Reflections

Bernard Peters spent ten years at the Tata Institute of Fundamental Research in Mumbai, starting from 1950. He had made an important discovery just before coming to India, having found heavy nuclei among cosmic ray particles. He was interested in studying cosmic rays from a place close to the equator and planned to do some experiments in India. During his stay in India, his group made seminal contributions to the research of cosmic rays, including a discovery of the radioactive isotope of Beryllium in ocean sediments.

Biman Nath

The Decade of my Association with Research in India

Bernard Peters

My first contact with India occurred soon after it was established that the primary cosmic radiation (CR) bombarding the earth consists of a variety of different nuclei. An obvious but very important question arose: Does this, the only material accessible to us from beyond the solar system, consist of matter only, or does it contain also antimatter (i.e. atomic nuclei of negative electric charge)? As far as it is known, both matter and antimatter are always created together and in equal amounts. Why only one kind (i.e. matter) can be found in the solar system and beyond is still an enigma.

At equatorial latitudes the geomagnetic field produces an asymmetry in the CR. It prevents positively charged particles in certain energy intervals from reaching the earth from the easterly direction, and, at the same time, it prevents negatively charged ones .(i.e antinuclei) from reaching it from the westerly direction. Thus, a very basic problem in physics and cosmology could be investigated by measuring the arrival direction of complex CR nuclei in the equatorial stratosphere.

I met Dr H. J. Bhabha in New York in October 1949 to discuss this problem. He had then already initiated a CR research programme at the newly created Tata Institute of Fundamental Research (TIFR), Bombay, and the programme included balloon flights into the stratosphere. Obviously, a cooperation on this fundamental experiment between the TIFR and the University of Rochester at which I was then teaching was indicated.

I arrived in Bombay on 31 August 1950, with an apparatus designed to measure such an

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asymmetry. It would keep airborne packages of nuclear photographic emulsions oriented in space, independent of wind-induced rotation of the balloon clusters.

An early letter to my family describes my first impression of the people and the conditions available for this cooperative experiment:

My first impression of the Tata Institute of Fundamental Research is very favourable, much more so than I had a right to expect. I have met a good many scientists, people with knowledge and interest, whom one likes at first sight. The institute, housed in a former royal officer club, has so much space, it would make everyone in Rochester green with envy. The library is large and adequate. The electronic labs and the machine shops look good. It is located at the Bay, from which it is separated by a small park with flowers. Mr Godbole, the secretary of the institute has reserved my room at the Taj Mahal Hotel ... looking out over the ocean with fishing boats and islands in the distance. It is hard to describe how beautiful it is .... I have not broached the subject yet, but who can pay for such royal quarters? I certainly can't ....

I have already talked to some of the physicists. I am very impressed and relieved that they have already made successful balloon flights to 95,000 feet for several hours with rubber balloons; so they know a great deal more about the subject of flying than I do. This was my greatest worry, so my hope for success is much increased. Their percentage of recovery, 60–90% return of equipment within two days, also sounds exceedingly good .... My first impression about facilities, competence of people, and their character is extremely favourable, but so far based on only four hours of contact .... Dr Taylor is the chief of the cosmic ray emulsion group, the division using photographic plates. He is half-time professor teaching at a college belonging to Bombay University and half time at the Tata Institute. An Englishman about 50 years old ....

And:

Bombay, Sept. 29, 1950

Taylor and I are flying to Madras on the 8 October, then drive to Bangalore, stopping at several places to pick out observation stations for theodolites. We will meet some of our crew in Bangalore, tranship equipment from there to Madras, and start flying on the 15.

A large number of rubber balloon flights were begun on 15 October from the cricket field of Madras Christian College in Tambaram. Another letter, of 22 October 1950:

I was sitting in a moonlit night at a brick fireplace in the woods, cooking balloons from midnight to 3 a.m. Then I woke up our group, and, as planned, at 5.40 a.m, twenty minutes before sunrise, our 24-balloon flight went off. It was the most elegant launching operation with 25 *people involved. Many college students volunteered. The flight stayed up for at least 10 hours and was observed by our theodolite stations in Madras, Vellore, Kolar and Bangalore. Wireless communication and weather perfect. Except for the fact that the old balloons did only go up to 75,000 feet instead of 95,000 feet, it was a perfect flight. Our score is now: first flight 15 October, a failure but recovered. Second flight, 70–80,000 feet. Weather permitted only four hours observation, but judging from the place at which it came down, it probably was an eight-hour flight. I am leaving tonight for Kuppam to recover it. Third flight today, probably 10-12 hours above 70,000 feet. I have no doubt that we will get excellent flights if we have better balloons and more rope.*

The flights continued into November.

