The incredible thing is that this man does make the discovery and does get the Nobel Prize six years later!"

In 1925 Raman wrote to G. D. Birla, the industrialist and friend of Gandhi, that he needed money for an instrument called a spectrograph: "If I have it, I think I can get the Nobel Prize for India."

Raman gave a novel derivation for the Compton Effect formula. He concluded that there must be an optical analogue in which a quantum of radiation can be absorbed in part and scattered in part.

In December 1927 the so-called polarized "weak fluorescence" was observed again in pure glycerine with greater intensity. The observation was made by S. Venkateswaran who now had a job in the Alipore Test House and so was only a part-time worker at the Association. Raman had picked up the scent again and wished to resume the chase. He now had a larger lens which would double the incident intensity and he wanted someone to use the winter sun of Calcutta (with its cloudless sky) all the time for the experiment. So he persuaded his best student K. S. Krishnan, who had been doing only theory for the previous three years, to come back to experiments. Krishnan starts to work on January 29th or 30th 1928, and, according to his diary, Raman and he work together continuously and detect the polarized "weak fluorescence" in *all* the liquids, gases and solids they examine. A later entry says: "Professor suddenly came to our house at 9 p.m. He came to tell me what we had observed must be the Kramers–Heisenberg effect that we had been looking for all these years. We decided to call it 'modified scattering'."

On February 28th, Raman examined the scattered track with a direct vision spectroscope and found that the classical and modified scattering appear in the spectrum as separate regions with a distinct dark region between them, a clear demonstration of a change of wavelength in scattering.

Raman was in a state of euphoria—a man who had at last come to the end of the trail he had been following for seven years. Krishnan's diary says: "He ran about the place shouting all the time. He asked me to call everybody in the place to see the effect."

They then used the mercury vapour lamp and photographed the first ever Raman spectrum with a Hilger baby quartz spectrograph. Besides the incident radiation several other lines were present in the scattered spectrum. A lecture entitled *A New Radiation* was given on March 16th 1928 in Bangalore and was printed in the *Indian Journal of Physics* on March 31st 1928. Three thousand reprints were posted the next day to all the leading laboratories of the world!

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*The reader will note from this and more to come that Raman had an obsession about the Nobel Prize. I used to think that this was because it was first instituted when he was at the impressionable age of thirteen and because so many of his heroes in science, like Röntgen, Lorentz, Zeeman, Becquerel, Pierre and Marie Curie, his own Guru *in absentia* Rayleigh, Lenard, J. J. Thomson and Michelson, were its recipients during his college years. But it became clear to me later that this, as everybody knows, is a widespread malady amongst scientists.

8. SOMMERFELD'S VISIT TO INDIA

Sommerfeld, the author of *Atombau und Spectralinien*, who shaped theoretical physics in Germany by the style of his lectures and his quality as a teacher, decided to visit the United States of America. Raman invited him to Calcutta. Sommerfeld decided to take the eastern route as he was "attracted to India by its fantastic religion and its remarkable philosophical systems".

Sommerfeld arrived in India, and promptly fell ill, as all westerners must! He came to Raman's laboratory on October 4th (1928) and Raman and Krishnan showed him the experimental verification of Sommerfeld's formula for the propagation of radio waves round the earth using a ball just 1 mm in diameter and light as the electromagnetic radiation. "Everything at the Institute very good," said Sommerfeld, and being an honest man, added, "but the bathrooms terrible." Sixty years have passed but we still uphold this tradition with bathrooms! On October 6th he says with great satisfaction: "Saw the Raman Effect visually; heard a wonderful lecture by Raman. Saw the Raman Effect in ice, also that we can see rotation of molecules as 'Modified Radiation'." So convinced was Sommerfeld of the reality of the Raman Effect that he arranged to propose Raman for the Nobel award. He stated when he left, "India has suddenly emerged in research as an equal partner with her European and American sisters."

Another incident! Immediately after the discovery Raman went out for a walk along the Hooghly with S. N. Bose—the inventor of Bose Statistics—who was a member of Raman's Physics Department at the University. Satyen Bose told him: "Prof. Raman, you have made a great discovery. You will surely get the Nobel Prize for it."

