

Preface

Professor K. S. Krishnan was born 100 years ago at the close of the last century. The special section in this issue commemorates the centenary of this eminent son of India.

To the general world of scientists, Krishnan's name is popularly known as the co-discoverer of the famous Raman effect. But to professional physicists KSK is known for his insightful and pioneering contribution to the Raman effect, crystal magnetism, magneto chemistry, ring current diamagnetism in aromatic systems, anisotropic magnetic and transport properties of graphite, theoretical and experimental studies of transport in alloys, liquid metals, and thermionics. For those who knew him personally he was also known for his deep understanding of religion and philosophy and a thorough knowledge of the Tamil language and literature, and of Sanskrit. Towards the end, when he moved to Delhi he was known as an important elder statesman of science with loads of committee responsibilities.

While reading, some months ago, G. Venkataraman's *Journey into Light*, an excellent biography of C. V. Raman, I realized that this year is the birth centenary of KSK. I have heard about KSK and his work on various occasions earlier. In particular, S. K. Rangarajan had told me good things about him and also about his writings on science and philosophy in Tamil. Once he showed me an article by KSK on philosophy written in Tamil and challenged me if I could understand it; I did not.

After I went through cursorily the collected works of K. S. Krishnan (edited by Krishan Lal and published by NPL/CSIR), my admiration for KSK shot up. Very impressive were the path-breaking and fine experiments he did and the ease with which this great experimentalist used theoretical ideas that were nascent at that time (1930s and 1940s): ranging from classical optics to subtle quantum effects in condensed matter systems. The theoretical notions involved in his work may look very standard now. But remember that KSK was comfortably and creatively using the various theoretical notions such as Fermi sea, Fermi surface, crystal field theory, Landau diamagnetism, and structure factors, when most of the scientific world barely started appreciating the meaning of these notions.

Sharing my enthusiasm and new knowledge about KSK and his work with Subbiah Arunachalam has resulted in my being the Guest Editor to this special issue of *Current Science*. It is with some reluctance I accepted this responsibility and also honour simply because my knowledge of KSK was through my strong and recent appreciation of only part of his work. You will clearly see the bias and my limitations as you read the issue.

The period of KSK's stay at C. V. Raman's laboratory at Calcutta seems to be a true resonance. The joint efforts of an established eminent scientist and a budding one seems to have produced light and fame. In one of his articles KSK calls his stay at Calcutta as a festive period in his scientific life. It may be fitting to go into the depths of the insightful works of KSK and Raman during KSK's Calcutta days in optics and magneto optics in a separate issue in this centenary year.

This special section contains articles from people who were associated with KSK or his work in some manner or other.

To give a glimpse of KSK's eminence for the general readership of *Current Science* we have an article by E. S. Raja Gopal, one of KSK's successors at the National Physical Laboratory, New Delhi. Raja Gopal gives a succinct account of KSK and his scientific contributions. T. V. Ramakrishnan, in his article 'K. S. Krishnan: a pioneer in condensed matter physics' points out that KSK was among the first to explore many interesting phenomena in solid and liquid states of matter after the birth of wave mechanics. While talking about the work of Krishnan and Ganguly on graphite, Ramakrishnan notes that some of the important questions raised by them 60 years ago have no deeper theoretical explanation even now—I agree with this, as some of us who started looking at graphite in the context of anomalous 2d metals find it intriguing indeed. Among other things, he discusses at some length the work of Krishnan and Bhatia on electrical transport in metals.

Arup Raychaudhuri, another successor of KSK at NPL, New Delhi, in his article 'Modern magnetism and the pioneering experiments of K. S. Krishnan' gives a masterly account of the work of KSK and his collaborators in the field of magnetism. He describes how KSK and colleagues did some of the most precise experiments in magnetism that gave the much-required quantitative base to the then new quantum mechanical theories of Bethe and Van Vleck. Arup brings out the essential themes and highlights the 'colossal contributions' of KSK to (i) magnetic double refraction in liquids, (ii) diamagnetic anisotropy and orientation of molecules in crystals, (iii) paramagnetic anisotropy in particular the crystal field effects, and (iv) the susceptibility of graphite and Landau diamagnetism, between 1926 and 1940 in 43 papers. At the end of his article Arup also brings out six very important lessons that an experimentalist can learn from the work and work style of KSK.

