In this issue

A titan passes away

In this issue we publish a tribute to Linus Pauling by C. N. R. Rao (**page 405**), a brief account of his contributions to biology by P. Balaram (**page 409**) and another on his controversial involvement with vitamin C by C. C. Kartha (**page 411**).

There is a story (probably apocryphal) that when a journalist desired to interview Linus Pauling on all the important aspects of his scientific career, Pauling smiled and asked, 'How many days will you be spending with me?'.

His versatility was phenomenal; the number of scientific problems he took up and solved was astounding. It would be difficult even to enumerate his contributions to chemistry; *he not only helped to lay the foundations of this subject, he also erected much of its edifice*. He recast chemistry into the mould of quantum mechanics; he pioneered techniques like X-ray, crystallography, electron diffraction, and magneto chemistry; he used his incredible theoretical and experimental gifts to unravel and systematize organic, inorganic and mineral structures. He built new pathways into biochemistry, biophysics, medicine, the diagnosis and cures of diseases. He is without doubt one of the greatest scientists of the twentieth century.

Linus Pauling was a child of the California Institute of Technology (Cal. Tech.), Pasadena.

During the last forty years I have visited universities all over the world, I now have the opinion that I had the greatest good luck in having gone to Pasadena in 1922. I do not think I could have found better conditions for preparation for a career in physical chemistry, anywhere else in the world.

The idea of developing this institution into an outstanding one was that of the astronomer Hale. Pauling attributed the success of Cal. Tech. to the structure of its administration – an executive council with a majority of academics (and a few businessmen).

It is my opinion that it is this form of administration which gave Hale, Noyes, and Millikan much freedom in putting their ideas about education and research into operation.

He felt strongly that in addition to inspiring students to carry on research it is necessary in the training of young scientists that they must be given a good background of the knowledge that has already been created.

It was Richard Toman who, in my opinion, made the greatest contribution to the achievement of this goal. He had a thorough understanding of the new developments in physics and also the conviction that chemical problems could be solved by the application of physical methods.

Pauling was also convinced that 'research conferences', i.e. discussions and seminars, by visiting scientists contributed much to the growth of students as also of science at an institution. To illustrate this, he gives a spectacular array of visiting scientists whose lectures he attended as a doctoral student: H. A. Lorentz, C. G. Darwin, P. Ehrenfest, A. A. Michelson, R. C. Gibbs, S. Loria, A. Sommerfeld, M. Born, V. Bjerknes, C. V. Raman, J. Franck, P. Langevin. Although he was a graduate student in chemistry, most of the courses he took were in mathematics, mathematical physics and quantum theory!

After his doctorate he went to Europe; in Munich (*Sommerfeld's lectures were outstanding, I think it my good luck that led me to spend one year with him*); in Copenhagen, at Bohr's Institute; in Zurich attending lectures by Schrödinger and Debye and at Ludwigshafen with Hermann Mark where he learnt electron diffraction. He came back to Pasadena accepting an appointment of Assistant Professor of Theoretical Chemistry and Mathematical Physics and found on his arrival that the appendage Mathematical Physics had been dropped from the title, obviously vetoed by Millikan and Noyes to keep him from 'straying out of chemistry'. He plunged into quantum mechanics and his comment on this subject is interesting.

I was not able to distinguish clearly between the unsatisfactory nature of the physical theory and the unsatisfactory nature of my own understanding them; and I tended to assume that my understanding was at fault.

Pauling was perhaps the first to apply quantum mechanical methods to systems with more than one electron.

Van't Hoft in 1874 made the most important addition to organic structure theory when he recognized that the optical activity of carbon compounds can be explained by the 'tetrahedral' carbon atom. Unfortunately the equivalence of the four bonds of carbon, which had become an integral part of organic chemistry, could not be reconciled with the quantum mechanical description.

Pauling recognized that this equivalence arose as a result of the resonance phenomenon in quantum mechanics (an idea he forcefully propagated) and is caused by the hybridization of the *s* and three *p* orbitals. This and the idea of resonance were the greatest contributions he made at that time to organic chemistry.