9. THE NOBEL CEREMONY

In 1930 Raman was awarded the Nobel Prize. Amongst those who nominated him were Lord Rutherford, Niels Bohr, Louis de Broglie, Charles Fabry, Jean Perrin, Eugene Bloch, C. T. R. Wilson and the Russian scientist Chowlson. There was one nomination for Raman and Heisenberg, two for Raman and R. W. Wood, and one for Raman, Landsberg and Mandelstam.

Lady Raman once showed me a copy of a letter a friend of hers had sent her from the United States, a letter written by the chargé d'affaires of the US in Sweden to the US Secretary of State in Washington reporting on the 1930 Nobel ceremony in which two US citizens had also been awarded the Nobel Prize—Sinclair Lewis for literature and Carl Landsteiner for physiology or medicine. I would like to read out a part of it:

> Of all the prize winners, the day was easily carried, however, by Sir Venkata Raman the Indian prize winner, who, upon returning to his seat on the platform after receiving his prize from the hands of the King, was visibly moved by his emotion and sat with tears streaming down his face.

Raman confirmed that this was true. "When the Nobel award was announced I saw it as a personal triumph, an achievement for me and my collaborators—a recognition for a very remarkable discovery, for reaching the goal I had pursued for 7 years. But when I sat in that crowded hall and I saw the sea of western faces surrounding me, and I, the only Indian, in my turban and closed coat, it dawned on me that I was really representing my people and my country. I felt truly humble when I received the prize from King Gustav; it was a moment of great emotion but I could restrain myself. Then I turned round and saw the British Union Jack under which I had been sitting and it was then that I realized that my poor country, India, did not even have a flag of her own—and it was this that triggered off my complete breakdown."

Then continues the letter from the US chargé d'affaires:

> At the banquet that evening Sir Venkata Raman's speech was a masterpiece of

eloquence, which called forth tremendous applause from a banquet-weary gathering not noted for its responsiveness. Less appreciative was perhaps the British Ambassador, who sat one place removed from me, who was forced to listen with equanimity to Sir Venkata Raman's reference, brief though it was, in passing only, to the congratulatory telegram which he received "from his dearest [sic] friend who was now in jail".

It is not difficult to guess who that friend was.

10. RAMAN THE SPEAKER

To the Gandhi Memorial Lecture, an annual feature at his Institute since 1959, Raman attached much importance. He believed that the way to pay homage to a person you revere and love is to give something of yourself—something you yourself can do best. Thus his tributes to the Mahatma, year in and year out, were in the form of popular lectures in science—two fields in which he was an acknowledged master.

I have in my career heard lectures from many many scientists, from India and abroad. But Raman in his heyday was perhaps the best. What made his lectures so gripping? He talked only of those things about which he felt intensely or those things which he understood well or wanted to understand better. He brought out things in their simplest and their most basic elements. He made his audiences feel that they had seen it all too.

His humour was infectious. He made his audiences roar with laughter. After one such "performance" (as he called his popular lectures) he went on about the subject of humour.

> As someone said, the relationship of a joker to a joke must be quick and desultory—as that of a bee to its flowers. He must make a joke and not harp on it. Like a bee approaching a flower he probably can buzz a little—for it is well to announce to a thick-headed world that a joke is coming or is intended.

11. RAMAN'S STYLE OF WRITING

To illustrate his writing style I shall read a little passage from an essay which describes the influence Euclid had on him.

> Not until many years later did I appreciate the central position of Geometry to all natural knowledge. I can give a thousand examples. Every mineral found in Nature, every crystal made by man, every leaf, flower or fruit that we see growing, every living thing from the smallest to the largest that walks on earth, flies in the air or swims in the waters or lives deep down on the ocean floor, speaks aloud of the fundamental role of Geometry in Nature. The pages of Euclid are like the opening bars in the Grand Opera of Nature's great drama. They lift the veil and show to our vision a glimpse of the vast world of natural knowledge awaiting study.

In his scientific papers too Raman's style of writing is confident and stately. He is never hurried, neither missing a word nor allowing an unnecessary one to slip in. The *mot juste* is always there. With Raman the style is the man himself.

