

Seventy years in scientific research

C. N. R. Rao

This is a story of my 70-year journey doing science. I hope that senior colleagues as well as young stars will find this to be of interest.



Prologue

I cannot believe that I am in my 70th year of scientific research. Of course, 70 is another number, but it cannot be ignored in view of the general scientific-life expectancy. Prof. H. C. Brown at Purdue, USA, continued research till his 94th year and published papers even the year he passed away. The same is the case with my eminent guru, Prof. Nevill Mott. They were both great scientists. It appears, however, that very few in India have been involved in research for 70 years. Some of my friends and associates felt that I should write an essay on how I have carried out active research this long, and how I could face adverse situations in the early days of my career. With much trepidation, I decided to write such an essay for the sake of record, hoping that my younger colleagues will view this effort with generosity and understanding.

Early days

I was born in Bangalore (now Bengaluru) in 1934 as the only child of my parents. Both my parents were highly academic in temperament. My father worked in the Mysore Education Department in various capacities. Whenever I think of my father, the image that I visualize is of him reading a book. I remember little of my early years, except that I was being regularly tutored at home by my mother. She was an excellent teacher. She not only

taught arithmetic, but also the intricate details of various classics, specially our great mythological works. She used to tell me wonderful stories and encouraged the habit of reading novels and mythological texts.

I joined a government middle school at the age of six and passed the lower secondary examination in 1944 at the age of 10, in first class. The important years of my high-school days were those spent in Acharya Pathashala, Bengaluru. We had fine teachers and I was a favourite of the science teachers. I used to edit a magazine (handwritten), and write short essays and stories. Two special events occurred during 1945. The first was seeing Mahatma Gandhi who had come to Madras (now Chennai), thanks to a wonderful teacher who took a few of the students for such a memorable event. The second was the lecture delivered by Prof. C. V. Raman in our school. Seeing Prof. Raman moving on the stage with great excitement while talking about Madame Curie was memorable. He was magnetic and I felt a spark that I could not forget for many years. That was probably the first occasion when I felt that I should become a scientist. I was 11 years old then. A few weeks later, Prof. Raman took a few of us around his laboratory at the Indian Institute of Science (IISc), Bengaluru. I did not understand fully what he said, but I felt uplifted.

I passed the secondary school leaving certificate examination in first class in 1947 when I was 13 years old. A few months later, India became free. I remember 15 August 1947 vividly. The excitement of that day can never be forgotten, when the nation heard our first Prime Minister at midnight. I was a first-year student in the intermediate college then. I must mention that I used to actively participate in debates and was part of a nationalistic group of students throughout my undergraduate days. I had taken physics, chemistry and mathematics as my optional subjects. The dream of my school days continued to haunt me. Becoming a scientist became my only desire. Hearing lectures by scientists like J. D. Bernal made this desire even more

intense. I was one of the very few students who obtained the B Sc degree from Central College, Bengaluru, with a first class in 1951. I was 17 years old then. I wanted to do an MSc in two years after my BSc, but there was no simple way of doing this in IISc or elsewhere in Bangalore. It was my luck that a chemistry lecturer in the College, Mallikarjunappa, told me of the two-year M Sc programme in Banaras Hindu University (BHU), Varanasi, which included research as well as courses. He was a past student of BHU. I decided to go to Varanasi to the great institution founded by Pandit Madan Mohan Malavia. As always, my parents fully endorsed my decision.

Early research experience

After a two-and-a-half-day train journey in an unreserved third-class compartment, I reached Varanasi on a hot day in June 1951. Varanasi, the eternal city, made a great impression on me. It continues to attract me because of its extraordinary history and the perennial philosophy that it represents. The University was an active place for research and had a true national character. In the very first week after joining the Chemistry Department, the Head of the Department (Prof. S. S. Joshi) asked me to start my research. He asked one of his postdoctoral fellows to help me. I was to work on electrical discharge through gases, which meant that I could only work at night. We had to convert DC electricity (provided by the city) to AC only at night and hence the limitation. I started working in the laboratory after dinner, returning to my room well after midnight. I used to see lights in the laboratories of science departments even after midnight. At the end of the first year, Prof. Joshi told me that I had done more than enough for my M Sc thesis during the first year itself, but I could continue to work in the laboratory if I wanted to. I made full use of this generosity. (The normal practice was for students to do research in the second year of M Sc). At the end of two years (1953), I

completed M Sc in Physical Chemistry with a high first class. I could publish four papers related to my thesis, one of them in *Science*. I decided that I should go to some other institution for doing my Ph D, although I was going to miss Varanasi.