Structural inorganic chemistry was born when Werner at the beginning *of the century showed that the properties of many complex inorganic substances could be explained by assuming that the metal surrounds itself by a number of other atoms (the number being very different from its valence); usually four atoms at the corner of a tetrahedron or a square, or six atoms at the corner of an octahedron.*

Again Pauling using quantum mechanics and his resonance theory showed that these arise due to sp^3, dsp^2, d^2sp^3 hybrid orbitals respectively. This again was one of the most important steps taken in understanding inorganic compounds.

Pauling started his research career doing X-ray crystallography. He prepared LiH to prove the existence of the hydrogen ion in solids but found that Bijvoet's school in Holland had preceded him. He then did the complete structure of molybdenite MoS_2 – what he learnt from his thesis adviser Roscoe Dickinson made a great impression on him.

The process of structure determination by X-rays involved a succession of logical arguments, and there is an emphasis on rigor. I realized then that questions about the nature of the world could be answered by experiments carefully planned and executed.

His respect for these subjects and its devotees obviously waned after seventy years:

The young crystallographer does not think, he puts the crystal into an automatic diffractometer, which is coupled to a computer, which then works out the structure – and it may be even coupled to a computer system that writes the paper!

Pauling's first doctoral problem – the structure of MoS_2 – led him to his great voyage of discovery which finally culminated in his being awarded the Nobel Prize. In molybdenite, the molybdenum atom is surrounded by six sulphur atoms, not at the expected corners of an octahedron but at those of a triangular prism. He then assumed atoms and ions to be spheres, calculated their radii using quantum mechanics and applied the principles of packing spheres of unequal radii to explain formation of crystalline solids. The number of anions surrounding the cations is determined by the *radius ratio*. He described many coordination polyhedra and in his early papers and books for some inexplicable reason he did not include the Platonic solid, the icosahedron. He then formulated a set of rules now called *Pauling's rules*, which at one stroke cleared the confusion that existed in the formation of crystals of inorganic and mineral substances and elevated crystal chemistry to the status of a Science. All this and much more appeared in his classic *The Nature of the chemical bond, the structure of molecules and crystals*, a book that truly transformed chemistry.

In 1934, Pauling and his students turned their attention to haemoglobin. They studied the effects and mechanism of oxygenation of this large molecule by measuring the magnetic susceptibility.

I thought this work would tell whether the interaction between the oxygen molecule and haemoglobin would be a weak one leaving the oxygen molecule in the triplet state or a strong one to cause electrons to pair.

Not only was the pair formation confirmed but they also got the surprising result that each iron atom has four unpaired electrons in haemoglobin and none in oxyhaemoglobin.

When one reads of his work on haemoglobin, the structure of antigens and antibodies, the nature of serological reactions and the template theory, his studies on sickle cell anaemia, his concept of molecular diseases, his approach to cure them (chemical metallaxis), his conjecture of genetic defects causing many diseases, his inspired guess as to how anaesthetics work, his solution of the structure of alpha helix by attacking it as a problem of structural chemistry and ignoring the X-ray photographs – (the world knows the price he had to pay for this attitude for had he seen the X-ray diagrams of DNA he might probably have solved its structure earlier than Watson and Crick), – one wonders whether he was a physicist, a chemist, a biochemist, a biophysicist, a medical scientist or a magician who could produce new solutions for any problem as though they were rabbits.

But humanity will have to be grateful to him (and his remarkable wife Ava Helen Pauling) for the fight they put up against nuclear testing and nuclear arms race – in spite of his being ostracized and isolated, his passport being impounded, his risking prison as he refused to give the names of those who helped him to get thousands of signatures from scientists all over the world (like the squirrel in the *Ramayana* I could say I too helped this great man in this endeavour).

The strangest thing is that he succeeded in 1963. USA, Soviet Union and Great Britain (and many other countries joined in) agreed to abandon nuclear tests in the atmosphere. This was at least a beginning. Pauling declared:

One day humanity will succeed in banning war. There is a greater power in the world than the evil power of military force and of nuclear bombs – the power of good, of morality and of humanitarianism.

Of people like him did the TORA say 'If anyone saves one life He saves the world entire.'

He was amongst the greatest: as a scientist and as a human being.

S. R.