12. THE CONTROVERSY OVER LATTICE DYNAMICS

I shall now briefly touch upon the painful controversy between Raman and Max Born, two physicists who were once great friends. Max Born had written a monumental paper on lattice dynamics. It was a work of art, looked upon with awe by many, carefully preserved as if in a glass casket, untouched by human hands for decades. No crystal property was ever calculated using it. There was absolutely no interest in lattice dynamics at that time. Then came Raman. He entered the field with a bang and literally opened up the subject. He started a massive experimental programme. In the second order Raman spectra of crystals recorded by Rasetti and later by R. S. Krishnan he saw many phenomena yet to be explained. Being the pragmatist he was, he

Raman with Mahatma Gandhi and Mahadeo Desai

wanted a theory to be useful, a theory from which he could extract numbers.

He disagreed with Born's notion of normal modes expressed in terms of travelling waves and he felt with some justification that Born's cyclic postulate had no physical basis. So he started with standing waves. An ardent student of Rayleigh, he used his master's definition of normal modes and imposed a reasonable condition that he derived and that is almost identical to the well-known Bloch condition in solid state physics. He derived a simple (and what I would *now* describe as a simplistic) form of lattice dynamics. At last he had a theory that could be used. He could now count the number of lattice frequencies in crystals. These were almost identical to those observed in R. S. Krishnan's excellent Raman spectra of NaCl, diamond, etc. He was able to calculate the actual frequencies using the concepts of force constants and nearest-neighbour interaction and again the agreement was almost exact. He computed the specific heats using the idea of Einsteinian oscillators and with no adjustable parameters whatsoever and here again the agreement with experiment was extraordinary. With this success he was convinced that Born was completely in error and so mercilessly attacked Born's theory. Because of his persistent attacks he provoked new interest in lattice dynamics and the Born protagonists broke the hallowed glass casket and looked in—and lo and behold, new physics literally poured out, revealing the innate richness of Born's theory! The concept of singularities emerged (which strangely was also discovered in Raman's laboratory by his student K. S. Viswanathan), and it was finally shown that Raman's theory was just a small part of the more comprehensive Born theory.

If Raman had presented his papers as a simple physical approach of deriving optical modes or of obtaining the physical properties of crystals, they would have been considered significant or even important at that time. But Raman would not have it that way. He could not see the missing elements of his theory. Rayleigh's definition was right, his derivation of the Bloch's condition was right—but alas it was only valid for travelling waves. Raman had imposed a travelling condition on a standing wave situation. It did explain many important features but it was very limited. Raman had leaned heavily on his intuition, which had never failed him so far from 1904 to 1939, but now it let him down badly. This pattern is not unusual in the history of science—intuition so responsible for a scientist's success often failing him as he grows older. But the greatest sadness and the pity of it was the bitterness this awful controversy created between two old and dear friends.

13. MAX BORN IN INDIA

The story of Max Born in India is an unbelievable one. Like Mahendra Lal Sircar other visionaries appeared who felt that science was the only path to salvation for India. J. N. Tata was one such and he conceived of the Indian Institute of Science. But the Viceroy, Lord Curzon, felt that this conception was a seditious act and so tried to abort it. The Institute did come into being in Bangalore sometime after J. N. Tata's death. But with his death the fire went out of the Tatas till it was kindled again, only much later, by the present Tata (JRD). In between, the Tatas leaned heavily on the British. The Director and many in the faculty of the Institute were always British. There was a strong feeling—quite justifiably—that what work was done at the Institute, with the British Resident as Chairman, only subserved British interests. Even so, at the height of the civil disobedience movement in 1933, Sir C. V. Raman was appointed its first Indian Director. Perhaps his British knighthood impressed the Government of India and the Tatas.

Raman however believed in excellence *per se* and was further convinced that if ever India was to make any economic advance it could only be based on such excellence. Says Max Born, "Raman found a sleepy place where very little work was being done by a number of extremely well paid people." Raman went in there like a bull in a china shop. He started

improving not only the intellectual but the physical environment. He planted beautiful flowering and avenue trees; the aesthete that he was, he made the Bangalore Institute the garden it is now. He started workshops to make precision instruments—as a necessary activity for building a strong base for experimental research and, for that matter, even industrial research. He started new schools of research; he blazed new trails in physics—in colloid scattering, ultrasonic diffraction, Brillouin scattering, crystal transformation—and put the Institute on the scientific map of the world, some say for the first time. He then identified gaps in knowledge in India and adopted the strategy of trying to recruit to the Institute faculty from among the reputed scientists who were fleeing from the tyranny of Hitler. Could his strategy have worked? In retrospect we know that a similar process of influx of German refugees into the United States improved the quality of science there by orders of magnitude. But unlike the United States, India was still a slave nation.

