## New ideas

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At one end of a panelled library at the Yacht Club there were two offices—one of the professor of mathematics, D. D. Kosambi, and the other of the professor of experimental physics, Bernard Peters. It was January of 1957, I had just joined TIFR and was on my way to see Professor Peters. As I entered his office I saw a strong face with deep-set, intense eyes and a broad smile welcoming me. I wanted to start research in cosmic rays. I had come to Bernard in search of a good problem to make myself familiar with the frontiers in cosmic rays. He immediately suggested that I work with him on the problem of composition of cosmic rays near the 'knee' of the energy spectrum at $10^{15}$ eV. I welcomed the offer.

This was the start of the rigidity cut-off model of Bernard Peters. We were trying to understand the variation of the content of nuclear-active particles in air showers through the 'knee'. In typical Peters style we developed an equilibrium model for shower propagation which made it possible to do calculations without the use of computers! Many different aspects of shower development were studied. We had many vigorous discussions, comparing results and discussing limitations of the particle-physics models. The model predicted that cosmic rays should have different elemental composition above the 'knee' compared with that at lower energies, composition becoming dominated by heavy nuclei above $10^{15}$ eV.

This prediction was a radical departure from known composition at low energies, which was dominated by protons and helium nuclei; the year was 1958! Only 30 years later are experiments pointing towards the validity of this prediction. Peters worked on phenomenological improvements and extension of this basic approach for the next five years. This work culminated in the comprehensive paper of Yash Pal and Bernard Peters on cosmic-ray propagation in the atmosphere.

Bernard always encouraged pursuit of new ideas, while at the same time examining them with a critical eye. He was the dominant figure in cosmic rays in India for over ten years. He established an outstanding school of cosmic ray physics at TIFR. Much of my work during the last fifteen years in cosmic rays reflects the deep interest that was generated while working with Bernard in the fifties. I extend my felicitation to Bernard Peters on his entering the ninth decade of his life.

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centre-of-mass system of the collision, one easily obtains from their angular distribution, if a large number of secondaries is involved, a precise determination of the velocity of this centre-of-mass system, and thereby the energy of the incident primary particle. Energies could here be measured which were several thousand times higher than those which could previously be deduced from particle trajectories in the earth's magnetic field. In our case, the incident magnesium nucleus had $7.8 \times 10^{12}$ electron volts (eV) per nucleon or a total incident energy of $1.9 \times 10^{14}$ eV. Most of the shower particles had energies of the order of $10^{11}$ eV.

These energy determinations indicated that complex primary CR nuclei exist at least up to those energies at which extensive air showers become observable on the ground. Their contribution to the extensive air shower phenomenon is probably significant if not dominant.

The microscopic investigation of the 24 emulsion-covered glass plates, which were traversed by the hundreds of shower particles, took us several months of very intensive effort, usually lasting late into the night. By scanning along the tracks of the created particles through successive emulsion layers, one found numerous interactions in this as yet unexplored energy regime, and could study their characteristics, in particular how they differed from the interaction of protons at comparable energies. One found numerous examples of electron–positron pairs produced by the decay gamma rays of neutral pions, and thereby obtained limits on $\pi^0$ abundance and lifetime. One also found not previously observed examples of electron–positron pairs produced by charged particles, i.e fast electrons and protons.

The entire field of particle physics and high energy remained the exclusive domain of CR research for almost another two years, i.e until 1954. Then the particle accelerators began to operate at Brookhaven and Berkeley. The tantalizing results obtained in CR were instrumental in stimulating the construction of those and even more powerful accelerators.

In these detailed studies of high-energy collisions there were indications that particles, other than pions, were created. However, a detector composed of glass-backed thin emulsion sheets did not lend itself easily to the identification of such particles and to the study of their properties. What was needed were solid blocks of pure emulsions, sensitive throughout their volume and yet capable of being studied microscopically with high magnification.

Our group experimented with various ways to process free-floating, large thin sheets of emulsion, which, although they swell up during processing, could then be dried to return them to almost their original dimensions, and to mark them precisely, so they could be brought back into the relative positions which they occupied when exposed as a solid block during flight, with precision of the order of a few hundredths of a millimetre. After some false starts we were successful almost beyond expectation. Now the decays and interactions of numerous charged and neutral particles could be observed. By tracing tracks backwards and forwards into the emulsion block, particle decay modes could be identified and the nuclear events could be identified in which the particles had been created. The particles observed in these detectors are now known as pions, K-mesons and hyperons. Their masses could be determined with good precision, their decay modes were clarified, and the association of K-mesons and hyperons in production and in nuclear capture was observed. The number of unstable subatomic particles in these preaccelerator years rose to about 14; it has increased only slightly since the accelerators entered this field more than 35 years ago.