RAPPAL SANGAMESWARA KRISHNAN

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R. S. Krishnan

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(1911-1999)

Elected Fellow 1959

BIRTH, PARENTAGE AND EDUCATION

RAPPAL SANGAMESWARA KRISHNAN was born to Sri RP Sangameswaran and Srimathi Parvathammal near Palghat, Kerala, on 22 September 1911. His father was a teacher in a school. Krishnan must have imbibed his scholastic values from his father. Krishnan was a brilliant student, consistently at the top of his class. After completing his school education he joined the St. Joseph's College, Tiruchirappalli, for his B.A. (Honours) degree. There were only a few colleges in the whole presidency of Madras, over which the Madras University had jurisdiction, which offered the Honours programme. Admission to this programme was based on exacting standards. A student could appear only once for the final examination. If he did not come out successful, the three years of study would be a waste and he had to start all over again in the bachelor's programme. Krishnan stood first in the University in the B.A. (Honours) examination. In 1933, he joined Professor CV Raman as a research scholar in the newly started Department of Physics at the Indian Institute of Science, Bangalore. He worked on light scattering and obtained his D.Sc. degree in Physics from the Madras University in 1937.

PROFESSIONAL CAREER

In 1938, he was awarded the prestigious 1851 Exhibition Overseas Scholarship for Research Work in Nuclear Physics and proceeded to the Cavendish Laboratory, Cambridge, to work under Sir John Cockroft famous for the Cockroft-Walton generator. During this period he studied nuclear transmutations induced by the deuteron using the cyclotron at the laboratory. The cyclotron was in the early stages of development and was a difficult instrument to operate. At the outbreak of war many scientists left the laboratory to take up other work related to the war effort. Krishnan took upon himself the responsibility of keeping the cyclotron running and the research efforts going.

Professor Cockroft, in a letter to the Vice-Chancellor of the Allahabad University in connection with Krishnan's application for a Professorship, had this to say about the abilities of Professor Krishnan.

"Dr. Krishnan worked in Cambridge under my supervision for three years; during two years of this, he was in complete charge of the running of, and work carried out on, the Cambridge cyclotron. The fact that he was able to do this, when the more senior staff was withdrawn at the outbreak of the war, is a very strong recommendation for Dr. Krishnan's abilities as an experimental physicist.

Dr. Krishnan is also skilled with work in electronic counters. Dr. Krishnan has shown originality and good judgment in selecting subjects for his research, and in my opinion, is the best experimental physicist from India who has worked in the Cavendish Laboratory during my residence there, that is over a period of 15 years."

Krishnan returned to India in 1941 with a Ph.D. in Nuclear Physics from the Cambridge University. He rejoined the Physics Department of the Indian Institute of Science, Bangalore, as the senior most academic staff member under Professor CV Raman. When Professor Raman retired from the institute in 1948, Krishnan succeeded him as the Head of the Department of Physics. He continued in this post till June 1973.

Till Professor Krishnan's time the work in the Physics Department was mainly concentrated on light scattering and Raman Effect. Professor Krishnan realized the need to build a strong research effort in the area of solid-state physics. To this end he spurred his students to work on different aspects of solid-state physics such as elastic and thermal properties, photo-elastic properties, lattice dynamics, X-ray diffraction, and Raman and Infrared spectroscopy of crystals. The work on light scattering and colloid optics was continued. Studies on nuclear geo-chronology, ultrasonics, nuclear magnetic resonance and electron paramagnetic resonance were initiated. In the twenty-five years of his stewardship, the Department of Physics grew in stature as a leading centre for research in condensed matter physics, a position it maintains till today.

In June 1945, he submitted a proposal to the Indian Institute of Science to expand the activities of the Physics Department to embrace Nuclear Physics. The proposal involved the development of a cyclotron, electrostatic accelerator and an isotope separator. This proposal was referred to a committee consisting of Professor HJ Bhabha and Professor HJ Taylor. This committee turned down the proposal and recommended that the Department should intensify its efforts in the areas in which it was working on. Looking back on the recommendation of the committee, I feel it was a pity that the Department of Physics was not allowed to develop activities in Nuclear Physics. Concentrating all activities on atomic research with the institutes under the Department of Atomic Energy was perhaps unwise as it deprived other institutes in playing a major role in developing activities in areas such as particle accelerators. It is also curious that in 1947 Professor Krishnan received an invitation from Professor HJ Bhabha to join him in developing Nuclear physics activities in Bombay; but Krishnan declined the invitation due to personal reasons.

