SIVARAMAKRISHNA CHANDRASEKHAR

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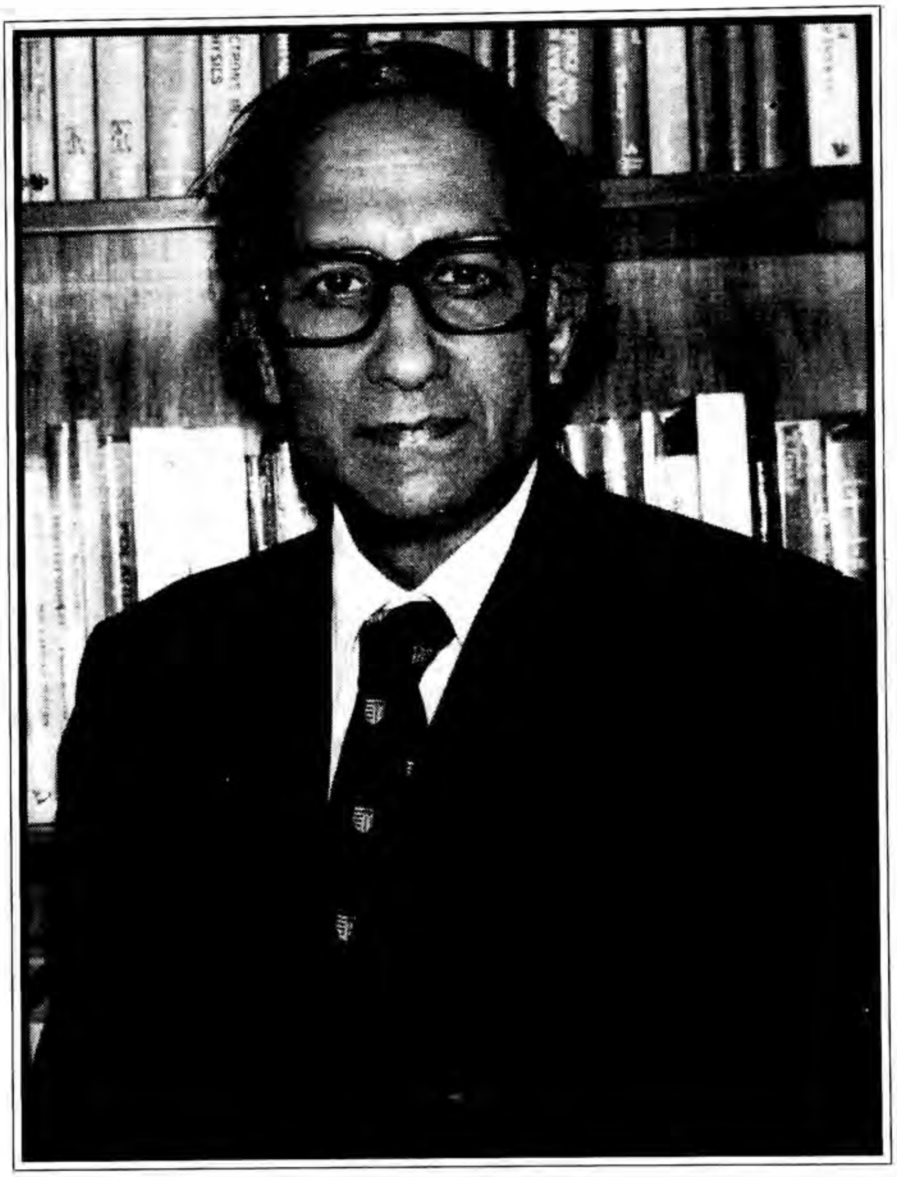

SIVARAMAKRISHNA CHANDRASEKHAR

(1930-2004)

Elected Fellow 1978

SIVARAMAKRISHNA CHANDRASEKHAR, the eminent liquid crystal physicist, died on 8 March 2004. His father, Sashiah Sivaramakrishnan, was an accountant general and his mother was Sitalakshmi. The fourth of five sons, he was born on 6 August 1930, a few months before it was announced that his maternal uncle Sir CV Raman was to be awarded the Nobel Prize for physics for that year. He belonged to the most distinguished family of physicists of India: another Nobel Laureate, the astrophysicist Subrahmanyan Chandrasekhar was the son of another maternal uncle; an elder brother, S Ramaseshan was a well known materials scientist and the younger brother S. Pancharatnam discovered the geometric phase in optics, which is now named after him. Chandrasekhar was mainly responsible for placing India on the international map of research on Liquid Crystals (LC), contributing to several aspects of the endeavor. He started the research work on the subject in the Department of Physics of the University of Mysore, and later established the well-known LC Laboratory in the Raman Research Institute, and finally founded the Centre for Liquid Crystal Research. The most important contribution was the discovery of columnar LCs in compounds made of disc like molecules. He authored a book entitled *Liquid Crystals*, which has become very popular. He also organized several International Conferences on the subject. In his death, the liquid crystal community has lost one of its most distinguished practitioners. He leaves behind his wife, Ila Chandrasekhar, a son and a daughter.