Subsequent examination of the emulsions at Rochester and Bombay gave a clear answer: The region of the galaxy where CR originates contains matter only; less than one in a thousand of the nuclei consists of antimatter. This answer stands today. The upper limit for antimatter has since been lowered from 10^{-3} to about 10^{-5}. This result is quite surprising and disturbing, if one accepts big bang models of cosmology. Various attempts to explain the asymmetry are still quite tentative.

The enthusiastic work of the TIFR emulsion group led by H. J. Taylor* of Wilson College in Bombay and the excellent help and cooperation we got from the Madras Christian College staff and students in carrying out this very arduous balloon campaign in Tambaram motivated me to accept Bhabha's offer to return to India for a longer stay. And so, having returned to Rochester at the end of 1950, I returned to India at the end of 1951 and brought my family.

The 1950 experiment was an auspicious beginning for my work in India, which should last throughout the decade. I realized then that the geographical position of India, combined with the facilities built up at the TIFR, presented a unique combination for research on many other basic problems related to CR, a fact which Bhabha had realized already when he founded the institute. The geomagnetic field at low latitude prevents the bulk of low-energy CR from reaching the earth's atmosphere, so that the very rare high-energy processes could be studied here without being swamped by background, a great advantage over the situation in the USA and Europe. It remained to identify feasible experiments, which could be expected to yield new and relevant results in high-energy physics. We chose to investigate the following problems:

1. The chemical composition of high-energy CR, especially a search for evidence that it may reveal traces of its prehistory, its acceleration by as yet unknown processes at unknown sources,

* See *Curr. Sci.*, 1990, 59, p.1267 for artible by H. J. Taylor.

and its passage through interstellar space. Are all atoms completely or only partially ionized before acceleration? In other words, what is the temperature in the source region? How many, if any, long-lived radioactive nuclei which may be present in the source have survived the transit to the solar system? How long have the particles been on the way, how much interstellar matter (mostly hydrogen gas) have they traversed?, etc.

2. What happens when CR nuclei of energy far greater than could then be produced in laboratories collide with other nuclei? How do complex nuclei then disintegrate? What are the collision cross-sections for the various disintegration products?

3. What unstable particles are created as the result of the prodigious energies released in these collisions? (Some of them were known to be pions which had been discovered a few years earlier by C. F. Powell in Bristol.) How many subatomic particles are created? What is their angular and energy distribution when they emerge from the collision centre and what can this tell us about the interaction of subatomic particles with nuclei and with each other? What are the rest masses of these particles, their decay times and other properties?

Thus an enormous research programme lay before us, in which the advantages deriving from India's geographical position could be exploited.

4. There is, however, at least one more subject of great interest in high-energy CR research which we did not take up, namely the study of the so-called extensive air showers. These are produced in the atmosphere by extremely rare CR primaries of extraordinarily high energies. Here India has no geographic advantage over other regions since the measurements on extensive air showers have to be carried out on the ground, where the thick over-lying atmosphere excludes low-energy background at all latitudes. A vigorous programme on extensive air showers was, nevertheless, also initiated at the institute at that time, and produced under the leadership of B. V. Sreekantan many useful results. The success of his work can in part be ascribed to the fact that India possesses in the Kolar Gold Mines one of the deepest underground installations suitable for CR research.

But the attention of the group which I had joined concentrated on high-altitude measurement and on the first three listed subjects. We employed nuclear emulsions and balloon technology and were able, in the course of time, to improve both these technologies significantly.

Intensive scientific work at the institute engulfed me almost immediately after returning from the US. Among the large number of CR interactions which had been found in the emulsions exposed in the 1950 flights there was one very rare and huge one with nearly four hundred created subatomic particles, initiated by a primary CR nucleus of magnesium. This interaction remained for years the largest nuclear disintegration observed anywhere in the world. It became the subject of much theoretical investigations on meson production, and it yielded a great deal of new information.

For one thing, it answered a question which was still under discussion at that time, namely whether pions are produced individually in successive encounters with nucleons of the target, or whether they are produced *en masse* in nucleon–nucleon collisions like a cloud whose size increases with energy. The several hundred particles created in our event were incompatible with single-production models.

The event also permitted a new technique for determining the very high energy of the primary. Postulating symmetry in the forward and backward emission of secondary particles in the 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 7.8×10^{12} electron volts (eV) per nucleon or a total incident energy of 1.9×10^{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 pates, 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 π^o 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 for 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 millimeter. 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 in 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.

At the 1953 CR conference at Bagnères de Bigorre, sponsored by the International Union of Pure and Applied Physics, the new results obtained by means of our emulsion block detectors played a significant role in clarifying the then confusing situation in particle physics. Yet, within a year, it became apparent that when high-energy accelerators would enter the field, the unique role of CR in this research area must come to an end. A change of direction in our CR research became necessary.

