CHAPTER-I

INTRODUCTION

Studies on different aspects of cosmic rays in the atmosphere and above are of fundamental importance from the point of high energy nuclear physics and astrophysics. The different components of cosmic rays carry information regarding their sources, distributions and propagation in the interstellar medium. Cosmic rays are an alternative source of high energy particles atleast upto 5 x 10^{20} eV for the study of high energy nuclear physics, in the atmosphere.

The important parts of these studies include the energy spectrum, chemical composition, dependence of energy on charge composition and arrival directions and localisation. For the study of these upto energy of $\sim 10^{11}$ eV the main measuring techniques are based on the combination of various detectors and electronic systems, flown to the top of the atmosphere by satellites and baloons. Above 10^{14} eV the extensive air shower (EAS) development in the atmosphere is studied by similar but elaborate technique to extract some of the important informations.

1.1 Extensive air shower

A primary particle of cosmic rays at energy greater than 10^{13} eV undergoes nuclear collisons in the atmosphere and gives rise to cascades of secondary particles developing into a shower of particles of great extension. Such extensive development is very complicated and the shower parameters depend on high energy interaction characteristics as well as primary composition. During the collisions the primary particle loses a great fraction of its energy and produces many secondary particles mainly pions, kaons, strange particles, nucleon and antinucleon pairs. Most of the produced hadrons including the surviving primary particles interact further with atomic nuclei in the atmosphere and produce more hadrons. The neutral pions decay to produce high energy gamma-ray photons which develop into electron photon cascades while some charged pions decay to produce muons. Thus the number of particles in a shower increase, spreading out over a large area around the axis of the shower and attaining a maximum in number and then the number of particles decreases with atmospheric depth due to loss of energy through various interaction processes with atmospheric atoms.

Particles in an EAS are grouped into three main components : electromagnetic component, muon component and hadronic component. The first group of particles are mainly responsible for production of optical Cerenkov radiation, radio wave and isotropic fluorescence from atoms. A comprehensive account of details of EAS development has been given by Greisen(1). A brief discussion on EAS components is given below.

1.1.1 Electromagnetic component

The electron cascades in an air shower with almost 90% of particles fix the shower size (N_e). Because of multiple coloumb scattering the shower particles spread out laterally to hundreds of metres with the decrease of particle density from the shower axis (shower core).

The total number of electron in a shower (N_e) is obtained by measuring the electron densities at different points in the shower front and fitting these data to determine shower core and shower age. The total number of electrons (N_e) can be used to estimate the total energy of the primary particle. The relation between the average shower size and the primary energy is given by the relation

$$N_e \propto E_o^{\beta}$$

where E_o is the primary energy and β is a constant and β = 1.15 for $N_e < 5 \times 10^5$ (De Beer et al$^{(2)}$). Thus the shower size spectrum represents the primary spectrum.

1.1.2 Muon component

Muons in an EAS carry various information regarding the primaries. Very few of them decay in flight and their interaction cross section with matter is very small. Muons constitute $\sim$10% of the total number of particles in EAS and spread out to wider area than the electron component. The size of an air shower depends strongly on the total energy of the primary, while the total number of muons fixes the energy per nucleon and the composition of the primary.

The longitudinal development of nuclear cascades in air showers has been studied using the muon component. The muons of different energies in EAS have been studied using magnetic spectrographs associated with air shower array by the Durhum group(3,4), the Kiel group(5), the Moscow group(6). The maximum energy of muons studied is arround 500 GeV. Lateral distribution of muons with various threshold energies have been studied by several groups. It was shown that the average number of muons (N_μ) per shower could be represented by a relation of the form $N_\mu \propto N_e^\alpha$, where α varries from 0.5 to 0.8.

1.1.3 Hadron component

Hadrons in EAS are few relative to other particles, but carry substantial amount of energy of the primary particle.

As hadrons undergo strong interactions, their energy degrades fast. So, the lateral distribution of hadronic component is very steep. It is very difficult to find the lateral distribution of hadrons since the high energy electromagnetic component is very near the shower core, and most of the hadrons are confined within few metres of the shower core. A mountain altitude is a suitable site for the study of hadrons in EAS.

A study of high energy hadrons includes the lateral density distribution, variation of their number with the shower size, the energy spectrum of charged hadrons and charged-to-neutral hadrons. The studies(7-14) done already are numerous, but the reliability of high energy hadron data from these experiments is restricted due to errors in energy estimation.