Raman had a long list of subjects that stirred his imagination. Some of these were practical too. Quantum mechanics, radioactivity, crystal chemistry–the handmaiden of modern materials science, vitamin chemistry, enzymology, and so on. In his list of people to attract were Max Born, Hevesey of radioactivity fame, V. M. Goldschmidt (the father of solid state chemistry whom Hitler had insulted and disgraced), Ewald, Kuhn, and a host of others. Many on his list got the Nobel Prize much later, testifying to Raman's discernment. Many of them in fact agreed to come, but finally did not because of what happened to Max Born.

Max Born (and his wife Hedi) came to India first on a short assignment. "We liked Lady Raman right from the beginning" says Born, and "When Raman appeared he looked to Hedi like a prince from the Arabian Nights." Later he says, "Frankly I like Raman very much, in spite of his all-too-human drawbacks; his conceit; his naïveté; his way of bringing himself into the light." Born continues, "He is an excellent physicist and so devoted to the Institute."

Born enjoyed his stay and his lectures were greatly appreciated. Raman decided to offer him a permanent position. Lord Rutherford was appointed Chairman of the Selection Committee and lo, Born's name led all the rest! In a meeting at the Institute Raman spoke of the extraordinary merits of Born as a scientist, as a teacher and as a human being. Then, unbelievably, a professor at the Institute, an Englishman, spoke in the most derogatory manner about Max Born, referring to him as one rejected by his own country, a renegade, and therefore a second-rate scientist, not fit enough to be a member of the faculty of the Indian Institute of Science! All this about the great Max Born. One could have wept—we know Born did.

After this public insult Max Born could not possibly accept Raman's offer, and all the other German professors naturally refused to come. India missed an incredible opportunity, and Raman too lost all hopes of revitalizing the Institute. Why did Raman fail? I quote: "The English faculty resented working under an Indian, Raman. They gained the ear of the colonial govérnment who could easily put pressure on the all-too-willing Tata group." And, "Raman, far too conscious of his superiority, made people feel small in his presence." And finally, to quote from a letter Born wrote to Lord Rutherford, asking him to intervene when all went against Raman: "There is no Indian physicist of the rank of Raman. No man can compare with him in regard to vigour and intensity. This European intensity which Raman exhibited seemed to make many Indians suspicious of him."

It was a battle between excellence and mediocrity, and mediocrity won hands down. The authorities decided to dismiss Raman. He was forced to resign the directorship and only by the intervention of Lord Rutherford could he retain his professorship and so continue to be in India and do scientific research. It is revealing that just a week after these incidents happened Raman wrote a very remarkable

scientific paper which was published in *Nature*.

14. WHAT IS IN A NAME?

Indian names are sonorous. But often one has to take a deep breath before enunciating them fully. For example when I say Sudhanshu Kumar Banerjee or Bidhu Bhushan Ray—two outstanding students of Chandrasekhara Venkata Raman—you will see (or hear) what I mean. Raman was clever and contracted his name from Venkata Raman to Raman. Raman Effect sounds far better than Venkata Raman Effect.

At the time Raman was being disgraced in Bangalore one of his friends (Born or Rutherford—I do not know who) thinking that he might like to leave India to lick his wounds, proposed him to the prestigious Zeeman Chair in the Netherlands. Raman was selected but was in a dilemma as he was reluctant to leave his country. Because the name Raman rhymes with many European names and because he had won the Nobel Prize, the City Committee (which had to approve all the university appointments) thought at first that he was of European origin. When they learnt he was an Indian, the appointment was cancelled, saving Raman the trouble of deciding what action to take.