I considered various possibilities for doing a Ph D, specially at IISc. Some of the professors that I met advised me to go to the new Indian Institute of Technology (IIT) at Kharagpur, where Prof. J. C. Ghosh was looking for young research students. That is what I did. (Prof. Ghosh had gone to the new IIT from IISc). I was to work on adsorption of gases on catalytic surfaces. I built the apparatus required and started working earnestly, but I got the feeling that I was not working on problems of current interest. Such a feeling arose because I could not understand papers in journals such as *JACS* which generally dealt with spectroscopy, molecular structure and other areas of chemistry, not practised in India. I decided to apply to US universities for Ph D admission, with the tacit approval of Prof. Ghosh. I received admission and fellowships from a few universities, but decided to go to Purdue University since there were professors working on spectroscopy as well as molecular structure determination by electron diffraction. This was the area to which Prof. Linus Pauling had contributed immensely. I had corresponded with Prof. Pauling earlier after his discovery of the alpha helix in proteins. I had been greatly impressed by his book *The Nature of the Chemical Bond*. I wanted to work in areas discussed in that book. Unfortunately, I could not work with Prof. Pauling since he wrote that he no longer worked on simple molecules, but on proteins. I did not clearly understand what he wrote, and decided to go to Purdue.

My stay in Kharagpur gave me an opportunity to enjoy Bengal and its rich cultural heritage. In late 1954, I left IIT Kharagpur for the US. My parents supported my decision and provided both moral and financial support. I was really touched seeing my father crying, as the boat (*S. S. Corfu*) left the shores of Bombay (now Mumbai).

Research in America

It took nearly 23 days to reach New York from Bombay by boat (via London), and

another day to reach Lafayette, Indiana, by a Greyhound bus. The Chemistry Department at Purdue had over 300 Ph D students and the course requirements were demanding. I took chemical physics as my speciality with physical chemistry as the major subject and physics as the minor subject. Besides chemistry courses, I took courses in solid state physics, crystallography, quantum mechanics and so on in the Physics Department. The fellowship that I had was under an organic chemist (Prof. Eugene Lieber), who wanted a physical chemist to carry out studies on kinetics, spectroscopy and other physical aspects of certain organic nitrogen compounds. I enjoyed the work and obtained several new results in the first few months. Prof. Lieber was overjoyed and published several papers based on the work.

The chemistry courses were very good, and I learnt much of modern chemistry. One of the aspects that I learnt in research was how to relate structure and reactivity. I tried to apply these principles to correlate spectra and other physical properties of organic molecules. By the end of the first year, I wrote two short papers and took them to Prof. Brown for advice. He looked at them and just said 'publish them'. Thus started my publishing career as an independent scientist.

By the end of the first year, I had to choose a research guide for my Ph D thesis. I decided to work with Prof. Robert Livingston (who was from the Pauling school) on molecular structure studies by electron diffraction of gases, a favourite subject of Pauling. I received a Purdue Research Foundation Fellowship to work with Prof. Livingston. We had to build a new apparatus, and this was accomplished by three of us in the laboratory. I picked Pauling's two pet molecules to start my work and obtained interesting results. Prof. Pauling visited Purdue around that time to inaugurate the new chemistry building. He was thrilled to see that the structural data obtained by me exactly corresponded to his early predictions. They were cited by Prof. Pauling in the third edition of *The Nature of the Chemical Bond*. After my initial successes, Prof. Livingston gave me freedom to work on whatever I wanted, and asked me to help his other students as well. I eventually ended with several papers on electron diffraction, though the tradition was for a person to work on one or two molecules for a Ph D.

Prof. Lieber left Purdue and went to Chicago. He wanted me to continue to be associated with his group, which required my going to Chicago over weekends. I was a co-author of several papers from Prof. Lieber's Chicago laboratory as well. By early 1958, I submitted my Ph D thesis. The final oral examination was unbelievable. As soon as I entered the room, wearing my new suit and tie (from borrowed money), the examiners got up, congratulated me and said that they cannot think of a more deserving Ph D candidate. That was it. I stayed in Purdue for a few more months as an Instructor teaching physical chemistry.