EDUCATIONAL BACKGROUND

Chandrasekar's primary, middle and secondary school education was at different schools located in Calcutta, Delhi, Nagpur, Madras and Coimbatore as his father was on a transferable job. He did his Intermediate Course in the Loyola College, Madras and obtained the B.Sc. (Hons) and M.Sc. (1951) degrees, standing first in the latter, from the College of Science of the Nagpur University. He then joined the Raman Research Institute, Bangalore, to work under the guidance of Professor C.V. Raman and obtained the D.Sc. degree of the Nagpur University in 1954. Later he went to the Cambridge University, UK, with an 1851 exhibition scholarship and worked for the Ph.D. degree (1957), under the guidance of Dr. Helen D Megaw and Dr. WH Taylor. His post- doctoral work was done first with Professor Dame Kathleen Lonsdale in the University College, London, during 1957 to 1959 as a DSIR fellow, and later with Professor Lawrence Bragg and Professor David Philips in the Royal Institution, London, during 1959 to 1961 as a research fellow.

RESEARCH AND PROFESSIONAL CARREER

In the mid 20th century, the University of Mysore had the departments of postgraduate studies split between the two main cities of the old Mysore state, viz., Mysore, the royal city, and Bangalore, which was the commercial and the post-independence political capital. All the science departments were in the central college at Bangalore, and the arts departments in the Maharaja's college at Mysore. With the view of starting a separate university in Bangalore, postgraduate science departments were started in Mysore, in the new campus around the Jayalakshmivilas mansion. Chandrasekhar was appointed as the first professor and head of the physics department, which was located on the wooden first floor in the hindquarters of the mansion itself. He joined the university in 1961, and at 31 years of age, he was perhaps the youngest professor at that time. Two other students of Raman, viz., D Krishnamurti and S Pancharatnam (the younger brother of Chandrasekhar) joined as readers. They set up laboratories for the Master's course and the first special subject to be started was spectroscopy. The annual meeting of the Indian Academy of Sciences was held in the university in 1961. Soon Chandrasekhar started a program of research on liquid crystals. As the laboratories were not yet equipped for research work, the initial contributions were theoretical in nature. His first Ph.D. student, MS Madhava, however worked on the experimental problem of measuring the optical rotatory dispersion of a few crystals, a subject on which Chandrasekhar had earlier worked for his own first doctoral degree in the Raman Research Institute. I joined Chandrasekhar as the first Ph.D. student to work on liquid crystals towards the end of 1965. Earlier that year the department had shifted to a new building and Chandrasekhar had organized a summer institute for college teachers, with a partial support from an agency of US, which had deputed two professors and donated some useful equipment. Some new faculty members were also inducted, and three new special subjects, viz., solid state physics, nuclear physics and theoretical physics were offered in the M.Sc. course. All these activities naturally enhanced the profile of the physics department in the university. Chandrasekhar himself pursued several research problems in liquid crystals and guided two other students in the area in Mysore. Though some simple experimental studies were conducted on liquid crystals, these were necessarily on a few mesogens, which were commercially available. Nevertheless, the research work on liquid crystals attracted international attention. Professor GH Brown, the founder director of the Liquid Crystal Institute at Kent, Ohio, US, who, in many ways helped the development of the research activities on the subject, visited the Mysore University around 1970.

Raman died in November 1970 after a brief illness. The Raman Research Institute (RRI) was his private institute, as Raman did not take any aid from the government. After him, the central government came forward to support RRI as a national institute, through the department of science and technology (DST), Chandrasekhar was invited to start a liquid crystal laboratory in RRI, and he moved to Bangalore with a couple of students (including myself) towards the end of 1971.The funding in RRI was better than in the Mysore University, and a well equipped laboratory was quickly established. Realising that cutting edge research would not be possible without the capacity to synthesise new chemicals, a synthetic organic chemistry laboratory was also started. Many new results were obtained and in a short time, the laboratory became a leading centre of research in the world. 1973 was the year of the silver jubilee of the founding of RRI, and a winter school followed by an international conference on liquid crystals was held in December. Leading researchers like Brown, Gray the well known chemist, Saupe, and de Gennes who went on to win the Nobel prize for physics in 1991 partly for his contributions to liquid crystals, took part in the events.

