Homi Bhabha and Cosmic Ray Research in India

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B V Sreekantan is currently the Sir S Radhakrishnan Visiting Professor at the National Institute of Advanced Studies, Bangalore. He was Director of Tata Institute of Fundamental Research, Mumbai during the period 75-87. He obtained his PhD from Bombay University in 1954 for his work on 'underground cosmic rays' under the guidance of Homi Bhabha.

Cosmic rays are very high energy particles arriving from the depths of space and incident on the earth's atmosphere at all places and at all times. The energy of these particles extends over 12 decades from around 10^9 ev to 10^{21} ev and mercifully for the survival of life, the intensity falls by atleast 22 decades from about 100 particles/cm^2/s to 1 particle/1000 km^2 year. Cosmic ray research led to the discovery of many of the fundamental particles of nature in the 30's, 40's and 50's of this century and ushered in the era of 'elementary particle physics' at man-made accelerators. Even 86 years after the discovery, the sources of these particles and the mechanism of acceleration continue to remain a mystery.

Homi Bhabha who became famous for his 'cascade theory of the electron' in the 30's did pioneering theoretical and experimental research in this field during his post doctoral fellowship in Cambridge and later at the Indian Institute of Science in Bangalore. The Tata Institute of Fundamental Research, which he founded in 1945, became under his leadership, a major centre of cosmic ray research covering practically all aspects of the radiation and continues to be active in this field.

Homi Bhabha is well known among the scientists of India and the public at large as the 'Father of India's Atomic Energy Programme'. What is not so well known however, particularly among the younger generation is the fact that he made outstanding contributions in the field of theoretical physics and played a very important role in initiating and fostering cosmic ray research in India. Thanks to the unique start given by him in the 40's, cosmic ray research in India grew into one of the largest

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activities in the world covering all aspects of the radiation in the 50's and 60's. In recognition of this, the Cosmic Ray Commission of the IUPAP held its 7th International Conference on Cosmic Rays, one of the earliest in the series, at Jaipur in India in 1963. It is most interesting and instructive to know how all this was achieved and what exactly motivated a young man in his thirties to initiate work in a highly sophisticated and highly technology dependent field so early in India. Let us look at the background of Bhabha and the times in which he began his research.

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Homi Bhabha at Cambridge

Homi Bhabha was born on 30th October 1909 and had his school education at the Cathedral and John Connon High School in Bombay and his college education at the Elphinstone College and the Royal Institute of Science. At the age of 18, he left for England to pursue further studies at Cambridge. As desired by his parents, he completed his Mechanical Tripos with distinction and persuaded them to let him do a Mathematical Tripos since his own interests were in physics. Immediately after his second Tripos, he got a travelling fellowship and had the wonderful opportunity of working for short periods with Wolfgang Pauli at Zurich and with Enrico Fermi at Rome. In 1934, he was awarded the Isaac Newton Studentship at Cambridge which enabled him to complete his PhD under R H Fowler. He continued his research at Cambridge till 1939. The research that he did during this period had a direct bearing on the resolution of several important issues of cosmic ray phenomena and the interactions of particles especially electrons, protons and photons at high energies, in the context of the developments in the field of quantum mechanics and relativity. To appreciate these contributions of Bhabha it is necessary to become familiar with the status of cosmic ray studies in the early 30's.

Cosmic Rays in the Atmosphere: The 'Soft' and 'Penetrating' Components

The presence of a penetrating ionising radiation of extraterrestrial origin was established in 1912 by Victor Hess

Figure 1. Victor Hess in the Gondola in which he went up to an altitude of 16,000ft for measurement of cosmic ray intensity in 1912.

through a series of manned balloon experiments (Figure 1). The name 'Cosmic Rays' was given to this radiation by Millikan in 1925.

Analysis of the radiation at sea level and mountain altitude by a series of experiments with Geiger–Muller telescopes and magnetic cloud chambers, revealed that the radiation contained two components with distinctly different properties. One component, called the 'soft component', was easily absorbed in a few centimetres of lead, quite frequently multipled in number in passing through thin sheets of lead and also arrived at the observational level in multiples – as a shower of particles separated by several tens of centimetres. The second component, called 'penetrating component' could penetrate large thicknesses of matter, even a metre of lead, without multiplying. The only fundamental particles that were known at that time were the electrons, the photons, the protons and the α- particles. To this small list two more were added in 1932, the neutron and the positron. The positron was discovered by Anderson in a cloud chamber that had been set up to analyse the cosmic ray beam and its discovery was a great triumph to the relativistic quantum mechanical formulation of the theory of the electron developed by Dirac at Cambridge. Around the same time in the early 30's, Blackett and Occhialini who were also working at Cambridge had recorded several instances of multiple charged particles which had obvious non-ionising links between pairs of them. These events fitted beautifully the phenomenon of pair production or conversion of quanta into electron-positron pairs according to Dirac's theory. The calculations on the energy losses of charged particles by Bethe and Heitler revealed several surprising features – higher losses for lighter particles, (more for electrons than for protons of the same energy), higher losses in passing through matter of higher atomic number, and higher losses at higher energies.

