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. This is also reflected in his papers, which will be there for everyone to study and build on, now and in the future.

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. Even though he was not himself an experimentalist, he understood the possibilities and problems of experimental data extremely well.

Rangarajan 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 might give 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 He occasionally did mention such solved but unpublished subjects to his friends and colleagues, such as his two-dimensional Laplace transform solution of electrochemical mass transport problems, or his extensive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 often 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 Rangarajan published papers on purely mathematical subjects, such as

Modified from an article to be published in the *Journal of Electroanalytical Chemistry*, (doi:10.1016/j.jelechem.2008.07.007) in which most of S K Rangarajan's papers appeared.

polynomials, series acceleration and perturbation expansion methods, Green's functions, and related topics. Here I will focus on the bulk of his scientific output, which was in electrochemistry.

The first topic, the one that got him interested in that field, was faradaic rectification, 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, and then to the Indian Institute of Science. He returned to Karaikudi for a short stint as its director, until he reached India's mandatory retirement age of 60. After that he was associated with the Institute of 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. Rangarajan would return repeatedly to this topic, 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, so-called non-faradaic 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. 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 that encompassed double layer charging, faradaic reactions, and mass transport. It included Delahay's effect as well as other couplings, such as that between interfacial electrode kinetics and bulk mass transport of the reactants and products, another set of processes that had seemed 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.

Rangarajan was an avid reader, and often spent entire days in the library, scanning books and journals on math, physics, and chemistry. Of course I do not know how he selected the problems on which he wanted to work, but I know how he approached new problems brought to him, once he agreed to look into them. He wanted a precise formulation of the problem, but he often did not want to read the published literature on it, because that might goad him into a mindset that so far had been unproductive. That meant that he had to go back to the basics, and blaze his own

trail to a possible solution, rather than following others on an established path where he might get stuck in a common rut. In this and other respects, Rangarajan resembled Ramanujan, the great Indian mathematician whose work he admired and often quoted.

Faradaic rectification is an example of a nonlinear response, and Rangarajan quickly put all such nonlinear responses on a solid mathematical footing. Another enduring interest was electrocrystallization, which he again approached systematically and with great success, and even extended to non-electrochemical, homogeneous nucleation processes.

In short order he began to contribute to some of the other then "hot" electrochemical topics, such as adsorption, chemisorption, and their effects on electron transfer reactions; the theory of electron transfer reactions; problems of current distribution, electrodeposition, and the electrochemical effects of surface roughness; the theories of porous electrodes and of polarographic maxima; the improved use of existing experimental methods and the development of new measurement techniques such as noise analysis; semiconductor- and photo-electrochemistry, membrane electrochemistry, and electrochemical corrosion and passivation.

In fact, a quick perusal of Rangarajan's publication list will show that he made contributions to many areas of theoretical electrochemistry. What such a list does not show is that a number of these were major contributions, in which he 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.

You may well ask, then, why his name does not occur more often in electrochemical textbooks. The answer, I believe, tells as much about current science as about Rangarajan. He was a superb teacher to a small group of interested students, but he was not keen on blowing his own horn. He wrote rather terse papers, implicitly assuming that his readers would have a level of mathematical facility and physical insight similar to his own. His lectures at international meetings likewise were full of significant and novel results, but his audience often had trouble following him. In private, he would be most patient in explaining any seemingly obscure step, but in neither his papers nor his lectures did he seriously consider didactics. In an age in which we are deluged with papers, few take the time to seriously study a tersely written article in order to extract its gems. Instead, we increasingly derive much of our information from meetings, where the speakers often provide self-promoting progress reports. Rangarajan did not fit that pattern, and this undoubtedly limited the general recognition he received outside India. I am sure time will remedy this.

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