We decided to study the production of radioactive isotopes produced by CR in collision with atmospheric nuclei and their subsequent fate. How many and what type of isotopes are being produced? How do they reach the earth? By what pathways and how fast are they distributed among the principal geophysical reservoirs, such as atmosphere, hydrosphere, lithosphere, biosphere and the polar ice cap? The concentration of these isotopes of different life-times should make it possible to study the turnover of matter in these various reservoirs, and the rate at which matter is transferred among them. One might study the exchange of air masses between stratosphere and troposphere, the ablation rate of rock surfaces, the sedimentation rate in lakes and on the ocean floor, the mixing of water between deep sea and surface layers, the ablation of polar ice by evaporation and by winds and ice flow. All these and many other phenomena should give rise to characteristic concentrations of the radioactive nuclei produced by CR.

For this new direction of research we had to acquire new unfamiliar techniques. Instead of emulsions and microscopes we now used:

– Ion exchange columns to extract certain nuclei from rain water

– Microchemistry to concentrate the extraordinarily small samples (one is always dealing with quantities far below the limits of visibility)

– Low level particle and gamma-ray counters to detect disintegration rates (sometimes as low as one or less per hour)

These then became our new research tools. More important still, we had to familiarize ourselves with many branches in geophysics and learn what was known at the time about the transport of air masses, global precipitation patterns, and, in particular, the build-up sediments on the ocean floor, where some of the long-lived isotopes, which could survive the transport, would finally come to rest. We began to collect samples in the stratosphere, troposphere, biosphere, in rivers, lakes and oceans, in deep-sea sediments and polar ice caps.

Through our emulsion work we had already accumulated a considerable body of knowledge on the number and kind of nuclear interactions which CR produce in the atmosphere at different heights and latitudes. This permitted us to make rather reliable estimates of the rates at which suitable radioactive isotopes were continually being introduced into the atmosphere. These rates are rather small. Typical values are: three nuclei of ^{10}Be per minute per kilogram of air, 0.1 nucleus of ^{32}Si per minute, and one nucleus of ^{26}Al every two hours. All these and many other isotopes are brought down to the earth in rain water and slowly diffuse into the various geophysical reservoirs while at the same time disappearing by decay at their characteristic rates.

We began the work by collecting enormous quantities of rain water. Large plastic sheets were spread over the roofs of the huts which served as temporary chemical laboratories at Colaba where later the modern laboratories of TIFR should arise. We even collected water on the large terrace of our apartment on Peddar Road. From there we channelled the monsoon waters through ion-exchange columns to extract the very small number of interesting atoms.

At that time the only radioactive nuclei on earth were those of the heavy elements of the natural radioactive series (whose life exceeds the age of the earth) and their decay products. All other radioactive isotopes on earth were cosmic-ray produced. This had been true through the ages until atomic-bomb testing began to disturb this peaceful state. From then on appropriate corrections became necessary.

Element	Half-life
^{3}He-	Stable
^{10}Be	1.6 m.y.
^{26}AI	710 k.y.
^{36}C1	300 k.y.
^{81}Kr	210 k.y.
^{14}C	5730 y
^{32}Si	l30y
^{39}Ar	270 y
^{3}H	12.3 y
^{22}Na	2.6 y
^{35}S	87 d
^{7}Be	53 d
^{37}Ar	35 d
^{33}p	25 d

Instead of launching balloons we now went on mountain expeditions. In one of our first experiments in search of the long-lived isotope ^{10}Be ($\tau \approx 1.6$ m.y.), we set up ion-exchange columns above Gulmarg in Kashmir, high up in the melt water of snow fields, to get hold of these rare atoms before they could make contact with the soil and adhere to it. Only two of the horses that carried our apparatus and equipment up to Khilanmarg were capable of going high enough. We extracted nuclei from thousands of litres of water. But soon, after verifying our theoretical calculations about production rates, we learned to extract most of the isotopes from much more modest samples of a few litres and began to analyse individual rain samples.

The CR-produced isotopes which can now be identified are shown in the table, many of them were first obtained in Bomhay.

The detection of the isotopes with very long half-lives was difficult. We finally succeeded in measuring the ^{10}Be concentration in deep-sea sediments using one of the very earliest deep-sea ocean cores, which had been obtained by Petterssen and B. Kullenberg in Göteborg, Sweden. Another important long-lived CR isotope, ^{26}Al, was not isolated in ocean sediments until many years later. The tiny concentration of ^{32}Si in ocean water was not measured until Lal extracted this isotope by a novel technique from hundreds of tons of water *in situ* and identified it through its short-lived radioactive decay product ^{32}P.

This branch of CR research has been prospering since its beginning in 1955; CR-produced isotopes continue to play a role in oceanography and other branches of geophysics.

It was primarily for family reasons that I decided to leave India in 1958. I then accepted a position at the Niels Bohr Institute in Copenhagen but my connection with India did not cease. I visited India and the TIFR repeatedly over the years. Scientists from the TIFR have been guests in Copenhagen and worked with me both at the Niels Bohr Institute and later at the Danish Space Research Institute. This connection has remained intact even after my retirement.