Linus Pauling (1901–1994)—A colossus in chemistry and an unparalleled crusader

An obituary by C. N. R. Rao

Linus Pauling is no more. With his passing away, the world has lost the greatest architect of modern chemistry and the first founder of molecular biology. We will miss the irrepressible crusader of modern times.

Linus Pauling was born in Oswego, a small village in Oregon, on 28 February 1901, when the frontier spirit of the west was still prevalent. On his mother's side, he had some unconventional relatives. His father owned a small drug store, and used to sell specially concocted Dr Pfunder's Oregon blood purifier. As a child, Pauling was interested in insects and minerals. At school, he had one or two teachers who made science exciting. Early in his life, he lost his father and had to work during spare hours to support his family. He finished school, but did not receive the diploma since he did not complete a course in civics. (The school awarded the diploma after he received the Nobel Prize for peace.) He had however completed all the requirements to join the nearby Oregon Agricultural College at Corvallis as an undergraduate student. His consummate faith in his own intellect was evident even at that time. On one occasion, he seems to have stood up in an open meeting of students during the address of the Dean, to correct some of the statements. He had nothing to apologise for and the Dean took it graciously. Pauling felt that he had to interject since he did not want the large assembly of students to be misinformed. Pauling had to take a break from his undergraduate studies after two years, because of financial difficulties. He could come back to the college only when he was made an assistant to teach quantitative analysis. He had a few good teachers in chemistry, in particular Fred Allen. I knew Fred Allen personally when he was at Purdue and have learnt much about the early student days of Pauling. In 1922, Pauling received a Bachelor's degree in chemical engineering. By that time, he had read the papers of Langmuir and Lewis on atoms and molecules. He had also taken courses in mathematics, physics and crystallography. During his undergraduate days, Ava Helen was his close friend and he adored her.

Although there was considerable pressure on him to take up a job to support his family, Pauling decided to pursue post-graduate studies. The choice he had was the University of California, Berkeley, where G. N. Lewis presided over a famous department or the California Institute of Technology where A. A. Noyes was the Chairman. He went to Caltech instead of Berkeley since he first obtained admission from Caltech. Robert Millikan was then the President of Caltech. In Caltech, he came under the influence of Noyes who encouraged him to take up crystallography for his Ph D thesis under Roscoe Dickinson. He solved the structures of several minerals with Dickinson. He also married Ava Helen at this time. During his Ph D studies, Peter Debye visited Caltech and Pauling wrote a paper with him.

After the Ph D degree, Pauling had the opportunity to take up an NRC fellowship with G. N. Lewis, but it appears that Noyes wanted him to go to Europe. Noyes was protective of Linus Pauling from the beginning and made financial contributions towards Pauling's European tour. Pauling went to Sommerfeld in Munich and later spent some time in Copenhagen (with Bohr) and in Zurich (with Schrödinger). During his stay with Sommerfeld, Pauling came in contact with Heitler and London and wrote a classic paper on the properties of multielectron atoms as revealed by quantum mechanics. He showed how one could predict atomic properties from quantum mechanics, in agreement with the results from crystallography. Lawrence Bragg, who was an important scientist of the time, did not particularly appreciate Pauling's paper. Bragg felt slighted, but Pauling was sure that he had nothing to be ashamed of.

Pauling returned to Caltech in 1928 as an assistant Professor in theoretical chemistry. At that time, Slater was making a beginning with his quantum mechanical work at MIT. One of the first things Pauling did was to reconcile the Bohr model of the atom with the Lewis model of atoms and molecules (Lewis wrote his classic paper in 1916). He wrote a series of papers under the heading 'Nature of the Chemical Bond', where he described the valence bond approach, and his ideas on a variety of topics such as resonance, ionicity, hybridization and so on. In 1930, he initiated research on electron diffraction of gases and derived the structures of many important molecules of direct relevance to the understanding of chemical bonding. Electronegativity and hydrogen bonding are the other topics he investigated. He published extensively and each of his papers is in a language that is biblical. Linus Pauling was then a fountain of knowledge that changed the direction of

chemistry. When one looks back, it appears as though Pauling looked at a problem, guessed the right answer and then did the experiment to prove it. This period in Pauling's life is somewhat comparable to that of Faraday, exactly a century earlier. What is surprising is that this monumental contribution of Linus Pauling in the early 1930s did not get him a Nobel Prize, although much lesser contributions in this area received the recognition in later years. Pauling as a child of the golden age of physical science, became the father of modern chemistry. In 1935, he wrote the classic book entitled *Introduction to Quantum Mechanics with Applications to Chemistry* along with Wilson. Around 1930s, Mulliken was coming out with his molecular orbital theory. In 1938, Pauling wrote the now immortal book, *The Nature of the Chemical Bond*, based on his Baker lectures at Cornell. (The book was dedicated to G. N. Lewis.) What is curious is that he makes little mention of molecular orbital theory in the book. Even in the revised edition of 1960, molecular orbitals do not get much importance. Then, that is Pauling. As someone wrote in a review of the second edition of the book, the book must be compulsory reading for all chemists and all those interested in atomic and molecular structure, but it should not be used as a text. In 1947 Pauling wrote what I consider to be the first proper textbook of General Chemistry for fresh undergraduate students. This was a trend-setter.