1.1.4 Cerenkov light

Galbraith and Jelley(15) are the first to detect Cerenkov light flashes in night sky in air showers. Electrons and positrons above a certain energy (depending on the refractive index of the medium) radiate Cerenkov photons during the propagation of the shower in the atmosphere. These photons (mainly in the visible region) cross the atmosphere with very little absorption in a clear sky. The Cerenkov light is linearly polarised and spread over a large area (about 300 m from the core). So, the Cerenkov detectors are spread over large area in an EAS array to trace the longitudinal development of the shower, which in turn is directly related to the primary mass number and high energy interaction characteristics. Moreover, the total number of Cerenkov photons in the shower, is proportional to electron and positron tracklength integral and hence gives a good estimate of primary energy. The lateral structure of Cerenkov photons is shown to be independent of primary mass and high energy interaction models (16-18). The experiments of Cerenkov light is very difficult since the measurements are to be carried out only during moonless clear night. It is also essential to carry out observations in almost identical atmosphere, otherwise the absorption and scattering in the atmosphere need to be considered.

1.1.5 Other components

During the development of the shower the macroscopic displacement of electric charge mainly due to geomagnetic deflections, creates electric dipole moments which give rise to radio waves. Radio waves at 60 MHz were detected in large EAS first by Jelly and his collaborators (19) in 1965. Radio waves from EAS have been studied by several groups to enlighten on the longitudinal development of the shower and the composition of the primary. Lateral distribution of field strength was obtained in the range 30-300 m from the shower core while the frequency spectra covered 0.1 MHz to 100 MHz measured by several groups (20-22). The study of radio waves in EAS is very difficult since the radio waves from geo-electric field (dominant during thunderstorms) cause serious problems. So, the detection of radio waves in air showers for the EAS studies so far done only by radio waves technique was not useful. This technique is useful if the data can be collected only during fair weather conditions and electrically undisturbed periods.

In an EAS from very high energy ($>10^{18}$ eV) primary particles, fluorescent light is produced due to excitation and subsequent deexcitation of molecules (mainly nitrogen). The emitted radiation is very isotropic in nature at the wavelength range 300-430 nanometre and spreads over a very large area (a few hundred sq. km). The longitudinal development of EAS and the primary energy spectrum could be studied in great detail by this method but the observation is restricted to long time. Cassiday and his coworkers(23) have developed a detection system called 'Fly's Eye' for the study of atmospheric scintillation light and the preliminary results are now available.

1.2 Simulation studies of EAS

Development of EAS through the atmosphere can be simulated in both longitudinal and lateral dimensions in detail with Monte Carlo simulation technique. Such simulations of air showers in atmosphere using Monte Carlo method have been carried out by several authors(24-38). Most of the EAS parameters are generally dependent upon the characteristics of particle interactions and primary composition. Thus various assumptions about the interaction models and primary composition have been made in these simulations for the interpretation of the experimental data. At accelerator energies, it is seen that the particle production characteristics follow Scaling behaviour(39-41). However some of the EAS data have been interpreted so as to indicate the violation of Scaling behaviour of particle interactions in the fragmentation region where EAS energies are greater than 10^{14} eV(42-45). Ouldridge and Hillas(46) and Linsley and Watson(47) argued that the Scaling behaviour remains valid at these energies provided the primary composition is mixed and the hadron-air inelastic cross section increases rapidly with energy.

Not a single model of high energy interactions has been emerged so far, which explains all the observed features of EAS. Two main approaches have been followed in interpreting the air shower data. In one approach, it is assumed that the Scaling continues to hold good upto highest energies and attempts have been made to interpret the experimental data in terms of iron group of nuclei in the primary. In the other approach, it is assumed that the primary composition is independent of primary energy to interpret the experimental data in terms of deviation from Scaling behaviour.

1.3 Present work

A new array covering 1200 m^2 for EAS measurements has been installed near sea level at North Bengal University Campus in the year 1979. The array is now operated with 21 plastic scintillators as electron density detectors in conjunction with two shielded muon magnetic spectrographs and a Neon flash-tube (NFT) chamber as muon detectors. The control electronics for the EAS measurements have been designed and fabricated by the author and his coworkers for a study of muons in EAS. A brief description of studies of electrons and muons in EAS by other groups has been given in the chapter II. The description of the present experimental set up with electronics and operation and maintenance technique has been presented in the chapter III. In the chapter IV the method of data analysis for the estimation of various parameters of air showers and the momentum measurement from muon trajectory in the magnetic spectrographs is described. The estimation of errors of these measurements is also discussed. The experimental results, with possible errors, on electrons and muons in EAS in the size range 10^4 to 10^6 particles are presented in the chapter V of the thesis.

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