I must mention that I collaborated with several faculty members as well as fellow graduate students in chemistry and had free access to the X-ray laboratory in the Physics Department. While I was determining the structure of a TiO₂ sample of a friend of mine, I found that it had the anatase structure. This led to the study of its transformation to the rutile structure. (Beginning of my solid-state chemistry interests.) By the time I left Purdue, I had published 35 research papers, of which 11 were entirely my own.

There was an interesting happening just after finished my Ph D work. The chairman of UPSC in India was visiting the US and wanted to meet a few Indian students. I was asked by the Indian Association to meet him with two others. It was a terrible meeting. He had a very poor opinion of American degrees. We explained to him about the usefulness of courses and the high quality of research published in leading journals. He just laughed it off and said that the real doctorate is the D Sc degree obtained by independent work. I did not know what a D Sc degree was. I found out that past graduates of an Indian university could submit a thesis for the D Sc degree based on independent publications. It took me a day to decide to submit my publications (excluding those submitted for the Ph D degree) for the D Sc degree of the University of Mysore. This was in 1958, just before leaving for the University of California, Berkeley, for my postdoctoral studies.

It was really difficult to leave Purdue which had given me so much love, freedom and recognition. It was in Purdue that I learnt modern chemistry and carried out research in many areas, including crystallography, spectroscopy and molecular structure. I had also learnt

some organic chemistry. I could never forget that the faculty members treated me like a colleague even though I was just a Ph D student. As I sat in the train leaving Lafayette and saw Prof. Livingston crying, I could not control myself.

The Chemistry Department at Berkeley has been number one in the world for several decades, because of the foundation laid by G. N. Lewis. I consider him to be the greatest chemist of the 20th century. He contributed ever so many new concepts and ideas, the most important one being the chemical bond. It is not surprising that Pauling dedicated his book *The Nature of the Chemical Bond* to Lewis. I was to do research with Prof. K. S. Pitzer, a multi-faceted physical chemist. I worked on low-temperature heat capacity of some solids (in Prof. W. F. Giaque's laboratory) and some spectroscopic studies, including one based on NMR spectroscopy. We studied, for the first time, the temperature-dependent NMR spectra of alcohols at various concentrations. The studies that I carried out involving spectroscopic and thermodynamic measurements in the first few months of my stay, were published by me as the senior author. Three of those were in *Nature*. Prof. Pitzer was indeed most generous. I published a few papers with him as well. My stay in Berkeley was exciting. Seeing great scientists in the corridors of Berkeley was a routine matter. I also enjoyed the restaurants and concert halls of San Francisco.

Early during my second year of stay in Berkeley, I had a letter from my father where he subtly asked if I was planning to come back home to see my mother. This got me started to think of India day and night. Those sleepless nights were occupied by thoughts of my career as a scientist, with the constant fear that it would be difficult to carry out research in India in areas of my specialization. No one in Berkeley, Purdue or elsewhere believed that I would go back to India. All the professors there felt that I had got so well assimilated that it would be a pity if I returned to India. I had around 40 research publications in good journals, and a few good US universities had expressed interest in having me as a faculty member. What I can never forget about my stay in the US is the enormous affection and generosity shown by all the professors, I worked with. I have done my best to emulate these fine teachers of mine.

While I was going through those agonizing days, the only pacifying thoughts were related to my selfless, religious mother, my love for India and my memories of the independence day. I decided to be more pragmatic in deciding what I should do. I often thought of some of the great Indian scientists. How did J. C. Bose carry out research on telegraphy in Calcutta (now Kolkata) in the late 19th century? How did Srinivasa Ramanujan become a great mathematician without college education or proper employment? How did Raman accomplish so much and eventually earn the Nobel Prize, without having a regular job as a scientist most of those years? These thoughts strengthened my resolve to return to India. The thought of my mother praying for hours each day and my own nationalistic feelings from childhood (encouraged by my father who had Gandhian leanings) won my mental battle. A few weeks after I sent letters of enquiry, I received some job offers. One was from a CSIR laboratory, with a relatively high salary and position, and another as a Reader from Panjab University, Chandigarh. The last was the offer of a lectureship in IISc on a basic salary of Rs 500 per month plus allowances (altogether Rs 720 per month). The last offer was the lowest in emoluments, but I decided to accept it since it seemed to be the most likely place where I might succeed in doing meaningful research.