Zachariasen, the doyen of X-ray physicists, told me this story in 1965. When Raman visited Chicago in the twenties as A. H. Compton's guest, Compton invited him to lunch. Also invited was Dean Gale, who was a specialist in optics and was familiar with Raman's work, but whom Raman had never met. At the Faculty Club, when Gale came in and saw the complexion of the man sitting with Compton he just looked straight through them and walked away. Zachariasen said that although Compton felt immensely ashamed of his countryman's behaviour, he was rather relieved that the incident had passed without Raman noticing it. I discovered later that Raman had, in fact, noticed it, but kept his silence as he did not want to embarrass Compton. Raman said: "As in India, there are many stupid fools in every country. I would like to remember the United States as the country of Jefferson and Franklin, Walt Whitman and Thoreau, Edison and Graham Bell, or my own friends Millikan and Compton."

15. THE INDIAN ACADEMY OF SCIENCES

In 1934 Raman started the Indian Academy of Sciences. His detractors said that he did this to pre-empt the formation of another Academy which was in the offing (later to become the Indian National Science Academy). There may be an element of truth in this accusation. But as Raman asked, "How can Indian Science prosper under the tutelage of an Academy which has on its council of 30, about 15 who are Britishers of whom only two or three are fit enough to be even its Fellows?" With the passage of time, and looking at the names of these council members, one can hardly disagree.

In any case the best scientists from all over India, and particularly the young ones, were elected into his Academy. Raman used his personal prestige and that of the Academy to encourage scientific talent wherever it was found and in whatever field it showed itself.

Distinguished scientists were always at the annual meetings—at Raman's travelling circus, as he called it—which were usually held in university towns. He and his troupe were the greatest salesman science ever had in this country. How many gifted men have admitted that they took to science just because they had heard Raman lecture!

He started and ran many scientific journals. Just before he died he said: "Do not allow the Academy journals to die, for they are sensitive indicators of the quality of science done in the country. They will tell us whether science is really taking root in the country or not."

16. RAMAN'S OBSESSION WITH SCIENCE

I do not have the time to elaborate on all his exploits—how at sixty when he retired from

the Indian Institute of Science he started the Raman Research Institute; how he lost all his life's savings; and how he went round the country collecting money, saying that our greatest men, Buddha, Sankara and Gandhi, too, were beggars; how the factories he had started sustained his Institute.

Nor have I the time to tell you of how deeply disappointed he was with the way Indian science was going after Independence; how it seemed to him that the administrators of science had no faith in the inner strength of our country and how they looked outside more and more for inspiration; how strongly he felt that the universities which till then had played the role of identifying and generating talent were being denuded and desertified by the exodus of scientists and teachers to better-paid positions in large impersonal governmental laboratories; how he disagreed with the philosophy that expenditure in science was equivalent to progress or growth of science and technology; how in this process quantity was invariably mistaken for quality; and how therefore he became a strong critic of Government and its policy, and so dissociated himself from it by refusing governmental funds for his Institute.

When one hears of all this one may conclude that his major activities were to start and run research institutions and laboratories, train students, get them lucrative positions, establish and publish scientific journals and persuade scientists to publish in them, establish Academies to encourage talented scientists, give popular lectures in schools and colleges to persuade the youth to devote themselves to science, fight anything that he felt was being done to decrease the self-respect and self-reliance of the country. All this he did and with gusto—but all these activities were subsidiary to his one real preoccupation and passion, that of doing science. Pursuit of science was the only reason for his existence, nothing else mattered. From 1905 to 1970, day in and day out he did science. For thirtyfive years when his intuition was at its peak his science was almost unmatched. This intuition did begin to decline but not his passion for science. He published 475 papers and wrote five remarkable monographs—a total of 4000 printed pages on topics so varied that one's mind boggles.

It was truly *l'affaire d'amour* with Nature—mostly with sound and light—a prolonged passionate affair lasting sixtyfive years.

17. HIS CHOICE OF PROBLEMS

Raman had a nose for significant problems and he chose them with *élan* whether they were for his own research or for those of his colleagues. I shall give two examples. When young Vikram Sarabhai came to work with him, Raman informed him of the chance observation in Germany that cosmic rays also make imprints of their tracks on photographic plates. Sarabhai said later that Raman exhorted him, "This is the most appropriate technique for our country, perfect the process of making these photographic plates, study cosmic rays at high altitudes using balloons; there may still be a Nobel Prize lurking for you." But it was Cecil Powell of Bristol and not Sarabhai who did pursue this line of research and was in fact awarded the Nobel Prize for his work.