One of the fields where KSK has a lasting impact is in the fundamental studies on graphite, carried out with Ganguly. Millie Dresselhaus and Gene Dresselhaus of MIT and A. K. Ramdas of Purdue in their article 'Impact

of K. S. Krishnan on contemporary carbon science research' bring this out in a commendable fashion. Establishing the anisotropic diamagnetic susceptibility and conductivity in excellent single crystals of graphite from Ceylon, Krishnan and Ganguly started the field of experimental as well as theoretical electronic structure studies of graphite. Dresselhaus *et al.* also elegantly bring out how the very early experimental work of KSK and Ganguly is the genesis of the modern field of intercalated graphite.

The pioneering works of KSK and collaborators on the ring current diamagnetism of organic molecules dates back to the thirties. In these molecular solids the molecules retain their individuality and thus a detailed knowledge of the crystal structure combined with single crystal magnetic susceptibility measurements can give valuable information about the magnetic susceptibility tensor of the individual molecules. The ring current diamagnetism arises from the π -electrons of the organic molecules. In the experimental papers that exhaustively study several organic crystals, the origin of large diamagnetism is not discussed from the quantum mechanical point of view.

However, following the experimental work on diamagnetism, in 1937 London came up with his theory of diamagnetism in aromatic ring systems – it is basically a non-interacting tight binding model of electrons in the presence of a magnetic field. KSK at once appreciated this theory in his Presidential address at the Indian Science Congress at Madras in 1940 (p. 619 of the Collected Works of KSK) and used it to explain a host of experimental results from his group and others in a beautiful qualitative fashion.

In the modern condensed matter parlance the aromatic ring current systems will be called mini Mott insulators – they are tight binding systems with one orbital per site with an average of one electron per site. Anusooya and Zoltan Soos from Princeton, in their article on 'Ring currents and correlation transition in regular annulenes' consider the important problem of effect of electron correlations in the diamagnetism of regular annulenes. Annulenes are benzene-like ring systems with larger number of carbon atoms. It is surprising that it has taken about 5 decades to understand the anomalies in the ring current diamagnetism in terms of electron–electron interaction. One hopes that these theoretical works will help to clarify the anomalies, as well as give a quantitative understanding of the diamagnetic current measurements made in the 1930s (p. 619 in the Collected Works) by KSK and others in systems such as the biologically important metal-free porphyrine rings.

The simple looking resistivity measurements of metals, alloys, and liquid metals contain valuable information about the quantum mechanical behaviour of electrons close to the Fermi surface, even at room and higher

temperatures. Krishnan and Bhatia recognized this in their pioneering experimental and theoretical works. They set out to study the attenuation coefficient of the de Broglie wave of the electrons close to the Fermi surface. This attenuation coefficient is closely related to the resistivity. It is a pleasure to read their paper which is very physical and also touches the heart of the problem. They make close analogy with classical wave propagation such as light and X-ray propagation in liquids and solids. The famous Krishnan–Bhatia formula for resistivity was derived in these works. The structure factor in metals and alloys that characterizes the density–density or concentration–concentration correlations appears in a natural way in their formalism. The use of structure factor or correlation functions by KSK and his collaborators predates the extensive use of these notions by Schwinger and his school, Van Hove, Kubo and others. Norman March of Oxford goes into some of these issues in his article 'Forces, structures and electronic correlation functions in liquid metals' in refreshing detail, and takes us to some modern developments involving local chemical bonding tendencies in liquid metals close to their liquid–vapour critical point. March, a close friend of Bhatia, shares his admiration for KSK.

Chromium is a pristine example of a metal with a spin density wave, and perhaps the closest experimental realization of what is called a nesting instability and the spin density wave state that Lomer and Overhauser envisaged in 1962. A. Jayaraman, currently at Washington DC, reviews the 'High pressure and itinerant antiferromagnetism in chromium and Cr-alloys', and presents this as an appropriate topic for KSK's Centenary issue – KSK was deeply attracted to magnetism. This article brings to me pleasant memories of student days at Bangalore, where, as a student I watched the Bell Labs–NAL collaboration, mediated by Jayaraman and a group of active people at Bangalore on related issues.

We are very happy that two of KSK's last students and collaborators, S. C. Jain, currently at IMEC, Belgium and R. Sundaram at New Delhi, have contributed articles to this issue. Suresh Jain, as a tribute to his teacher, has an article entitled 'A review of our recent work on Raman scattering and a tribute to K. S. Krishnan'. He describes his recent theoretical work on Raman effect in strained semiconductors. Sundaram in his article 'K. S. Krishnan – the complete physicist' shows an example how up to date his guru was in appreciating new and important developments such as BCS theory and also reminisces his association with him.