The evening before I left Berkeley, I was making a few samples for NMR studies. Prof. Pitzer dropped in the laboratory and exclaimed, 'I thought that you were leaving tomorrow?'. He then took me for dinner at his home.

Back to India

I came back to Bangalore in September 1959 and joined the Inorganic and Physical Chemistry Department at IISc the very next day. It took me only a few days to find out the total absence of any sophisticated instrument that I could use. To add to my discomfort, I had no office of my own. I was to use a room assigned to me as the laboratory, as my office as well. I felt this to be a real punishment since I had planned to do a lot of writing. I decided not to react to such problems. Using available facilities in IISc and elsewhere (NCL and AMU), I started publishing papers in spectroscopy. Prof.

Raman was kind to allow me the use of an IR spectrometer in his institute. I did not have the same consideration by the Physics Department of IISc. A pleasant memory that I have is of the Organic Chemistry Department (Prof. D. K. Bannerjee) offering me the use of its facilities and students to work with me. I had six Ph D students by the end of the first year. In spite of all the difficulty that I faced, I could publish a few papers in spectroscopy (some of them are well cited). I started some work in solid-state chemistry, hoping that this unknown area (at that time) will enable me to do some novel chemistry. That was a great decision. The world at large had only a handful of solid-state chemists at that time.

In 1960, I got married to a charming girl, Indumati, of whom I knew through my grandmother. She was a graduate in English literature. On an unbelievable afternoon in 1961, I received a brown envelope from the University of Mysore. It had a letter from the Registrar informing me that University was awarding me the D Sc degree in the next convocation. I had forgotten about the thesis that I had submitted in 1958. In 1961, a book of mine entitled *Ultra-violet and Visible Spectroscopy* was published by Butterworths, London. It became famous in the next few years and was translated into five languages. What I often recount regarding those early years of mine in Bangalore are scarcity of money for research and the near impossibility of obtaining foreign exchange for purchase of equipment. Even standard chemicals were difficult to obtain commercially. I remember making benzoic acid in the laboratory.

After three years at IISc, I got the opportunity to go to the US for giving a talk in a spectroscopy conference. I could get only US\$ 8 for the trip and had to depend on help from American friends to be able to reach my destination. I stayed on for five months at Purdue (where I taught a summer course) and Chicago. I needed time for contemplation. I concluded that I should leave IISc if I have to do well in science. I started getting feelers from the US universities right away.

IIT Kanpur

Early in 1963, I learnt of a new IIT being established in Kanpur with the support of

a consortium of US universities. Soon after I returned to India, I was interviewed and offered an associate professorship. I joined IIT Kanpur (IIT/K) in April 1963. Four of my students received Ph Ds from IISc in 1963 and two more a little later. I should record the great loyalty and friendship of my students in those difficult days.

Just before joining IIT/K, I submitted the manuscript of a book on infrared spectroscopy to my publishers in New York (Academic Press). The book (680 pages) came out shortly afterwards, but I had to show IIT/K as my place of work. Prof. C. V. Raman wrote a congratulatory letter after going through the book. This was followed by my election to the Indian Academy of Sciences (IAS), Bengaluru in 1965, my first academic recognition (thanks to Prof. Raman). This was followed by the Marlow Medal of the Faraday Society, England (1966).

I really enjoyed working on various aspects of a young IIT/K, the core curriculum, architecture, faculty recruitment and so on. We had a wonderful director (Dr P. K. Kelkar) who gave freedom and responsibility to young people. The Chemistry Department was outstanding in both teaching and research. We introduced Ph D courses, tutorials for first-year undergraduates, student and faculty seminars and thorough comprehensive examinations. As the first Head of the Department, it was a great opportunity to learn and serve. I must mention that my family was the first to move into the IIT/K campus (which was barely habitable then). We enjoyed growing with the campus. Campus life was truly enjoyable at IIT/K.

I started research with Ph D students within a year of joining IIT/K. We had fairly good research facilities, thanks to the American collaboration. I had a group working on spectroscopy and molecular structure, and another on solid-state chemistry (phase transitions and defect solids). I took a sabbatical in Purdue during 1967–68 for learning new things and to decide my future plans for research. My wife obtained a M S degree in education from Purdue at that time. I decided to concentrate more on solid-state chemistry in the light of major developments in the area, such as metal-insulator transitions and transition metal oxide materials. My contemporaries in oxide research were Hagenmuller (France), Goodenough and Honig (USA).

