case for first group elements. $S(q)$ has a peak near the smallest reciprocal lattice vector $\mathbf{G}_s$ of the solid into which the fluid freezes. So if the elastic scattering events $|\mathbf{k}+\mathbf{G}_s| \cong |\mathbf{k}|$ are not possible with $|\mathbf{k}| \cong k_F$, electron scattering will be low. If they are, the scattering is substantial and the resistivity is high. They argued that this is the essential reason why divalent liquid metals with longer k_F are much more resistive than monovalent ones [$S(q \sim 0)$ is typically twenty or more times less than $S(q \cong G)$]. The work anticipates, by almost two decades, that of Ziman[11] on resistivity of liquid metals and that of Greene and Kohn[12] on the electrical resistivity of sodium. The additional crucial idea these authors use is that of a weak pseudo-potential, i.e. the relative weakness of the effective interaction between an electron and an ion (in an *sp* band or simple metal). This pseudopotential can be calculated and then a low order expansion in it suffices. The lowest order process involves the structure factor (in general the dynamic structure factor $S(\mathbf{q}, \omega)$). For example, Greene and Kohn[12] show how the conventional electron–phonon scattering theory of Bloch, and the liquid metal transport theory of Ziman[11] are contained in a single formalism, and how quantitative resistivity calculations can be made knowing the pseudopotential $v(q)$, the phonon spectrum for $S(\mathbf{q}, \omega)$ and the measured static structure factor $S(q)$ for the fluid phase. They also remark on the location of the Fermi wave vector with respect to the peak of the structure factor (or the smallest reciprocal lattice vector **G**) and made a detailed analysis of the relative importance of umklapp processes.

Perhaps the last major contribution of Krishnan to condensed matter physics was a new approach to determining the work function of a metal[13]. Here again the basic idea is deceptively simple: measure the equilibrium saturation vapour pressure of electrons coming out of the hot metal from a hole in it and in thermal equilibrium with the metal. The actual measurement of this small pressure from the effusion current is a delicate affair, but the approach has obvious advantages, such as independence with respect to surface conditions and partial electron reflection from the surface (which affect thermionic emission rates). The results for graphite, several semiconductors, and transition metals have since been superseded, but it remains an original attempt.

For almost a quarter of a century, Krishnan seems to have been more or less the lone Indian practitioner of the quantum approach to understanding phenomena in condensed matter, doing both theory and experiment as necessary.

The ease of approach, the sure touch, and the freshness of many of Krishnan's contributions coming across a gap of more than half a century are indeed unusual. I am grateful to the editors of the centenary issue for this experience, and invite readers to savour the treat for themselves.

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K. S. Krishnan—the complete physicist

R. Sundaram

In the scientific circles abroad C. V. Raman was described as a giant light scatterer, M. N. Saha as a great astrophysicist, S. N. Bose as a great theoretician of boson fame, H. J. Bhabha as a great theoretician of cosmic ray fame and K. S. Krishnan as the complete physicist. Krishnan started his career with Raman and did extensive investigations on the scattering of light in a large number of liquids. He also did original work on the magnetic properties of crystals in relation to their structure. Later he did theoretical investigations on the electrical conductivities of metals and alloys. He had attained international fame at an early age. He could comment on all areas of physics with a high degree of excellence. He had an uncanny ability to penetrate to the roots of any problem, be it classical or quantum. It is because of his versatile knowledge, we felt, he was chosen to be the founder director of the National Physical Laboratory, India. I had the good fortune to be selected by Krishnan as a scientific assistant from the very inception of the laboratory. In this centenary year of Krishnan I pay my tributes to this eminent physicist in this brief article describing his passion for physics.

Krishnan or Sir K.S. as he was referred to by his admirers, took over the directorship of the National Physical Laboratory in 1948. He was almost the first to arrive in the laboratory every day and the assistant working on the research problem assigned by Professor was invariably there. Krishnan was a great critic and the assistant will have to face his incisive logic and ruthless criticism. He had always a research problem of his own apart from the general guidance he

gave to all the other divisions of the laboratory. All the problems he undertook for his research fall under the general area called solid-state physics which has earned the generalized name of condensed matter physics since the seventies. Krishnan authored many papers both in *Nature* and in *Proceedings of the Royal Society*, London, in the area of alkali halide crystals–anharmonicity of lattice oscillations, elastic constants, polarization field; thermionic constants of metals and semiconductors; the temperature distribution along electrically heated tubes, coils and filaments. The last mentioned area has applications to electrical technology. Nobody should have the mistaken notion that Krishnan encouraged only basic physics. The work on ferrites and carbon was initiated in NPL by Krishnan and later NPL made praiseworthy contributions in these areas. He remained a research professor rather than the director of the laboratory. He was accessible to everybody. As Director, he could have remained in the hill-top with lot of hurdles placed on the way up, as was the practice of the Directors of many other institutions, but he was so gentle and humane that he refused to be a bureaucrat. This tradition in NPL set up by Krishnan has been followed by all the Directors who have succeeded him.