From his mineral collection Raman gave crystals of iolite and amethystine quartz to Pancharatnam, saying "If you study these, you will surely advance crystal optics, but you may even perceive some strange properties of light itself." As a result Pancharatnam published a series of papers on the generalized theory of the interference of light which have in fact now become part of the standard literature on the subject. In 1954 Pancharatnam also discovered what Michael Berry (one of the most perceptive authorities on wave phenomena) calls the Pancharatnam phase, a property of light which is revealing new directions even in purely quantum mechanical applications.

18. SOME OF RAMAN'S RESEARCHES

Some of Raman's researches and discoveries were so outstanding—like the Raman

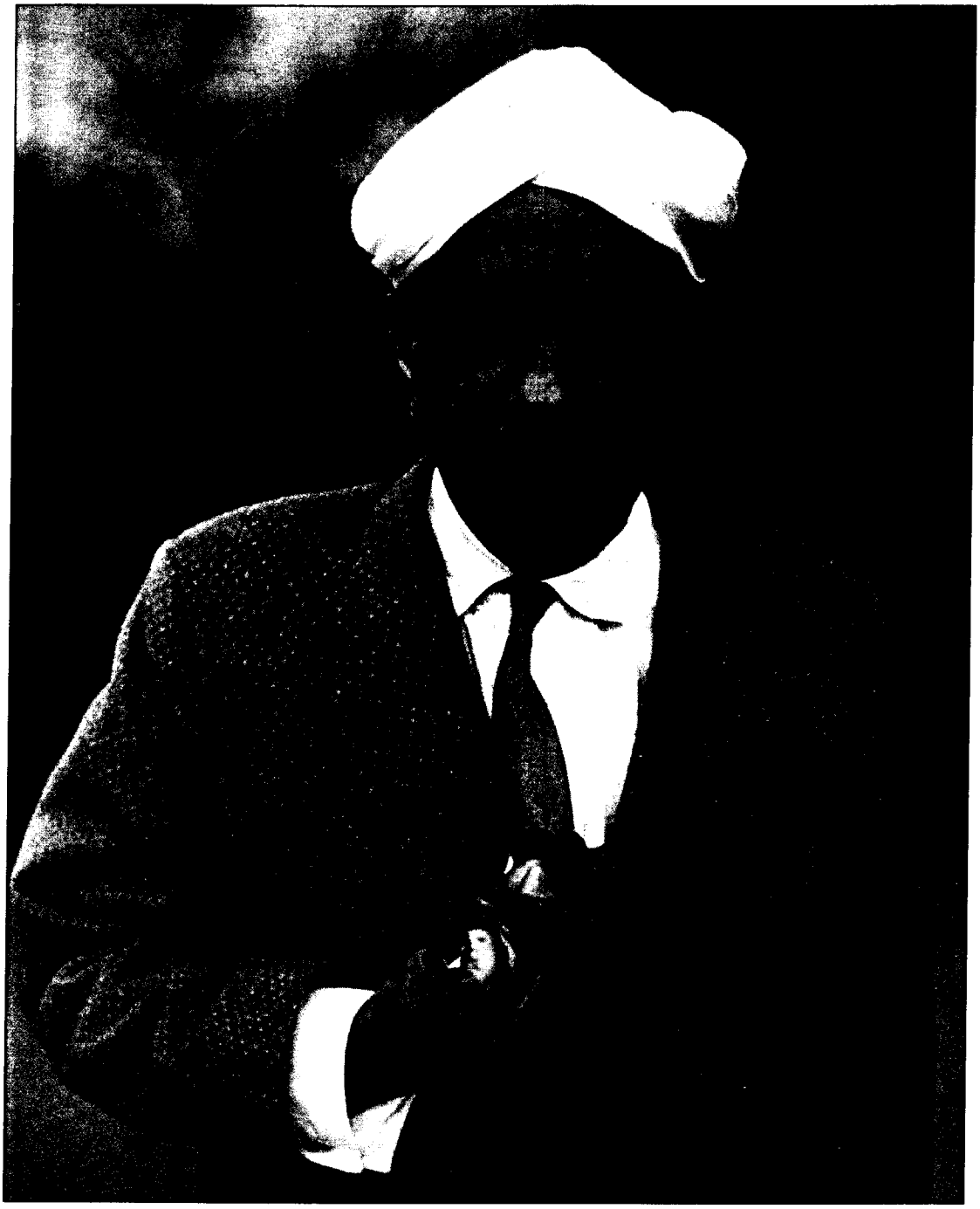
Effect (1928), the Raman–Nath theory (1934–1936), his studies on Brillouin Scattering (1933–1940), and the soft mode process (1938–1940)—that they overshadowed many of his other beautiful and significant contributions. Just listing all the scientific problems Raman tackled will take too long. I shall therefore choose only a few—almost at random—to indicate the eye and ear he had for beauty, the concern he had for basic questions, and the range of his scientific interests.