We started publishing extensively from 1965. I organized Winter Schools in solid-state chemistry with international experts such as Goodenough and J. S. Anderson giving lectures. Two major books came out of the proceedings of the Winter Schools in 1970 and 1974 (Plenum and Marcel Dekker). During my stay in IIT/K (1966–1976), I published around 200 research papers with my students. I had fantastic students, many of whom helped initiate new lines of research. In 1968, I received the Bhatnagar Prize when I was 34 years old.

Oxford experience

I had the most amazing experience during 1974 when I was walking through the corridor at IIT/K to have a cup of tea with my colleagues. An attender came rushing to give me a telegram from UK. I could not believe my eyes. It was from Oxford University inviting me to be the Commonwealth Professor of Chemistry. Soon a detailed letter arrived explaining that the professorship included travel for me and my family, and the salary of an Oxford professor for a year. I would also be a Professorial Fellow of St. Catherine College. I considered this as a great opportunity since Oxford was probably the best centre for solid-state chemistry at that time. There were faculty members in Oxford working on all aspects of the field, employing the best of equipment.

I went with my family to Oxford with great expectation and I was not disappointed. I worked on many topics and collaborated with several colleagues. I used atomic resolution electron microscopy, electron spectroscopy and many other tools routinely. My wife used to tell me that I was working like a student and not as a professor. The Head of the Department, Prof. J. S. Anderson, became a great friend and I collaborated with him as well. I made many friends there, of whom Tony Cheetham is special. He has become a close family friend. It was during my stay in Oxford that I got the opportunity to meet Prof. Mott who had come to give a talk. He was interested in some of the work that I was doing on oxides. We wrote a joint paper at that time and our relationship blossomed over the years.

We enjoyed our life in Oxford in many ways. My wife studied in the education

department and we went to London theatres during weekends. When I had to leave Oxford at the end of the year, I found that I had 17 papers from the work done there. Oxford taught me a major lesson. One cannot carry out experimental research at the frontier without the right infrastructure, specially sophisticated instrumentation. Setting up such a laboratory in India became my obsession. I did not want to go to the US or elsewhere, although I was getting attractive offers from several universities in the US.

I had to go to New York in 1976 to receive the Centenary Medal of the American Chemical Society. That was a wonderful occasion since Pauling was the centenary lecturer and Glenn Seaborg was the President of the Society (who presented the Medal). Deans of some US universities talked to me about opportunities and facilities that they can provide.

When I was going through a mental turmoil, I met Prof. Satish Dhawan in the annual meeting of IAS. As soon as he saw me, he asked (I quote), ‘Ram, I hear that you are not happy, and are considering the possibility of moving to the US. Why are you doing this? What does it take to get you back to IISc?’ Only Dhawan could have asked such a question. He was a wonderful friend. I explained to him my agony. He immediately offered me a position in IISc. I told him that I need the freedom to build an outstanding laboratory and create a new research group in solid-state chemistry (now materials chemistry) without much interference. His reply was ‘we can set up a new Unit for you to work in this area. I cannot however give you the kind of funds that may be required’. After this conversation, I decided to move back to IISc and started exploring how best to get started.

Back to IISc

In November 1976, the Solid State and Structural Chemistry Unit (SSCU) was established in IISc, thanks to Prof. Dhawan. When I arrived on the campus, I could not find an office room or a laboratory that I could use in the various chemistry departments. I was told that there was no space (an old habit). Fortunately, chemical engineers gave me an office and some laboratory space. I modified the solvent shed and an open garage as

laboratories. Even as I was preparing to leave Kanpur, the Department of Science and Technology, New Delhi, gave me two substantial grants amounting to about Rs 70 lakhs (a lot of money then) for equipment and other purposes (thanks to Dr Arcot Ramachandran). I ordered most of the equipment (TEM, SEM, diffractometer, IR, UV and EPR spectrometers, etc.), including a laser Raman spectrometer (amazingly, the first one in the Institute). I had to obtain import licenses from the Government of India (GoI) to get the equipment from abroad, and this was made easy by an old friend from IISc who was the Officer-in-Charge of the concerned office. The University Grants Commission (UGC), New Delhi, then recognized SSCU as a Centre of Advanced Study and granted money for a building, and for some faculty and equipment. In the meantime, IISc received a modest grant from UGC in support of a Materials Research Centre (MRC). Prof. Dhawan asked me to take care of the MRC affairs as well. It was a busy period. Within a year or two, after starting SSCU, we began publishing research papers. We had a good team of young faculty working on theoretical as well as experimental problems. It soon became a vibrant department attracting good students and faculty.