All these features came in very handy in the explanation of cosmic ray anomalies. Clearly, Bhabha was at the right place at the right time. The very first paper of Bhabha entitled 'Zur Absorption der Hohenstrahlung' published in 1933 in *Zeitschrift Fur physik* was concerned with the explanation of the absorption features and shower production in cosmic rays. In 1936, Bhabha in collaboration with Heitler formulated the 'cascade theory of the electron' according to which a high energy electron passing through matter gave rise to a high energy photon by bremstrahlung process and the photon in turn produced a pair of positive and negative electrons; these in turn led to further production of photons and the cascade process continued until the energy of the particles fell below a critical value. Carlson and Oppenheimer also developed a similar theory simultaneously in the USA. Based on Bethe–Heitler cross sections, Bhabha and Heitler made quantitative estimates of the number of electrons in the cascade at different depths, for different initiating energy of the electrons. These calculations agreed with the experimental findings of Bruno Rossi in cosmic ray showers. The problem of the 'soft' component was thus totally resolved.

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In a classic paper entitled 'On the penetrating component of cosmic radiation' communicated to the *Proceedings of the Royal Society* in July 1937, Bhabha made a careful analysis of the experimental data on the soft and penetrating components and concluded that a 'breakdown' of the quantum mechanical theory of radiation at higher energies as proposed by some theorists would not explain the experimental results on the latitude effect of cosmic rays and the shape of the transition curve of large cosmic ray bursts. He emphasised that these features would find a natural explanation if cosmic radiation contained charged particles of mass intermediate between electron and proton and set the mass as ~ 100 electron masses.

Around the same time, Neddermeyer and Anderson, and Street and Stevenson discovered in their cloud chamber experiments, charged particles of intermediate mass whose mass was set at ~ 200 electron masses. The name 'meson' was given to this new particle.

Bhabha predicted (in a paper in *Nature*, 1938) that the meson would be unstable and would probably decay into an electron and neutrino. The phenomenon of meson decay was helpful in resolving anomalous absorption of the penetrating component in the atmosphere. The relativistic elongation of time as predicted by the special theory of relativity was confirmed through meson decay experiments.

Bhabha and Cosmic Ray Research at the Indian Institute of Science, Bangalore

Bhabha came on a brief holiday to India in 1939. He could not go back to England as planned, since the second world war broke out in September 1939, and there was the prospect of heavy bombing over England by the Germans. Bhabha decided to stay back in India for a while. This decision turned out to be a turning point, a landmark not only in the academic career of Bhabha, but also in the advancement of Indian science and technology in the post independent era.

Bhabha joined the Physics Department of the Indian Institute of Science, headed by C V Raman. He got a special grant from the Sir Dorab Tata Trust. He gathered some students to work with him in theoretical particle physics and one of them was Harish-Chandra, who later held a professorial chair in mathematics at the Princeton Institute of Advanced Studies.

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In parallel, Bhabha also started experimental work in cosmic rays. He was cognisant of the unique advantages of India to work in this field – wide range of latitudes from equator in the south to 25° N in Kashmir within the boundaries of a single country; mountain stations in the south and north and the deepest mines in the world. Millikan had come all the way from the USA to do experiments at several stations in India in the mid 30's.

With a uniquely designed GM telescope, which Bhabha built with the help of S V C Iya, the penetrating particle intensities were measured at altitudes of 5000, 10,000, 15,000, 20,000, 25,000 and 30,000 ft, using a B-29 bomber aircraft belonging to the US Air Force. These constituted the first measurements at such high altitudes in an equatorial latitude. Comparison with the measurements of Schein, Jesse and Wollan in the USA, established that no marked increase of intensity occurred between 3.3°N and 52°N even at an altitude of 30,000ft., in contrast to the total intensity which exhibited very pronounced latitude effect at such altitudes.

At the Indian Institute of Science, Bhabha also got constructed a 12" diameter cloud chamber identical to the one operating in Manchester. R L Sengupta, who had worked in Blackett's Laboratory helped Bhabha in the design and construction of this chamber, which was used by M S Sinha to study the scattering characteristics of mesons. Vikram Sarabhai set up a telescope to study the time variation of cosmic ray intensity.