When he listened to the notes of the *ectara* (a single-stringed instrument), commonly used by the poorer itinerant musicians of India, he made a detailed study of it and discovered many unforeseen acoustical properties which led him to design a new type of sonometer! He found that in the *veena* the overtones do not die down rapidly, and that they behave in a manner quite different from those in most plucked stringed instruments. He deduced that it is the curved bridge which endows this class of instruments with the property of producing the normally forbidden harmonics rendering their sound closest to the human voice. His keen ear discerned that the Indian concert drums (the *mridanga* and the *tabla*), unlike most drums of the world, are *not* musically defective. They are in fact capable of producing harmonics (at least five of them) mainly because their ancient designers had centrally loaded the stretched membrane. His *magnum opus* in acoustics was his monograph *On the mechanical theory of bowed strings of the violin family*, which is referred to by acousticians even today, seventyfive years after it was written. One can only marvel at his experimental skill in producing remarkable vibration curves of great precision and sharpness, much before the triode valve or the condenser microphone were invented. He extended his acoustical studies on whispering galleries to show that the striking beauty of the pearl—the gem that does not require the services of a lapidary—is essentially because it is a leaky, spherical optical whispering gallery.

His pioneering studies on the sound produced by impact led him to propound, with rare insight, the mechanism of the breakdown of solids due to impact—a field that he was amongst the first to open up. The renowned polymer chemist Staudinger used Raman's phenomenological theory of viscosity to correlate the viscosity of polymer solutions with the states of polymerization of the molecules. Raman was amongst the earliest to suggest that optical birefringence and magnetic anisotropy should be used to predict (or to verify) the arrangement of molecules in a crystal, a procedure followed so ably by his students S. Bhagavantam and K. S. Krishnan.

The obsession he had for the beauty of the haloes he saw surrounding the sun and the moon when a thin cloud (of water droplets) came in front of them resulted in his discovery of the speckle phenomenon as early as 1919. It led to his theory of X-ray diffraction of liquids (with K. R. Ramanathan), the calculation of the X-ray structure factor of an atom, and the classical derivation of the Compton Effect formula. It should be noted that X-ray topography was also discovered in his laboratory (by G. N. Ramachandran) during studies on the imperfections in diamond.

He discovered and explained one of the strangest cases of image formation, that of a sharp image forming not at one point but continuously on all points on a line when light emerges after travelling along a singular direction in a birefringent crystal. He propounded the geometric theory of Fresnel diffraction, in which the intricate diffraction pattern could be simply deduced as due to the interference of a few rays emanating from edges and poles whose positions are easily identifiable. Only in recent times has optical theory been rewritten to make these rays meaningful in such situations, thus catching up with Raman's intuition three decades earlier. The first qualitative statement of the presently accepted theory of the scintillation of stars, that it is an effect created by the random corrugation, due to the density variations in the atmosphere, of the plane wavefront arriving from a distant star, was given by Raman. He claimed to have made a most intriguing observation of a second type of twinkling of stars, due to the



Chandrasekhara Venkata Raman
1888 – 1970

The last photograph

statistics of photons striking the retina. He made detailed studies of the not-too-well-known property of the unaided eye of detecting polarized light (as bees seem to do).