In 1982, I was elected Fellow of the Royal Society and the very next year, Cambridge University invited me to be the first Nehru Professor. I was also to be a Professorial Fellow of King's College. I went to Cambridge in September 1983 and started collaborative work with several faculty members, specially Prof. John Thomas and Dr Peter Edwards. I was coming to Bangalore every three months to interact with my students. I enjoyed my frequent meetings with Prof. Mott who was reaching his 80th year. I edited a *Festschrift* (Taylor & Francis) for the occasion, along with Edwards. I enjoyed the dinner parties with Mott. It was in Cambridge that I first met Mike Klein, who has since become a close friend.

When I was in Cambridge, I was informed that the Institute Council had decided to ask me to be the next Director. Satish Dhawan called to make sure that I did not refuse the offer. I became Director of IISc after my return from Cambridge in October 1984. I did not allow my duties as the Director to interfere with my research. I started the morning

(~8 a.m.) in the laboratory, and went to the Director's Office after 10.30 a.m. only to come back to the laboratory before 1 p.m. I would spend around two hours in the office in the afternoon and go back to the laboratory by 4 p.m. I must, however, admit that the quality of my research did suffer a little, particularly during my second term as Director. I, therefore, did not accept the third term of directorship that was offered. I did my best to serve IISc as Director, specially to make it a great academic institution. I formally retired from IISc in 1994 at the age of 60. The Institute conferred its Honorary Fellowship and made me an Honorary Professor for life. This allowed me to have Ph D students as long as I desired. I visited Grenoble and Cardiff in the early 1990's for collaborative work, but during 1995–2006, I regularly went to UC Santa Barbara to collaborate with Tony Cheatham on hybrid materials.

The main areas of research that I pursued during 1976–1994 are transition metal oxides, superconductivity, fullerenes and nanotubes, metal nanoclusters and photoemission spectroscopy of solids and surfaces. I also started work on colossal magnetoresistance. High-temperature superconductivity became a hot area of research in early 1987. I got to learn about its discovery in December 1986 in a conference in Bangalore from Prof. Phil Anderson. After I gave a lecture in the conference one afternoon, Prof. Anderson asked me if I knew about the new oxide superconductor that had been reported. I found out that it was based on a copper oxide that I had studied as early as 1971. I was thrilled. Prof. Anderson spent several hours in my laboratory that evening to find out what I had done earlier. I had a large group in superconductivity during 1987–1997. We were one of the three groups to discover the first liquid nitrogen superconductor (123 cuprate).

JNCASR

From 1994, I started taking students in the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bengaluru, of which I was the founding President. The Centre had its own campus by 1994 and has since developed excellent facilities for materials research in association with the International Centre for Materials Science, Bengaluru. I used

to sit in my office at IISc over weekends till 1999, but thereafter fully shifted my activities to JNCASR. In JNCASR, I have worked on organic–inorganic hybrids and MOFs, colossal magnetoresistance, electronic phase separation in solids, multiferroics, various aspects of nanoscience (including graphene and other 2D materials) and solar reduction of water and CO₂. I formally retired from the Presidentship of JNCASR in 1999 and the Centre made me an Honorary Professor for life. I am glad that JNCASR has been getting increasing recognition in recent years (being rated seventh in the world in quality by *Nature*).

I have to mention a great personal and professional loss that occurred in 1996. Prof. Mott passed away in 1996. The giant of solid-state science was no more. Just a few months earlier, Edwards and I had edited a *Festschrift* to celebrate Mott's 90th birthday. We had a Royal Society discussion meeting on M-I transitions later in 1996, and Mott wanted to attend it. He wanted to make introductory comments in the meeting. That was not to be.

Looking back

From 1976 (when I came to IISc) to 2020, I have published around 1300 research papers with my students. But for my students, I would be nowhere. I trust that I have given them all the love and support that they fully deserve for their contributions and loyalty. I have no way other than publishing papers to share what I am doing. I truly believe in Faraday's famous statement, 'Science is just work, finish and publish'. I also endorse Prof. Brown's dictum, 'it is not worth doing, if it is not worth publishing'. I have also enjoyed writing and editing books. I have written/edited 53 books to date, and some of them are for school children.

