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S.K. Rangarajan, a tribute

The scientist, the man and the mentor

Sarukkai Krishnamachari Rangarajan (fondly referred to as SKR by his friends, colleagues and students) passed away on 29th April, 2008. He was a genius, a man of many talents, unique in that his ability in science was matched by his fine qualities as a human being.

SKR was born on September 9, 1932. He obtained his B.A. (Hon) in mathematics from the Madras Christian College (MCC), in 1953. After graduation, he started off as a film critic, and also wrote for the Tamil arts magazine "Ajanta". He then took up a tutorship at the MCC, worked there for some time, and then joined the postal department until he was offered an assistant professorship (1955) at the Alagappa Chettiar College of Engineering & Technology in Karaikudi. While teaching there, he was actively pursuing research in mathematics.

At that time, the Central Electrochemical Research Institute (CECRI), also located in Karaikudi, was headed by the distinguished electrochemist Prof. K.S.G. Doss. He had just discovered the phenomenon of faradaic rectification, and was looking for someone to develop a proper theory for the process. Doss approached SKR, expecting the theory to be developed in about a year, but the

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problem was solved in a day! Doss was so impressed that he persuaded SKR to join CECRI. He did so in 1960, but left in 1970, after the retirement of Doss. Doss, who had contributed significantly to electrochemistry, is reputed to have said "my most significant contribution to electrochemistry was finding SKR".

SKR spent the next two years as a Homi Bhabha fellow at the National Aeronautical Laboratory and continued there as a scientist till 1975, when he was invited by Prof. S. Dhawan, Director of the Indian Institute of Science in Bangalore, to join its Department of Inorganic and Physical Chemistry (IPC) as a professor. During his term at this department, he was a visiting professor at Georgetown University and was a Science Research Council Senior Visiting Professor at the University of Newcastle. He spent a sabbatical year visiting the IBM Thomas J. Watson labs in the US and has been a frequent visitor to that lab. In addition, he travelled widely in the world, attending conferences, giving invited lectures and collaborating with scientists from different parts of the world. During 1988–1992, he was on deputation from his parent department, working as the Director of CECRI.

At the Indian Institute of Science, SKR had a very active group and had several bright students, who continue to be very active in the field. SKR worked mainly on theoretical problems in electrochemistry. In addition he also continued to work on mathematics, biophysical chemistry, theoretical physics and even mechanical engineering. After retiring from the IPC department in 1993, he was a senior professor at Matscience for three years, and after that he was a visitor at the Raman Research Institute. The IPC very much wanted him to spend time in the department, and persuaded him to visit them once in a week. He was very active until the very end, was working on an interesting and important problem, and had solved it just the day previous to his death. A week before his death, he had come to the IPC and excitedly told us that he was planning to give a series of lectures on "Stochastic Problems in Chemical Sciences" and that he would start in a week's time.

SKR was an outstanding theoretician and electrochemist. Though the only degree that he ever had was a bachelor's degree in mathematics, he was a world renowned theoretical electrochemist, and was on the editorial boards of international journals in the field. While at the Indian Institute of Science and elsewhere, he was an inspiration to a large number of bright students, even though they were not working with him. To quote one such, S. Arunachalam: "A truly great teacher, SKR was a selfless and self-effacing man. He gave away his knowledge to anyone who came to him without ever expecting any return. The very thought of returns never occurred to him. He was not a man of mere intellect. Indeed, it was just one small part of him. At a time when lesser mortals get easily tempted to fall prey to the ways of the world, he remained steadfast in his values and principles, never once deviating from his chosen, or should I say preordained path".

He was well recognized by the usual standards – was elected as Fellow of the Indian Academy of Sciences, Fellow of the Indian National Academy, and Fellow of the Third World Academy of Sciences. In addition, he was given the Alumni Award (1993) of the Indian Institute of Science and the lifetime achievement award of the Chemical Research Society of India (2008), as well as many other awards and honors. However, to those who were privileged to know him closely, his abilities were far more than what these awards convey.

K.L. Sebastian
Department of Inorganic and Physical Chemistry,
Indian Institute of Science,
Bangalore,
India
E-mail address: kls@ipc.iisc.ernet.in

He is survived by his wife, daughter and four sons. His eldest son, Sundar Sarukkai, works at the Indian National Institute of Advanced Studies, and is well known in his own right. In SKR's death, the world, and especially electrochemistry, has lost an outstanding scientist. Personally, I have lost my brilliant, warm hearted, affectionate, kind "Guru", a sorrow shared by all his students and admirers. He will live on in our memory for ever.

The publications of Prof. S.K. Rangarajan

In the memories of those who have known S.K. Rangarajan, he will live on as an exceptionally kind and wise man. But he is no longer with us, and those fond memories are not transferable. S.K. Rangarajan was also as close to a scientific genius as I have had the privilege to know, and this is reflected in his papers, which will be there for everyone to study and build on, now and in the future. This short annotation is a guide to some of those papers.

S.K. Rangarajan was trained as a mathematician, and often seemed to think in purely mathematical terms. But he was much more than that, because he had great insight in physics and theoretical chemistry, and the rare gift to apply both his mathematical skills and his physical insight to practical problems, especially in electrochemistry, which became his scientific home. And even though he was not himself an experimentalist, he well understood the possibilities and problems of experimental data.