Krishnan had asked me to give a series of lectures on differential equations in physics in the NPL colloquium. I started the series by quoting Arnold Sommerfeld. Sommerfeld in Munich had classified physical processes into two classes, equalization process and oscillation process and had identified Laplacian as the governing operator for equalization and biharmonic operator governing oscillation processes. Heat conduction (equalization of temperature differences), electrical conduction (equalization of potential differences), and diffusion (equalization of material densities) are all governed by a Laplace equation. At this stage Krishnan interrupted me and said 'This elegant generalization is mathematically very appealing; but physics means facing facts. You should take up case by case'. This is the same advice Krishnan gave me when I first met him; this profound advice guided me all through my scientific career.

Professor encouraged every scientific assistant to speak in the NPL colloquium. Many reputed scientists from abroad addressed the colloquium. Norbert Wiener, Casimir, Abdus Salam were some of them. One occasion is worth recalling when we had invited D. S. Kothari to address in our colloquium in 1958 on the newly published BCS theory of superconductivity. What we witnessed on that day was something like an encounter between two great giants, Krishnan a vigorous supporter of London's theory and Kothari an ardent votary of the new microscopic theory of BCS. The discussion centred around the derivation of Meissner effect, which follows directly from the London equation. However, to derive Meissner effect from the BCS model one had to do a lengthy calculation. Krishnan was not easily convinced of the pairing interaction. I may add that, perhaps the discovery of flux quantization, i.e.

Φ, magnetic flux through a ring

$$= \text{integer} \times \frac{hc}{2e}$$

and its beautiful experimental verification (specially of the factor 1/2) by Deaver and Fairbank and Doll and Nabauer would have convinced Krishnan of the correctness of the BCS pairing in the ground state. The report of this verification appeared only in 1961 but by then Krishnan was no more.

From the late fifties, physics has progressed very fast, since quantum field theory had offered many techniques for handling many-body problems. The problems in solid-state which are many-body problems could be solved by these advanced methods. I hold the view that the quantum field theoretic methods can be compared with Keat's poetry wherein you have an idea-packed language for example, poles of a Green function give the excitations of a system, singularity in T-matrix gives phase transition and so on. Classical treatment can be compared with Mathew Arnold's prose wherein ideas are primary and the language in which they are clothed is secondary. The power and potentialities of the new methods are tremendous. Krishnan did not live long to see these advances although he had a glimpse of it in the BCS theory.

I include a few of the so-called Krishnan anecdotes which reveal his personality and style of functioning. On one of those early days, when Krishnan was standing near the main entrance of the new building, a USA trained young scientist approached him with a request to visit the laboratory. He did not know who Krishnan was. Krishnan took him around the laboratory, explained to him every aspect of the work to be undertaken, but not once did he reveal his identity. The swank and superior airs of the young man were in such bounteous measure that he refused to discern the enlightened conversation of Krishnan. At last Krishnan brought the young man to the room marked 'Director' and said 'this is my room' (This room was named by me and my friends as high temple). The chinks in the armour of the young man were then visible and he was profusely apologetic. That was the typical Krishnan style, shall I say Gandhian style, of humbling arrogance.

Once when I was in the high temple, a file was brought by the Administrative officer for the urgent sanction of a fairly large sum of money. While signing the file, Krishnan said 'I hope I am not signing my death warrant'.

Krishnan had a personal driver for his car. He was being paid every month by Krishnan. Once when he went abroad, his family members asked the driver to take them for shopping in the city. The driver bluntly refused saying 'I work only for Sahib'. The family members got enraged but could not do anything except to wait for Professor's arrival. When reported about the driver's behaviour Krishnan did not do anything. On the expected pay day the driver approached Krishnan. He asked him to collect his salary from the family members. They drove him away saying he should collect the salary from Sahib. Thus he was made to shuttle four to five times between Sahib and the family members until he asked for forgiveness.

Another incident which proved him to be Director extraordinary was when the confidential report of a scientific assistant was submitted to him for approval by the head of the division. The divisional head had written some nasty unfavourable remarks just because the assistant had his own research problem and he refused to do the odd jobs assigned to him. Krishnan was infuriated and the divisional head was called to his room to be told 'Either you write a proper report or I will write the report'. He then tore the report into pieces.