Bhabha and Cosmic Ray Research at the Tata Institute of Fundamental Research

While at the Indian Institute of Science, Bhabha recognised the need for setting up in the country an institute solely devoted to the pursuit of fundamental research especially in the area of nuclear science that was emerging as a virgin area of fundamental science. The developments in the field of cosmic ray studies and in the area of nuclear physics with accelerators had convinced Bhabha that the future lay in these areas. With financial support from the Sir Dorab Tata Trust and the Government of Maharashtra, Bhabha established the Tata Institute of Fundamental Research in Bombay in June 1945. The formal inauguration of TIFR was at IISc, Bangalore. The TIFR became an aided institution under the Department

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of Atomic Energy later and was recognised as the National Centre for Nuclear Science and Mathematics by the Government of India. Bhabha himself used to say that TIFR was the 'cradle of the Atomic Energy Programme' of the country. Bhabha was the Director of TIFR from 1945 to January 1966 – till his untimely death in a tragic air crash on the Alps.

The TIFR naturally started with a major experimental programme in cosmic rays, taking cognisance of the fact that cosmic ray research had entered its second phase the world over. The π-meson as the parent of the μ-meson was discovered in 1947 by Powell and his collaborators at the University of Bristol exposing the newly developed high sensitivity nuclear emulsions in the Jungfraujoch mountains in Switzerland. Rochester and Butler discovered the same year the V^0 particles, which were later identified as the K-mesons and hyperons through nuclear emulsion experiments by several groups. Bradt and Peters discovered around the same time the presence of α-particles and other stripped heavy nuclei in the primary cosmic radiation which consisted predominantly of protons. Also, most importantly, the act of meson production had been caught both in nuclear emulsions and in multiplate cloud chambers.

With these developments, the new directions of cosmic ray research had become clear. To enter the international arena in this field, the emphasis had to be on: (i) the investigations on the primary component – spectrum, composition, anisotropy of arrival directions; relative proportions of rare nuclei, electrons, γ-rays; (ii) the detailed study of the characteristics of nuclear collisions of the primaries as well as of the secondaries produced in these collisions; (iii) the studies on the penetrating components – muons and neutrinos in deep underground installations; (iv) studies on the extensive air showers initiated in the atmosphere through the nuclear and electromagnetic cascades by the primaries; (v) study of the radio isotopes produced by cosmic rays; (vi) time variation studies on cosmic ray intensity and correlations with solar activity (*Figure 2*).

These multidimensional studies to be carried out in a variety of locations with specially designed detector systems, required the inhouse development of a variety of technologies – to name a few – plastic balloon fabrication technology, fabrication of GM counters, plastic scinti-llators, multiplate cloud chambers, pulsed electronic circuits and even a digital computer. Thanks to the organisational genius of Bhabha, all this was done in a record time in TIFR itself. The Indian industry was very backward in the 40's and 50's and importing then was just not thinkable because of shortage of foreign exchange and the enormous delays of transportation. The cosmic ray programme did get a fillip in the 50's by Bernard Peters, the co-discoverer of heavy primaries and M G K Menon who worked for 8 years in Powell's Laboratory, joining the Nuclear Emulsion Group of TIFR.

Figure 2. Bhabha and A S Rao with a typical cosmic ray telescope – of the type that was being launched from the Central College grounds, Bangalore in the late forties, on clusters of rubber balloons.

At the International Conference on Cosmic Rays held at Bagneres in 1953, TIFR made its first impact by presenting very significant results on K-mesons and hyperons obtained from the analysis of emulsion stacks exposed at Hyderabad. The emulsion group kept a high profile of original contributions in the field of high energy interaction studies, the relative abundances of Li, Be and B in the primaries, hyperfragments and on the spectrum of primary electrons. The deep underground experiments in the Kolar Gold Fields initiated at the instance of Bhabha as early as 1950, and which continued for more than four decades, till 1994, was another line of activity in which pioneering contributions were made – most accurate μ-meson intensity and angular distribution measurements upto very high energies (*Figure 3*), detection of neutrino induced interactions with a visual detector, limits on the lifetime of protons etc. These involved very large scale installations and also international collaborations. Extensive air shower array with a variety of detectors for different components – scintillators, Cerenkov counters, total absorption spectrometer, multiplate cloud chamber started operating in the late 50's in

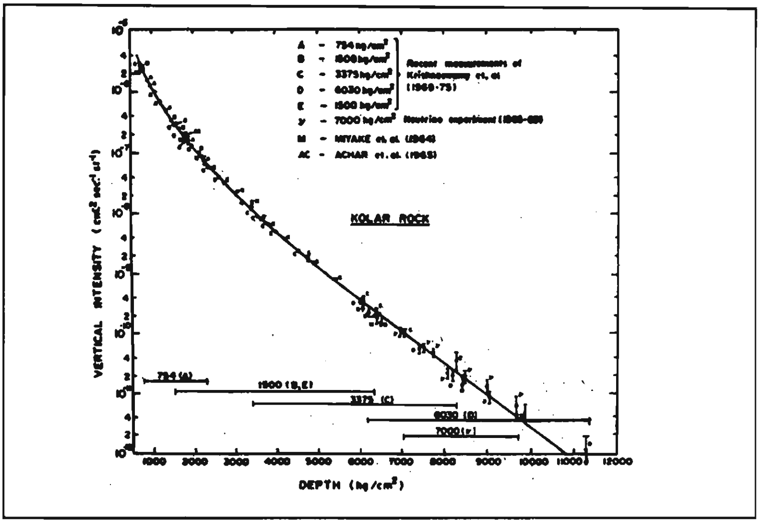

Figure 3. The variation of intensity of penetrating particles as a function of depth-based on a variety of experiments at the Kolar Gold Fields.