He was primarily interested in the mathematical *structure* of a problem; once he understood that to his satisfaction, he often moved on to another interesting topic. Many of his publications therefore came in the form of a short burst of papers on one such topic, typically stimulated by a good graduate student or coworker, although he often returned to some problems, such as adsorption, crystallization, and linear as well as nonlinear perturbation effects, and the interactions ("coupling") between various seemingly unrelated phenomena, that kept his interest throughout the years. If he solved a problem and could not find a worthy student to work out its details with him, he sometimes gave a talk about it at some conference, but before writing it up for publication he might get interested in solving another problem. He occasionally did mention such solved but unpublished subjects to his friends and colleagues, such as his two-dimensional Laplace transform solution of electrochemical mass transport problems, or his extensive model for electrochemical machining, and some may still be recoverable from his personal notes and the extensive viewgraphs he prepared for his talks, but most likely only by someone who is already well on his way to reach that level of understanding.

Rangarajan practiced science as it was commonly done before World War II, without grant applications and publication pressure; his drive to produce was entirely internal. He worked to solve a problem that intrigued him, and if it were not for the benefit of a graduate student, many more of his papers might have remained unwritten. He realized clearly how far ahead of his time some of his models were, but he completely lacked any urge to self-promote.

Throughout his career he published papers on purely mathematical subjects, such as polynomials [7,8,16–27,37], series acceleration and perturbation expansion methods [90, 106–107,111–112], Green's functions [126], and derivatives [181]. Below I will focus on the bulk of his scientific output, which was in electro- chemistry.

The first topic, the one that got him interested in that field, was faradaic rectification [1], initially called the redoxokinetic effect by its discoverers, K.S.G. Doss and H.P. Agarwal. Doss, the director of the Central Electrochemical Research Institute in Kairakudi, asked for Rangarajan's help, recognized his gifts, and promptly hired him. A few years after Doss retired, Rangarajan moved to

Bangalore, first to the National Aeronautical Laboratory, then to the Indian Institute of Science. He returned to Karaikudi for a short stint as its director, until he in turn reached India's mandatory retirement age of 60. After that he was associated with the Institute for Mathematical Sciences in Madras and, after his return to Bangalore, with the Raman Research Institute as well as the Indian Institute of Science. He spent some extended time periods abroad, at the University of Newcastle on Tyne with Thirsk and Fleischmann, at Georgetown University in Washington, DC. with me, at the IBM Watson Center in Yorktown Heights, NY, and at the Materials Science Laboratory of Pennsylvania State University. He often visited his children, four of whom now live in the US, but he always returned to his cultural roots.

The theory of the electrochemical admittance was the topic of his next papers with Doss [2,4–6,12,13]. Rangarajan would return to it repeatedly [10,15,31,32,39], and I will briefly dwell on it because it gives a good indication of how he worked. He was clearly intrigued by Delahay's 1960 conclusion that two quantities that were conceptually seemingly unrelated, double layer charging and faradaic current, would actually become "coupled" in the presence of strongly adsorbed reagent or product of the faradaic process, and he convinced himself of its correctness by a simple thought experiment [46]. But rather than following Delahay's derivation, he looked at the problem in a much wider context, which allowed him to find a powerful and elegantly compact general formalism [67–70] that encompassed double layer charging, faradaic reactions, and mass transport. It included Delahay's effect as well as other couplings, such as that between electrode kinetics and mass transport of the reactants and products, another set of processes that had seemed to be unrelated and that, not long before, had been associated by Vetter with mutually independent types of "overvoltage". Rangarajan's approach was so general that he could also apply it to ion transport through lipid bilayer membranes [94].

Faradaic rectification is, of course, an example of a nonlinear response, and Rangarajan quickly put such nonlinear responses on a solid mathematical footing [71-73, 78].

Another enduring interest was electrocrystallization [28,29, 34–36,40,53,60,63,64,87–89,99,100,102,105,106,143,163,164], which he again approached systematically and with great success, and even extended to non-electrochemical, homogeneous nucleation [110,111].

In short order he began to contribute to some of the other "hot" electrochemical topics of the time, such as adsorption (many with Sangaranarayanan) [46,47,61,62,74,81,84,93,103,104,114–119,170], chemisorption [95,123], and their effects on electron transfer reactions (many with A.K. Mishra) [70,130,132–135,140,154,175]; the theory of electron transfer reactions [128,131,149,153,154]; problems of current distribution [33], electrodeposition [161,168,172], and the electrochemical effects of surface roughness (with R. Kant) [165,171,174,182]; the theories of porous electrodes [44,51,86, 91,138] and of polarographic maxima [75,77]; the improved use of existing experimental methods [43,45,50,66,82,83,97,98,101, 120–122,139,141] and the development of new measurement techniques [58,59,65,79,80] including noise analysis (with Seralathan) [125,126]; semiconductor- and photo-electrochemistry [142, 144–147,150,156,160,162,166,167,173], membrane electrochemistry [92–94], and electrochemical corrosion and passivation [30,42,52, 54,56].

In fact, a quick perusal of the publications listed below will show that Rangarajan made major contributions to many areas of theoretical electrochemistry. In these he aimed for and often reached his highest goal: a general, formal understanding of the phenomena, from which he would then derive the most popular approximations and illustrate their ranges of applicability. In doing so, he inspired and trained a group of gifted Indian electrochemists, and put much of electrochemistry on a far higher theoretical level than where he had found it.

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R. de Levie [1]
Orr's Island,
ME 04066,
USA
E-mail address: rdelevie@bowdoin.edu

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