Pandit Jawaharlal Nehru had described Krishnan as a shy person but he added 'behind this shyness lies a profundity of knowledge'. Panditji held Krishnan in high esteem and we were told, the name 'APSARA' for a reactor in Bombay was provided by Krishnan. He was an erudite scholar of Sanskrit and Tamil classics. Among the many honours he received, mention must be made of F.R.S. in 1940, Padma Bhushan in 1954 and the first Bhatnagar Memorial Award in 1961.

Krishnan was very fond of travel. He once mentioned that his hobbies were travel, tennis and Tamil classics. In fact, his first heart attack can be attributed to his frequent travels. Even while travelling he used to work on scientific problems. Once, while going to Bangalore, he asked me to accompany him up to the aerodrome. During the car drive, he asked me to tell him all about beta and gamma functions. In the aerodrome he said 'let me think over these functions in my journey. On my return, we will discuss more about them'. A year later, on a similar occasion, the story turned out to be different. On the last day he spent in the laboratory, we had met for fifteen minutes when we talked about Fermi surfaces of metals. On the next day, he was to fly to Bombay. He told me 'May be we can discuss more on my return'. 'May' includes 'May not', as they say. It was like a premonition. He had another massive heart attack at night which proved fatal. I remember Krishnan with the highest regards, as he was my *Guru* who readily accepted me as his student, taught me, wisely controverted me and above all created holy curiosities in me.

Krishnan must have had an unshakeable faith in the famous quotation from Proverbs XVI, 16 'How much better is it to get wisdom than gold. And to get understanding is to be chosen rather than silver', for, how else, could he have pursued physics till the last day of his life?

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A conversation with K. S. Krishnan on the story of the discovery of the Raman effect

S. Ramaseshan

Prof. K. S. Krishnan, whose birth centennial we are celebrating this year, was perhaps one of the best scientists India has ever produced. Of him C. V. Raman once said to me in 1945, 'one can scarcely ever meet a person more intelligent, more astute and having a more thorough understanding of any subject in general, and in science in particular, and who is better endowed with such superb experimental skills'. In the thirties, Krishnan plunged himself into modern physics with gusto and his understanding of it was incredible. (One had to hear him expound a subject to perceive the depth of his knowledge and understanding.) He did much to propagate modern physics in India and has contributed greatly to its advancement by his exceptionally original scientific papers (both in theory and experiment). He was a good friend of my father's and they often used to play bridge together and also tennis. He could discourse on any subject with much insight. I met him first when I was a boy and he treated me like a grown-up and discussed with me the relative merits of football players of East Bengal and Mohan Bagan, the two top teams in the Calcutta football league. Later I have heard him delivering a few scientific lectures when he came to the Nagpur University where I was an undergraduate. I still recall the clarity of his exposition and the humorous stories with which he laced these lectures. I remember taking him to play tennis in our college tennis courts. I met him everytime he came to Bangalore and lunch with me in the afternoon was routine. (Incidentally he enjoyed his meals greatly.) We also used to discuss optics and magneto-optics, subjects in which he was a master.

He was a man of many parts and a great respector of our traditional values. He was a well rounded human being. He made one feel that he was at peace with himself. His knowledge of the arts was substantial. Anything he did in science or otherwise, he did with some elegance and elan. It was a delight to meet him. His conversation was so vivacious and he was so full of fun.

One of the most memorable experiences I have had was the conversation I had with Krishnan about four or five years before he died.

In this conversation, he was so forthright in his statements and the phrases he used and sentiments he expressed were so vivid that they made a deep impression on me. However, one should consider what follows as a recollection of something that happened four decades ago rather than an exact record of the conversation.

At about the time (1953), when the controversy as to who discovered the Raman effect had cropped up, I had occasion to go to Delhi. As was my custom I went to see Krishnan at the National Physical Laboratory. It was about 5.30 in the evening when I met him and I told him that I wanted to spend some time with him as I wanted to ask him some serious questions. He said 'as it is not the day on which I play tennis, I am going home. Why don't you come along with me and have some coffee'. After a delicious cup of coffee, when we were alone, he asked me what I wanted to discuss with him. I requested him to relate to me the story of the discovery of the Raman effect. He enquired as to why I asked him this question. I said there was a view that he (Krishnan) had discovered the Raman effect for Raman and this view had again surfaced. His reply was 'It is a blatant misrepresentation. The best I can say is that I participated actively in the discovery. Let me take out my diary to remind myself as to what happened. I really don't need