From 1973 to 1977 he worked as Vice-Chancellor of Kerala University where he attempted to improve the quality of education and research in the university. Like many progressive Vice-Chancellors he had to contend against the negativism entrenched in the bureaucracy and the intransigence of the trade unions.

From 1977 he worked as a Retired Scientist in the Indian Institute of Science. He was involved in a monumental project on preparing a Source book on Raman Effect Data financed by the Department of Science and Technology from 1977-1982. From 1982 he worked as a Visiting Scientist in the Materials Science Division of the National Aeronautical Laboratory and continued his work on the Source book of Raman Effect data. He was an Emeritus scientist of the CSIR from 1990 in the National Aeronautical Laboratory. He passed away while still in harness on October 2, 1999. He left behind his wife, Rajammal, and four surviving children, two daughters and two sons.

RESEARCH CONTRIBUTIONS

(A) Krishnan Effect:

The Tyndall effect deals with the scattering of light by colloidal particles. If a beam of un-polarized white light is sent through a suspension of colloidal particles, and the scattered light is viewed in a direction at right angles, it shows a distinct colour and state of polarization depending on the shape and size of the colloidal particles. Using a double image prism Krishnan split the un-polarized incident light beam into two components H (horizontally polarized) and V (vertically polarized) and sent the two beams simultaneously into the scattering medium. He also used a double image prism to analyze the scattered beams into their horizontal H and vertical V components. The four tracks can be labeled HH (horizontally polarized incident beam and horizontally polarized scattered beam), HV, VH and VV. If the scattering particles are spherically symmetrical, the intensity of the HV and VH tracks should be zero. Krishnan found a universal reciprocity relation, namely that the intensity and colour of the HV track was identical to those of the VH track. However the VV track differed in intensity from the other three beams. Its brightness in relation to the HH track depends on the state of aggregation of the colloidal particles.

Krishnan continued his study on the scattering of light by liquids and liquid mixtures and glasses. He showed that even in these materials, in which molecules or aggregates of atoms exist with different sizes and shapes, he could get the four components of which the intensity of the VV component was more than the intensity of the other components.

The existing theories of light scattering predicted that, in pure liquids and optical glasses, in which the light is scattered by aggregates of atoms, the intensity of the HV, VH and VV tracks should be the same. However the experiments of Krishnan showed that the VV track was unexpectedly brighter than the HV and VH tracks. This is called the Krishnan effect. This indicates the presence of large molecular clusters in liquids and glasses. The full theory of the Krishnan effect was worked out by Dr. Hans Mueller. The theory was published in the *Proceedings of the Royal Society* (London) which accounted for all the experimental observations made by Krishnan. The Krishnan effect was used by two scientists of the Goodyear rubber company of the U.S.A. to estimate the physical and chemical nature of rubber in organics solvents.

There are several publications by Krishnan on this effect that will take too much space to cite here. Two of his reviews in Kolloid Zeitschrift and one on depolarization of optical glasses are cited below:

1. Über die Dispersion der Depolarization bei der Leichtstreuung in Kolloiden Systemen, *Kolloid Zeitschrift* (1938), **84**, 1.
2. Eine Methode zum Nachweiss molecularer Aggregation durch Leichtstreuung. *Kolloid Zeitschrift* (1938), **84**, 8.
3. The anomalous depolarization of light in optical glasses *Proceedings of the Indian Academy of Sciences* (1938), **A8**, 442.

(B) Deuteron Induced Fission:

During his stay in the Cavendish Laboratory he worked with the cyclotron on nuclear transformations induced by deuterons. He studied the disintegrations in the heavy elements Uranium and Thorium produced by deuterons and published a series of papers in the Proceedings of the Royal Society (London), Nature and other journals. Two important publications in this field are cited below:

1. Fission of Uranium and Thorium with deuteron bombardment (with Dr. Banks) *Nature* (London), (1940), **145**, 860.
2. Cross-section measurements for disintegrations produced by deuterons in the heavy elements (with Mr. Nahum), *Proceedings of the Royal Society* (London), (1942), **180**, 321.