I have become a member of many academies, and received many prizes and awards, but the greatest award has been the joy that I have experienced in my life doing research with my students. Another equally happy experience has been to give talks to school children all over the country.

I worked in various honorary capacities in the country, and also in several science academies and international

scientific organizations such as IUPAC. I have, however, not taken any regular position that interfered with my research. I was Chair of the Science Advisory Council (GoI) of four Prime Ministers and Chair of the Vision Group for Science and Technology of Karnataka with four Chief Ministers. I have enjoyed building scientific institutions and creating improved environment for science, but I have not yielded to persuasions to become a full-time administrator in the Government or a member of the Rajya Sabha. Now that I am in my 87th year, I am really happy that I have stuck to science all my life. Science is a demanding master and I have fully submitted myself to its rigorous demands. I have thoroughly enjoyed working with young students and collaborating with fine friends from all over the world. My wife has been of great support to me. She takes care of everything at home, including money matters, income tax and so on. She works closely with me in the science outreach programmes. My science, along with a wonderful wife and family as well as highly dependable students, have made me one of the happiest men in the world. I have been asked what I would do if I were to do everything all over again. My answer has been that I would do exactly what I have done, and go to the US to do a Ph D.

Epilogue

I realize that 70 years in scientific research is not an occasion for celebration like the diamond jubilee of one's marriage (my wife and I have just celebrated such a jubilee). It may, however, be an occasion to review what one has done in science and related endeavours, and also to ponder about the status of science in the country. In this context, I must repeat what I have been saying for some time.

To my great disappointment, we are not at the top in the world of knowledge and science. Like Prof. Raman bemoaned just a few weeks before he passed away, I feel sad that we are not doing as well in science as many other countries. Most people attribute this to poor funding of education and science sectors. While this is true, it is not the only cause for our marginal performance. I feel that we may have somehow lost our idealism (I do not like to use the word nationalism) and competitive spirit. We just do not work hard like our Asian neighbours. It is also possible that we do not work on the right problems, and do not give sufficient support and recognition to young people.

Occasionally, when I feel down and out, I think of the three great scientists of pre-independent India, Bose, Ramanujan and Raman. How did they conceive of ideas that were world class and perform so well in the absence of any support mechanism or ambience for doing good science? In the past, we have had great personages who brought light into the dark environment prevailing during those periods.

I feel that the greatest Indians are Gautama Buddha, Adi Shankaracharya and Mahatma Gandhi. I have seen somewhere that Prof. Raman thought so as well. Around 2500 years ago, Buddha sought to understand the secret of life and human misery. After years of penance, he became the 'Enlightened One'. According to Immanuel Kant, the motto of enlightenment is 'Dare to understand'. This clearly holds good in the case of Buddha. What is truly amazing is that no one in India has exported an Indian idea to so many distant lands as Buddha.

Adi Shankaracharya spent his life in relentless search of knowledge and wisdom at the highest level. His thirst for knowledge became evident even when he was 10 years old, which made him walk from Kerala all the way to Onkarnath

Caves in Madhya Pradesh. He traversed India from the deep south to the Himalaya, Nepal and Kashmir by foot at least twice, and propounded a new philosophy. He set up centres for his school of philosophy in the different corners of India. One may not entirely endorse his philosophy, but one can never deny his brilliance and originality. His memory was phenomenal. He dictated books and composed verses in Sanskrit spontaneously. Clearly, he is the greatest Hindu philosopher.

Mahatma Gandhi started a freedom movement in India without any of the modern facilities. There were no phones, planes and any of the modern gadgets. He dared to face the imperial British powers, without an army. He used simple words and was straightforward in his expression. Gandhiji's doggedness and faith in his ideology gave us freedom. He had novel ideas in economics and education suited to India, and by ignoring them completely, we have paid a heavy prize.

I have tried to be honest and truthful in what I have written here. I have avoided dwelling on issues related to my own being. I am more concerned about the young scientists of India who will determine our future. India has several million young people, specially in our villages. They are our hope. They may provide the badly needed leaders who are not only outstanding in science, but are also deeply committed to the cause of making India a great scientific power.

I dedicate this article to our scientists with respect and humility.

C. N. R. RAO

*Jawaharlal Nehru Centre for Advanced
Scientific Research,
Bengaluru 560 064, India
e-mail: cnrrao@jncasr.ac.in*