I was also intrigued, when I saw it first, by the only published mathematical paper of KSK in his Collected Works – it smelled like Shanon's sampling theorem that my colleague Rajaiah Simon was telling me a week earlier, in a totally different context. Even when I showed him this paper holding it in my hand at a

distance and started telling what it was about, Simon also saw 'Shanon's sampling theorem' in it. You will see this being elaborated in Simon's insightful paper in this issue: the beautiful 1948 paper of KSK in fact foreshadows Shannon's path-breaking sampling theorem, that was to appear later.

Some of KSK's work had the character of being ahead of time. They were developed years later by others. One can cite the example of his study of graphite, the resistivity of metal and alloys, crystal magnetism and so on. In a short note 'K. S. Krishnan and the early experimental evidences for the Jahn-Teller theorem' I bring out one such case. A short paper was published by KSK in *Nature* in 1939 on the famous 'Jahn-Teller' theorem within a year after the publication of this theorem. In this paper, that we reproduce in this issue, KSK quotes at least four existing experimental results including some from the Raman group at Calcutta, as a good support for Jahn-Teller theorem. Unaware of these important suggestions of KSK, precise experimental confirmation and intense activity in this field of Jahn-Teller effect started more than a decade later during the fifties.

Apart from these papers on KSK's physics and work as a physicist, we wanted to include a couple of articles on the human side of the man, for without it the centennial celebration would be incomplete. Who better to write such an article than Sivaraj Ramaseshan who knew both Raman and Krishnan like no one else does? We also invited the Delhi-based sociologist of science, Shiv Visvanathan, known for his iconoclastic views and who has researched on Krishnan and his NPL days. He is the only non-scientist to contribute to this issue.

In his article 'A conversation with K. S. Krishnan on the story of the discovery of Raman effect', Ramaseshan recollects, from his memory, in a rather vivid fashion a very personal conversation he had with Krishnan, concerning the discovery of Raman effect. Extracts from KSK's diary are reproduced to help reconstruct events. The article also brings out, the strong feelings of reverence that Krishnan had all through his life for his *guru* and, probably for the first time, the deep sense of hurt that he lived through after the one-sided conflict that developed. Ramaseshan's article also complements a very informative historical research article 'Sir C. V. Raman and the story of the Nobel prize' by R. Singh and F. Riess that appeared in a recent issue of *Current Science* (1998, 75, 965).

Shiv Visvanathan's article 'The tragedy of K. S. Krishnan: a sociological fable' attempts to analyse the humanism of Krishnan, Krishnan as a University man and his failure as a science administrator. It has history, based on conversations and work that are less known. Krishnan's career after he moved to Delhi is brought out as a tragedy that may befall any excellent scientist when he becomes an administrator. Here is a lesson – there should be a conscious attempt not to fritter away excellent scientists. He also dwells on the Raman-Krishnan issue, and argues forcefully that we should not shirk looking at events dispassionately.

It is very likely that the Raman-Krishnan issue, touched upon by Ramaseshan and Viswanathan, has become complex by circumstances. In a recent correspondence with Shiv Viswanathan, I wrote: 'It is my personal opinion, that Raman-Krishnan controversy is no controversy ... Raman, a great scientist, was in a tireless pursuit of an important phenomenon and was fortunate to get a young and great student like KSK. A careful look at KSK's diary as reported in G. Venkataraman's book and a host of other factors clearly illustrate this – Raman deserved the Nobel Prize for the Raman effect. And the then young Krishnan grew into a great scientist on his own right.'

In bringing out this special section I have consulted and corresponded with various people and I am grateful to them. Special mention should be made of E. S. Raja Gopal who has remained as a spiritual guest editor through his valuable suggestions and involvement. Daughter and son-in-law of KSK, Mrs Kumudini Srinivasan and T. M. Srinivasan (Madras) and grandsons Thiruvadi Vijayaraghavan (Bangalore) and K. Badri Narayanan (Watrapp) were very helpful and gave valuable materials. Others include Subbiah Arunachalam, K. R. Balasubramanian, Jayant Bhattacharya, Dipankar Chakravarty, M. Dresselhouse, G. Dresselhouse, M. K. Das Gupta, Chanchal Majumdar, N. H. March, R. Ramachandran, S. R. Rajagopalan, G. Rajasekaran, Shiv Viswanathan, A. K. Ramdas, S. K. Rangarajan, A. Sen, R. Simon, G. Venkataraman and (Ramani) Venkataraman.

I also take this opportunity to thank all the authors who contributed to this special issue readily in spite of the short time that was available to them.

G. Baskaran