(C) Brillouin Scattering in Crystals:

The atoms in a crystal lattice vibrate in different patterns called normal modes. These modes are characterized by a frequency ν and a wavelength λ or a wave vector $2\pi/\lambda$. Of these different normal modes three are assigned to the acoustic modes corresponding to one quasi-longitudinal and two quasi-transverse elastic waves in the crystal. Along certain symmetry directions of the crystal the two quasi-transverse acoustic modes are degenerate. The periodic strain produced by these modes causes a periodic change in the refractive index in the crystal through the photo-elastic effect.

When a light beam of frequency ν_i and wave vector k_i is incident on the crystal it will be scattered with a modified frequency ν_s in a direction making an angle θ to the incident beam by the periodic modulation of refractive index by the acoustic mode with wave vector $q = 4\pi\sin\theta/\lambda$ The change in frequency of the photon is the frequency $\nu(q)$ of an acoustic mode with the wave vector q. Since the frequency of the acoustic mode is one hundredth to one thousandth of the photon frequency it was difficult to see Brillouin scattering even using spectrographs of high dispersion available at the time. The unmodified Rayleigh scattering of the incident beam was much more intense than the modified Brillouin scattered beams and produced a wide halation on the photographic plate which masked the weak Brillouin scattered light.

This problem was solved by Krishnan in an ingenious way through his natural instinct as a skilled experimental physicist. He used the 2536 A radiation from the mercury arc. This is the most intense line emitted by mercury and is advantageous in recording the weak Brillouin lines. At the same time, this line, called the resonance radiation of mercury, is strongly absorbed by the cold mercury vapour and the spectral width of the absorption is very narrow. By putting a dish containing a drop of mercury inside the spectrograph, the Rayleigh scattered line can be selectively absorbed and weakened several fold without a major reduction in the intensity of the Brillouin components. By this ingenious technique Krishnan overcame the effect of halation due to Rayleigh scattering and recorded the Brillouin scattering in diamond, fused quartz and the alkali halides. With the advent of the laser and improvements in detection techniques it is now comparatively easy to record Brillouin scattering. But to record the Brillouin components before the lasers were discovered was a stupendous achievement. The theory of Brillouin scattering was worked out by V Chandrasekharan and RS Krishnan. The citations on this work are given below:

1. Thermal scattering of light in diamond, *Nature* (1947), **159**, 749.
2. Thermal scattering of light in crystals–Part I: Quartz (with V Chandrasekharan) *Proceedings of the Indian Academy of Sciences* (1950), **A31**, 427.

(D) Second Order Raman Spectra of Crystals:

The dynamics of crystal lattices was enunciated by Max Born. According to this theory the normal modes of vibration of a lattice with p atoms in the unit cell consist of 3p branches of dispersion relations connecting the frequency of the mode as a function of its wave vector. This view was contested by Raman who held that the normal modes should consist of three acoustic branches and 24p-3 discrete frequencies of vibration.

To test this, experiments were undertaken to photograph the second order Raman spectra of simple crystals like diamond and the alkali halides. In these spectra one will see the sum and difference of the frequencies of normal modes allowed by selection rules. If the normal mode frequencies were spread out over a band one would expect to see a continuous spectrum in the second order with some features.

Krishnan was the first to record the weak second order Raman spectra of diamond and the alkali halides using the powerful 2536 Å radiation from the mercury arc. These spectra showed a weak continuum with sharp peaks. Intense theoretical activity by both the camps followed this discovery. The group of Max Born could explain the peaks as arising from peaks in the continuous density of states in a crystal. The emergence of inelastic neutron scattering as a powerful direct tool to record the normal mode frequencies saw the ideas of Born vindicated.