the mountain station at Ooty. The time structure measurements of hadrons with the total absorption spectrometer, led to the first recognition of increased cross section for the production of nucleons and antinucleons at high energies. Bhabha, when he visited the Ooty Laboratory in 1964, was thrilled to see the world's largest multiplate cloud chamber operating there. This cloud chamber gave unique information on the highest energy jets produced by the incidence of several parallel hadrons (*Figure 4*). At the Kolar Gold Fields, a second air shower array was set up at the surface of the mines with large area detectors at several depths underground that recorded the associated very high energy muons. This set-up gave very valuable information on the composition of the primaries in the crucial

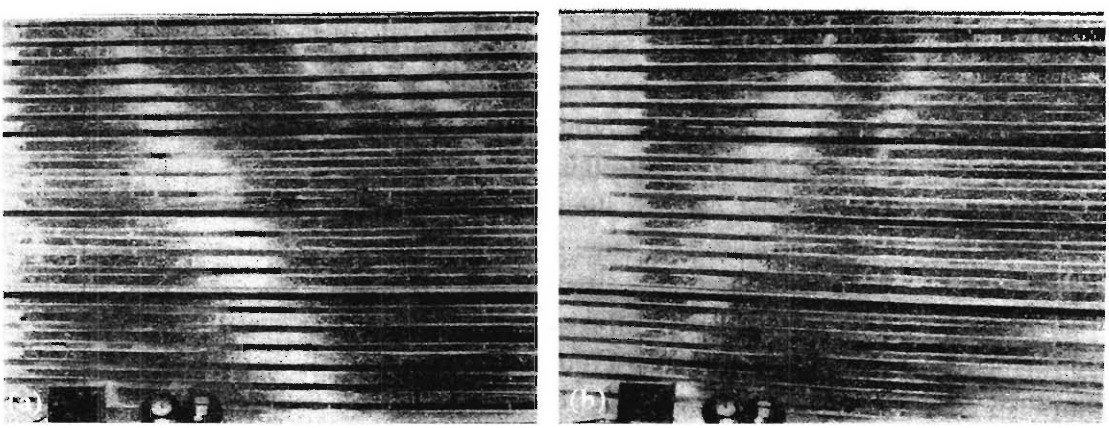

Figure 4. Development of cascade in a multiplate cloud chamber at Ooty. (a) A cascade having an elongated tube-like structure which is not completely absorbed even after 20 radiation lengths, the estimated energy is 2.4TeV. (b) A cascade which develops from the first plate of the chamber and shows a rapid absorption after the maxima. The method of cascade widths has been used for energy estimation which is 750GeV.

knee region 10^{14}–10^{16}ev.

In a short article like this it is difficult to do full justice and bring out the full flavour and ramification of all the work in cosmic rays that got initiated at the instance of Bhabha. Bhabha's was a multidimensional, many splendoured personality that influenced not only cosmic ray research, but many other fields too. But cosmic rays were very dear to him, all through his life, may be because his very first paper was on cosmic rays.

Even 86 years after the discovery of cosmic rays, 50 years after entering the second phase, despite colossal efforts by groups all over the world, not a single source of cosmic rays of high energy (> 20 Gev) has been identified even though it is firmly established that the spectrum extends beyond 10^{20}ev. The mechanism by which particles are accelerated to such high energies is also not known. The high rotating magnetic field environments of the neutron stars in pulsars in the galaxy and the extragalactic AGN (active galactic nuclei) with suspected giant blackholes in their centres are thought to be the strongest candidates. Gigantic multiplex installations are coming up to settle this question. What other exotic particles there are among the primaries and what new particles are produced in super high energy collisions are other aspects which are receiving special attention in the design of next generation cosmic ray experiments.

Suggested Reading

[1] **Bruno Rossi.** ***Cosmic Rays.*** **McGraw-Hill Book Company, 1964.**

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Homi J Bhabha in his address to the International Council of Scientific Unions on January 7, 1966.

An important question which we must consider is whether it is possible to transform the economy of a country to one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force ... the problem of establishing science as a live and vital force in society is an inseparable part of the problem of transforming an industrially underdeveloped to a developed country.