The similarity between periodic precipitates in nature and wave phenomena had been noticed previously. But Raman (with K. Subba Ramaiah) gave substance to this analogy by actually detecting in these precipitates the existence of phase relationships in the form of interference and diffraction effects. Raman's study of the scattering of light brought out many important prescient conjectures much ahead of their time. He suspected the periodic compositional segregation in minerals corresponding to what are known today as modulated structures. In the very first paper on the subject Raman argued that the large Rayleigh-like scattering of light in complex glasses must be due to sizeable compositional variations, marking the beginning of a powerful way of probing a class of systems and phenomena not fully understood yet. Finally Raman considered protein molecules in solution, and, probably for the first time, the protein was thought of as a thermodynamic system and not as particles like dust.

19. LATER EXTENSIONS OF RAMAN'S RESEARCHES

Many of Raman's researches had a much wider application to many other situations. For example the mathematics needed in the multiple beam dynamical theory of electron diffraction is just that introduced by Raman and Nath twenty years earlier to deal with the diffraction of light by ultrasonic waves.

The remarkable paper by Raman and Pancharatnam on mirages, which brings out the interplay of geometrical optics with wave optics, is another case in point. The solution to the wave equation showed the wave to be made up of three sheets, joined at the cusp, which travel along the caustic surface in which three images are to be expected. The principles elucidated by Raman and Pancharatnam for terrestrial mirages were reintroduced many years later for cosmic mirages, the formation of multiple images by distant quasars caused by the gravitational bending of light by intervening masses. Efforts to model these "gravitational lenses" also give a prominent role to an odd number of images and the cusped wavefronts moving along caustic surfaces. In fact the Raman–Pancharatnam paper will therefore be remembered not only for the wave-optical treatment of the image but also for the clarification of the associated geometric-optical limit.

20. HIS LAST DAYS

On October 2nd 1970 Raman gave his last Gandhi Memorial Lecture. For the first and only time in his life he asked of his large audience permission to answer 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 was expected to die within four hours. He survived and refused to stay in hospital as he preferred to die in his Institute home, surrounded by his flowers. When he asked and was told that there was little chance that he could lead a normal life, he refused any medication since he would not care to live in any way other than that in which he had always done. Two days before his death he talked about his hopes for the future of his Institute. He held a meeting of the Board of Management of the Institute, conducted the proceedings from his bed, and dictated the minutes of the meeting, introducing in it the sentence, "Since Sir C. V. Raman was not in a position to hold a pen he requested that the minutes be taken as signed by him." He even instructed his secretary to make sure that the travelling allowance was paid to the members.

He died peacefully on the morning of November 21st 1970. There was a simple, clean cremation with no mumbo-jumbo in the gardens of his Institute, as he had desired.

21. UNIQUENESS OF RAMAN

What were the characteristic features that set Raman apart from most others as a scientist and a man?

I have never seen anyone who enjoyed science so much. The sheer joy of seeing things and doing science filled him with exuberance and excitement. He had an incredible zest for life. He enjoyed his food, his jokes, his travel, his story books and novels, his fights and quarrels. Yet the enjoyment he had for his science was something apart. In this pursuit it was as if his ego disappeared completely in the presence of effulgent Nature. Yes, he was truly lost in the wonder and beauty of what he was trying to comprehend.

I have never seen him in fear—he was a man truly unafraid. He feared nothing, no situation, no one and no authority, and in this respect he was very different from those around him.

We are celebrating the centennial of his birth. The question we should ask is, "Is Raman relevant today?" Once, after he had made a very pungent attack on the manner in which universities were being neglected and despoiled, I asked him whether he had not been too harsh. This provoked a long discourse on the need to express one's opinion with honesty. In short he said: "Even a man of sensitivity and imagination can become bound and unfree when he has to falsify his feelings. If he forces himself to say that he likes what he dislikes and that he believes what he does not believe then he will have to pay the price in that his spontaneous and his creative faculties will dry up."

In his day, Raman was amongst the very few who stood up and spoke their mind. Today we have a very much larger number of scientists in this country but one scarcely hears any of them speaking out.

The main purpose of celebrating a great event like the Raman centennial should be to derive inspiration from it.

Young scientists, like so many of you here, must learn to enjoy doing science as Raman did and to stand up to authority and speak your mind. Only then will the future of science in our country be assured.