But Krishnan's experimental results had the sanguinary result that the lattice dynamical ideas of Born were refined and elaborated and the idea of critical points and van-Hove singularities in the frequency spectrum was put on a firm foundation. Two references on this work of Krishnan are cited below:

1. The second order Raman spectrum of diamond, *Proceedings of the Indian Academy of Sciences*, (1946), **24**, 25.
2. The vibrational spectra of alkali halides (with PS Narayanan), *Proceedings of the Indian Academy of Sciences*, (1948), **28**, 296.

NUMBER OF PUBLICATIONS

Professor RS Krishnan published a total of 220 publications, some individually and some with co-authors. It will be impossible to list all of them. But a perusal of the list shows the very wide range of topics in condensed matter physics pursued by him and his students. This set a solid foundation for the growth of the Department of Physics, Indian Institute of Science, as a major centre for condensed matter research in India.

Books Published

1. Progress in Crystal Physics (1958).
2. One chapter on the Raman Spectra of Alkali Halides in the book entitled "Essays on Structural Chemistry" (1970), MacMillan.

3. One chapter on Historical introduction and another on Brillouin scattering in the book "Raman Effect Volume I" (edited by A Anderson), Published by Marcel Dekker (1971).
4. Thermal expansion of crystals (with R Srinivasan and S Devanarayanan) Pergamon Press (1978).

DISTINCTIONS, AWARDS AND HONOURS

In his long career Krishnan was conferred with many distinctions and honours. He was elected a Fellow of the American Physical Society in 1940, a Fellow of the Indian Academy of Sciences in 1944, a Fellow of the Indian National Science Academy in 1950 and a Fellow of the Institute of Physics, London, in 1953. He was a member of the International committee on Ferro-electricity from 1972-1980, and a Member of the editorial board of the Journal of Raman Spectroscopy.

The National Science Foundation of USA awarded him a Visiting Professorship at the North Texas State University at Denton, Texas, for one year in 1971. He was awarded the platinum Jubilee Distinguished Alumni award of the Indian Institute of Science, Bangalore, in 1984 and the Sir C.V. Raman Centenary Gold Medal in 1988.

He lectured in many universities in UK under the Commonwealth Exchange scheme in 1954. He was a visiting professor at the Universities of Perth, Adelaide, Melbourne, Canberra and Sydney under the auspices of the Australian Spectroscopy Association in 1965. In 1966 he was a visiting scientist at the Bell Telephone Laboratories in U.S.A. and undertook a lecture tour of the major universities in U.S.A. In 1967 he was a visiting professor in Toronto University and lectured in many Canadian universities. In 1968 he visited different universities in Germany under the German Academic Exchange programme. In 1974 he was invited by the U.S.S.R. Academy of Sciences to visit the Moscow State University and the Institute of Optics in Leningrad.

SOURCE BOOK ON RAMAN EFFECT DATA

After retirement he worked on a monumental project to collect all published Raman Effect data from 1928 and codify them as a Source Book of several volumes. After the discovery of the laser, there was a renaissance in Raman Spectroscopy and many new phenomena such as Stimulated Raman and Brillouin scattering, Coherent Anti-Stokes Raman Spectroscopy, Coherent Stokes Raman spectroscopy, Surface enhanced Raman Scattering etc. were discovered. The application of Raman spectroscopy covers a wide range of disciplines such as physics, chemistry, biology, medical diagnostics, engineering and technology. It should be mentioned that nearly 3000 publications appear annually on these aspects. A need was felt for a Source Book on Raman Effect data.

He planned to publish a Source Book in many volumes containing complete bibliography of all papers published with a comprehensive index of compounds studied with classified subject and author index. This was a Herculean task and any one at his age would have been daunted by its magnitude. But he went ahead with his characteristic zeal to collect the references and get the material for his source book.

More than 30,000 references were collected for the period 1928 to 1981. They were cross-checked and relevant information was extracted to publish the data in a format for ready reference. This monumental task consumed most of his time from 1987 till his death in 1999.

Four volumes of the source book have already appeared, the first volume covering the period from 1928-1957, the second from 1958-1970, the third from 1971 to 1974, and the fourth from 1975-1977. The volumes were published by the Publication Information Directorate of the C.S.I.R. The fifth volume was also completed (except for the preface) before his death. The preface was written by one of his students and the volume was sent for publication. His death has created a hurdle in the completion of this work.