Around 1935, Pauling got interested in biology under the influence of Morgan. He carried out experiments on haemoglobin and protein denaturation. In the early 1940s, he started working on polypeptides and proteins. He had to deal with Dorothy Wrinch who had come out with symmetry arguments and with the cyclol model. Pauling in one of his papers decimated her, showing how her model was completely wrong and was against all chemical intuition. This was the style of Pauling and many scientists did not like the way he dealt with Dorothy Wrinch. Pauling had his own chain model for the structure of polypeptides and proteins, based on the planarity of the peptide bond. By 1950, Pauling and Corey had worked out the alpha-helical structure of proteins. Apparently, the idea of the alpha-helix struck Pauling in an Oxford College where he was recovering from a cold.

Pauling was not only a person with extraordinary talent and intuition but also one with great confidence and courage. He was extremely quick in grasping a problem and worked very hard at it. If he believed in something, he would go to any length to make the other arguments meaningless. The vehemence with which he did this is illustrated by the manner he dealt with Jordan, who had published a paper on biological specificity. Pauling wrote a very decisive note with Delbrück and proposed the idea of complementary units in genes, to show how Jordan was wrong. Pauling himself was subject to considerable criticism by some scientists for his unusual methods and approximations. He was accused of mathematical deficiency and lack of thoroughness. His ideas on resonance were criticized by Fajans. Slater was generally not happy with Pauling's papers although they had mutual admiration in the earlier years. One should remember that Pauling was a phenomenon in chemistry. Individuals like Pauling cannot be expected to worry about details; details seem to be the task for lesser people. Pauling was looking at the beauty of forests while the others were looking at the trees.

Pauling's main contributions to structural biology were made between 1947 and 1952. In 1949, he wrote the famous paper on sickle-cell anemia where he showed that a change in one amino acid residue out of 146 was responsible for the disease. He called it a 'molecular disease'. Some reservations were expressed initially by some scientists in Britain, regarding the alpha-helical structure of proteins. However, this important discovery was there to stay. He got close to solving the structure of DNA. It is during this period that Pauling met Einstein with whom he had discussions on human rights, determinism, peace and other topics.

In 1950, Pauling made a public statement on the need to avoid war. This was the time when McCarthy ruled supreme. Pauling came in open support of Oppenheimer and of the Rosenbergs and got into disfavour of the powers in the United States. He was unable to obtain a passport to attend the important meeting of the Royal Society in 1952 where he was to discuss the structure of proteins. In spite of appeals from Einstein, Fermi and a number of other scientists, the United States refused to give him the passport. In 1954, Pauling was refused a passport to visit India to attend the Indian Science Congress. I remember having gone from Calcutta to Hyderabad to see him, but he did not come. (I met him in 1955 in the US when I was working for my Ph D degree.) Late in 1954, Pauling received the Nobel Prize for his work on the alpha-helical structure of proteins. Shortly after the Nobel Prize, he worked on the molecular basis of mental illness and showed the importance of vitamin B_3.

By the middle of the 50s, Pauling's activities in the peace movement had increased. He made fervent appeals for stopping nuclear testing and warned the world community about the dangers of nuclear radiation. On the danger of radiation, he had the support of the great biologist, Müller. There was however major disagreement with Libby who found little wrong with radiation levels caused by nuclear testing. Unfortunately, even Joe Hildebrand did not approve of Pauling's role in warning the world community about the dangers of radiation. Pauling wrote to President Eisenhower pointing out the danger of nuclear weapons, particularly its

biological effects. He wrote to Eisenhower again enclosing his book *No More War* where he stated, 'May our great nation, the United States of America, be the leader in bringing morality into its proper place of primary importance in the conduct of world affairs'. He did not receive any response. Instead, the press and the community at large developed tremendous antagonism towards him. This extended to educational and scientific institutions as well. At Caltech, pressures were increasing in a manner that made him resign from the chairmanship of the chemistry division in 1958. There was pressure on him to give up some of his laboratory space, which he did not particularly appreciate. In the late 1950s, he had debates with Edward Teller about nuclear testing and the adverse effects of radiation. Pauling called nuclear testing, a crime against humanity. He again came to the defence of Oppenheimer who had been declared a security risk. He visited Albert Schweitzer to obtain support for the peace movement.