As is well known, liquid crystal displays (LCD) are used in all portable devices, and are replacing the familiar cathode ray tubes even from tabletop computer monitors and TV sets. The LCDs were introduced around 1970, and the scientists of RRI started a cooperative effort with the engineers of Bharat Electronics (BE) to develop an indigenous know-how for the manufacturing of simple LCDs. BE continues the manufacturing of such LCDs. The high point in the scientific career of Chandrasekhar came in 1977, when his book on liquid crystals was published, and even more importantly, with two coworkers he published a paper announcing the discovery of columnar liquid crystals made of disc like molecules. Chandrasekhar was the Nehru Visiting Professor and Fellow of Pembroke College, University of Cambridge during 1986 to 87. He retired from RRI in 1990, and was awarded the Bhatnagar Fellowship newly instituted by the Council of Scientific and Industrial Research. In 1991 he started the Centre for Liquid Crystal Research (CLCR) in a building made available by BE on its campus in Jalahalli, Bangalore. He was the director of the Centre till 1998, and subsequently continued as an Honorary Professor. The Centre was initially supported by the department of electronics, which later was renamed the department of information technology. The DST has taken over the Centre since 2003.

SCIENTIFIC CONTRIBUTIONS

(A) Optical Rotatory Dispersion of Crystals

The topic on which Chandrasekhar worked for his D.Sc. degree under the guidance of Raman in the Raman Research Institute was the optical rotatory dispersion (ORD) of crystals He set up an experiment to measure the temperature dependence of ORD. The measurements were made on single crystals of sodium chlorate, quartz, cinnabar and benzil. He showed that the ORD is better described by a quadratic formula in which the rotatory power is $\propto \lambda^2/(\lambda^2 - \lambda_0^2)^2$, where λ is the wavelength of light and λ_0 that corresponding to an absorption band, rather than the

Drude type formula which was usually used. He showed that the quadratic formula could be derived using the coupled oscillator model of Kuhn. After he joined the Mysore University as a professor, he revived the studies on ORD with a Ph.D. student. ORD of sodium chlorate and sodium bromate which have opposite configurations, and that of mixed crystals of the two species were measured.

(B) X-ray Analysis and Extinction Errors

Chandrasekhar, who went to Cambridge as an 1851 exhibition scholar, worked for a Ph.D. degree mainly on correction for extinction in crystal structure analysis using X-ray scattering. The extinction arises due to the mosaicity of crystals. He developed a simple experimental method for implementing such a correction. After he moved to the Royal Institution, he continued his studies on crystal structures, and was involved in the analysis of the structure of Bytownite. After he returned to India, in collaboration with Ramaseshan and Singh, he demonstrated a method of measuring the extinction by the use of polarized X-rays.

(C) Studies on Liquid Crystals

Chandrasekhar, of course, is most well known for his work on liquid crystals, a subject on which he started investigations soon after he joined the Mysore University as professor. As the new department of physics in the University did not have experimental facilities, the initial studies were theoretical in nature. The most important experimental studies were taken up after he moved to the Raman Research Institute and a well- equipped laboratory was set up. He carried out investigations on several problems in collaboration with colleagues and students, as seen in the publications listed below. In the following, I summarise only the most important results.

The first really significant work was on the application of the dynamical theory of reflection from X-rays to cholesteric liquid crystals (LCs). In such LCs, rod-like chiral molecules have a helical arrangement with a pitch P~0.5 μm, which is of the order of wavelength of visible light. The light beam with one sense of circular polarization is totally reflected while the component with the other polarization is transmitted. Earlier, an exact theory of the optical properties of cholesteric LCs had been proposed by de Vries, and the dynamical theory provided a simpler method of calculation, whose results are almost similar to those of the exact model. A particularly interesting consequence is the analogue of the Borrmann effect in crystals, in which, by adjusting the absorption band of linearly dichroic solute molecules to coincide with the reflection band of the cholesteric LC, an anomalous enhancement of the circular dichroism is seen, compared to the non-absorbing case. The effect was demonstrated both theoretically and experimentally.

The simplest LC is the nematic phase, which has a purely orientational order of non-chiral molecules. The molecular theory developed by Maier and Saupe (MS) accounts for the main features of the nematic to isotropic (NI) transition. In this theory, the single particle orientational potential is assumed to be proportional to $\cos^2\theta$, where θ is the angle made the molecular long axis with the average orientation direction, or the director. The theory predicts a universal value of the order parameter S (= $\langle 3 \cos^2\theta\text{-}1\rangle/2$, where the angular brackets indicate a statistical average) at the NI transition point. Experimentally, however the order parameter varies over a wide range, depending on the nature of the chemical. This was accounted for by extending the MS theory to include the $\cos^4\theta$ dependent term also in the single particle potential, which was shown to arise from the dipole-quadrupole component of the intermolecular dispersion potential. The Pople-Karasz theory of melting and orientational transitions in molecular crystals made of anisotropic molecules was used to calculate the general phase diagram including both crystal to nematic and NI transitions, which reflects the observed trends qualitatively. A major deficiency of the mean field theories is the overestimation of the strength of the first order NI transition. Inclusion of near neighbour correlations was shown to improve the theoretical prediction. Perhaps the most important molecular theoretical development was to show that near neighbour molecules with large longitudinal dipoles have antiparallel short-range order, and to account for the experimentally observed positive jump in the average dielectric constant at the NI transition point.