STUDENTS

Krishnan's major contribution was in training students, in giving them independent responsibility to work in chosen areas and in encouraging them to gain confidence and self-reliance. Sixty students were awarded the Ph.D. degree working under him. Some of them have gone on to earn a name for themselves and to promote the cause of science in the country. This perhaps overshadows his personal achievements in research. It cannot be summed up better than by quoting from the letter of Professor S. Ramaseshan to Professor Krishnan on the occasion of the latter's Sathabhishekam. This letter was published in *Current Science* (1993), 65, 493.

"He (RSK) had a knack of picking young scientists and encouraging them to start new things and making them work in almost independent groups. He courageously started such activities like dating of rocks, mass spectroscopy, ultrasonics, crystal dynamics and crystal properties, especially photo-elasticity, paramagnetic and nuclear magnetic resonance and also X ray crystallography. Many of these had never before been done in the country. By creating these semi-independent groups, Krishnan was in a sense (perhaps unconsciously) responsible for breaking the "GEHEIMRAT" system in which the Professor is supreme and all the members in the lab work for him. Unfortunately, this old system still persists at many places in the country.

You chose VS Venkatasubramanian (VSV) to work on dating of rocks. The work you and he did was truly path-breaking. The first mass spectrometer was built in the Physics department under your guidance (and not in Bombay). With VSV and LS

Raja Gopal, ultrasonics research came of age and elastic constants (of solids also) were determined using the most modern techniques. Your encouragement of Suryan, who was so full of ideas, was truly phenomenal. The first paramagnetic resonance and nuclear magnetic resonance set up was done in the Physics Department. Indeed, modern electronics really entered into physics because of you in your department. The remarkable work of R Srinivasan, his theoretical and experimental acumen, is something you and all of us can be proud of. I think Chidambaram, under your inspiration, became one of the best in India in instrumentation and he produced notable science in many fields.

I remember you egged me on to finish my doctoral thesis and later persuaded me to change my field from magneto-optics and paramagnetic resonance. When GN Ramachandran left, you 'picked' me and said that you had decided to put me 'in charge' of X rays and said 'Try to build a group worthy of this department'. I am personally very thankful to you for this decision of yours. Students who came out of this group attained world renown: Vishwamitra, Venkatesan, Vijayan and NV Mani (who died young) and also *their* students. I flatter myself in thinking that your experiment in this regard was not too unsuccessful.

You can be truly proud of V Chandrasekharan, VS Venkatasubramanian, R Srinivasan, ES Raja Gopal and R Chidambaram for they are as good as any in the world. You can feel immensely proud of and pleased with some of the products of your laboratory who occupy/occupied a few of the highest scientific posts like the Chairman of the Atomic Energy Commission, Director of the National Physical Laboratory, Director of the Indian Institute of Science etc."

What prescience did Krishnan have in generating a group of young scientists to provide leadership in education and research!

PERSONAL QUALITIES

Professor Krishnan was very humane and kind. The author can relate many experiences of Professor Krishnan's friendly solicitude towards his students. But he hid his gentle nature under a gruff exterior. He was forthright in his speech and would not pull his punches. It took some time for a new student to realize that he had a warm heart under his awesome presence.

He used to say that the best way to train a student was to suggest a general area of work to him and leave him alone. A worthy student will learn to work by himself and develop independent thinking. As a rookie I first felt alarmed that I had to venture on research on my own. But later I realized the merit of this approach as I gained confidence. If he found a student worthy of his confidence he would go to any lengths to help him.

I have written this memoir as my humble tribute to my great mentor.

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1970 Raman Spectra of Alkali Halides for the Essays on Structural Chemistry MacMillan London

1971 Contributed two Chapters one on Raman Effect (Historical Introduction) and one on Brillouin Scattering for the Book entitled Raman Effect vol I Published by Marcel Dekker New York

1978 Joint Editor for the Proceedings (two volumes) of the VIth International Conference on Raman Spectroscopy Bangalore

1979 A Book on Thermal properties of Crystals published by Pergamon Press London

1928 Bibliography on Raman Effect in five Volumes containing more than 26000 references from to 1979 Nearlycomplete for publication

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(C) Nuclear Physics:

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