In 1960, Pauling sent an appeal to the United Nations with signatures of over 1500 scientists and others about nuclear test ban and disarmament. It only brought the wrath of the US Senate, but this did not stop Pauling from continuing his crusade. He inserted advertisements in newspapers against the Senate Committee. Many universities would not allow him to lecture, because he was slowly getting to be considered as antinational or unamerican. There was an interesting incident in 1962. Pauling was leading a picket line in front of the White House. The same evening there was a dinner for the American Noble laureates hosted by President Kennedy. Pauling left the picket line in the evening and went to the White House for the dinner. I believe that he danced with Jacqueline Kennedy as well.

In 1962, Pauling received the Nobel Prize for Peace. This created more problems for him and antagonism increased from innumerable quarters. The chemists at Caltech did not celebrate his second Nobel Prize. Many journals and newspapers considered the Nobel Prize to be an insult to America. Life magazine wrote an editorial how America had been slapped in the face by giving a Nobel Prize to Pauling. The behaviour of the American Chemical Society was not particularly pleasing. He was not even allowed to publish a rejoinder to an attack against him in its news magazine. Pauling resigned from the membership of the American Chemical Society. He decided to leave Caltech in 1964. Pauling was a harassed man from 1954 onwards, but he continued to work on scientific problems. He published some papers on nuclear structure and on certain biological problems. The Vietnam war made Pauling renew his peace efforts. He wrote directly to Ho Chi Minh. News commentators like William Buckley went after Linus Pauling and publicly accused him of being a communist sympathizer. He strongly objected to such insinuations and sued some of the papers and individuals, but to no avail.

In the late 60s, after receiving two Nobel Prizes, Pauling did not have a proper place to work. He first worked in the Centre for the Study of Democratic Institutions in Santa Barbara for some time and later in the University of California at San Diego. During this period he started research on orthomolecular psychiatry and showed how mental patients were deficient in ascorbic acid, pyrodoxine and vitamin B_3. He worked for a short time at Stanford from 1969, when he wrote his paper on the genetic and stomactic effects of high energy radiation. He founded the Linus Pauling Institute of Science and Medicine in 1974.

It was only in 1970 that Pauling's name was removed from the list of persons considered to be communist sympathizers. In the meantime, he had started working on vitamin C. Based on a thorough literature research and his own intuition, he proposed that vitamin C was good for common cold. Although there was publicity against some of the statements he made, slowly people have come to recognize that vitamin C is useful in preventing common cold. This has found support from Harker and many others. Pauling initiated work on vitamin C and cancer with Cameron. The usefulness of vitamin C in relation to cancer or heart disease has been a matter of considerable debate. Pauling however would not give up and continued to champion this cause. There appears to be some agreement now that vitamin C has beneficial effects because of its role as a free radical scavenger.

In 1975, the US administration seems to have fully exonerated Linus Pauling of whatever he was accused of earlier. He was awarded the National Medal of Science. In 1976, Caltech celebrated his 75th birthday. In 1976, the American Chemical Society celebrated its centenary (which I had the pleasure of attending). The President of the ACS then was Glenn Seaborg, the former Chairman of the U.S. Atomic Energy Commission. It seemed as though everybody had decided to shake hands with Pauling. He gave the ACS centenary lecture. In 1981, Ava Helen, Pauling's dear wife, passed away. She was his partner through thick and thin and fully shared his enthusiasm for movements dealing with peace and women's rights.

Even in the 1980s, Pauling carried out some of his own research. He wrote a note on quasi-crystals in 1985 where he disagreed with the view of Shechtman and another on superconductivity in 1988. These papers are reminiscent of the old Pauling, still interested in structure and bonding. In 1991, on the occasion of his 90th birthday, the US National Academy of Sciences honoured him with a special citation. I had the pleasure of witnessing the event.

How does one look at this great colossus? Linus Pauling was clearly the greatest chemist of this century.

He was the person who brought chemistry into the realm of physics and created modern physical chemistry which Ostwald dreamt about. This could not have been done by Lewis or Noyes who were his mentors. Linus Pauling was the first person who made chemical bonding his primary concern through which he changed the course of chemistry. Pauling created modern structural biology through the discovery of the alpha-helix and by showing sickle-cell anemia to be a molecular disease. Then, he was a crusader for human rights and for peace. He was fearless and his courage was unequalled. I know of no one in this century or any other time, who took on the entire world just because he believed in something, by undergoing personal suffering and harassment for long periods. Pauling had a multi-dimensional personality. Uni-dimensional persons have difficulty in assessing persons like Pauling and tend to find little faults in their work, but people who are masters in picking little mistakes generally do not change the course of science.

Pauling was my hero. He was the person who created the kind of chemistry I love. He was ahead of his times. He was not only the scientist of the century, but a man for all time. *Long live Pauling*!

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