High-pressure studies, conducted using the facilities in the National Aeronautical (now Aerospace) Laboratory, were used to demonstrate that mesomorphism could be induced by pressure. The most important discovery for which he is well known is that of the columnar liquid crystalline phase in compounds made of disc like molecules. Since the LC phase was discovered by Reinitzer in 1888, only rod like molecules had been investigated, till Chandrasekhar and his coworkers decided in 1977 to look for mesomorphism in compounds made of molecules with a different shape. The symmetry of the columnar LC that was discovered, with one dimensional liquid- and two dimensional crystalline- order was not found in thermotropic LCs till that time. Since then, a large number of other disc like molecules have been studied and the original paper, published in *Pramana,* is one of the most highly cited papers in the field of liquid crystals.

Another interesting result was the synthesis of the first paramagnetic nematogenic compounds, while typical mesogens are diamagnetic in nature. The nematic phase exhibited by practically all mesogenic compounds is uniaxial in nature. The biaxial nematic phase in which the medium is not cylindrically symmetric about the main director, is well established in lyotropic LCs, in which amphiphilic molecules aggregate in a solvent like water to form micellar structures with shape anisotropy. Chandrasekhar with various coworkers made an extensive search for the biaxial nematic phase in thermotropic mesogens made of small organic molecules with strong shape biaxiality. Indeed his last paper, submitted about a month before his death, is also on the possible occurrence of biaxial smectic and nematic phases in a compound, the molecules of which have both rod like and bent core moieties.

Chandrasekhar authored or coauthored several review articles, mainly on LCs of disc like molecules, and a few on other topics like phase transitions, high-pressure studies, and defects in LCs. His book on Liquid Crystals and the review articles are well known to researchers in the field. His book, which was originally published in 1977, was translated to the Russian and Japanese languages, and an enlarged second edition was published in 1992. Chandrasekhar was also a very good organizer. He established three laboratories (in Mysore University, in RRI, and CLCR). He organized several conferences, in 1973, 1979, and 1982, the last one being the 9th in a series of conferences, originally scheduled to be held in Poland, but cancelled due to an adverse political situation. Other conferences organized by him include the Second Asia Pacific Physics Conference in 1986, the Indo-US conference on Liquid Crystals in1996, and a conference on the occasion of the 25th year of the discovery of LCs of disc like molecules in 2002. He edited the proceedings of all these conferences.

In short, Chandrasekhar contributed to all aspects of the growth of the subject, and is mainly responsible for putting India on the international map of liquid crystal research.

AWARDS AND HONOURS

Chandrasekhar was an elected Fellow of the following Science Academies: the Indian Academy of Sciences (elected in 1962, and on its council during 1971-73 and1986-88); the Indian National Science Academy (elected in 1978, on its council during 1985-87 and its Vice President during 1989-90); the National Academy of Sciences (Honorary Fellow); the Royal Society of London (elected in 1983); the Institute of Physics of London ; the Third World Academy of Sciences (founding Fellow). He was presented with the CSIR Silver Jubilee Award in 1972, the SS Bhatnagar Prize for Physical Sciences in 1972, the FICCI Award for Science in 1979, the Sir C.V. Raman Award of UGC in 1981, the Mahendra Lal Sircar Award for Physics of IACS in 1984, the Homi Bhabha Medal of INSA in 1987, the CV Raman Centenary Medal of IACS in 1988, the Meghnad Saha Medal of INSA in 1992, the RD Birla Award of the Indian Physics Association in 1992, the Royal Medal of the Royal Society in 1994, the Niels Bohr Gold Medal of UNESCO in 1998, and the Freedericksz Medal of the Russian Liquid Society in 2000. He was the recipient of the Karnataka Rajyotsava Award in 1986, of the Padma Bhushan Award in 1998 and the entitlement 'Chevalier dans L'Order des Palmes Academiques' of the French

Government in 1999. He was also a member of several international and national committees on science and education. He was the founder president of the International Liquid Crystal Society (ILCS) during 1990-92, and of the Indian Liquid Crystal Society till the end. He was named one of the Honored Members of ILCS in 1998. He was an editor of the journal *Molecular Crystals and Liquid Crystals* for 20 years. Professor Chandrasekhar was awarded the Sc. D. degree of the Cambridge University in 1987, and the D. Sc. (hc) degree of the University of Mysore.

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