CHAPTER II

COSMIC RAYS

2:1 PRIMARY COSMIC RAYS

In the early years, some physicists had indentified the penetrating particles observed near sea level with primary cosmic rays. These penetrating particles were known to be mesons (that is π-mesons and μ-mesons), protons, electrons, photons and other nucleons (neutrons and heavier nuclei). Since the primary cosmic rays are high energy particles which approach the earth from the outer space, the particles have to be stable. Mesons do not live more than a few microseconds, and neutrons not more than 20 minutes. The mesons (π-and μ-mesons), and the neutrons, therefore, could not be part of the primary cosmic rays.

In 1940, experimental studies of the effect of the earth's magnetic field on the incident radiation had shown that most, and possibly all, primary cosmic rays are positively charged particles. This was proved by several experimental investigations. In the early 1940s, Marcel Schein and his group, at the University of Chicago (18) undertook a series of balloon experiments (up to altitudes of about 70,000 feet, where the pressure is about one-thirtieth of an atmosphere). The results convinced them that primary cosmic rays were not electrons, but were probably protons. In 1948, two strong cosmic ray groups were established by Edward P. Ney and by Hans L. Bradt and Bernard Peters, respectively(18). The two groups working in collaboration, sent a sounding balloon, carrying nuclear emulsion plates, up to an altitude of 40,000 feet. The result supported the previous experiments.

Therefore, primary cosmic rays are mostly protons and to a lesser extent, bare nuclei of heavier elements. The relative abundance of the various nuclei is given in table 2.1 (19).

Table 2.1 Composition of primary cosmic radiations.

nuclei	Z	Relative number
Hydrogen (p)	1	100,000
Helium (α)	2	6,770
Light nuclei	3 to 5	146
Medium nuclei	6 to 9	430
Heavy nuclei	10	246

The total gives the number of different nuclei per 100,000 protons in the primary radiation. The table lists only primary particles with energy greater than 2.5 Gev.

In the experiments performed by Edward Ney and by Hans Bradt and Bernard Peter respectively(18) in 1948 a number of very dense tracks were found most of which passed through the entire pile of emulsion plates. From the grain density it was possible to estimate the rate of energy loss along the path and therefore the total energy spent by the particles in traversing the plates. The conclusion was that the particles had energies of at least many Gev.

The energy of primary cosmic rays is distributed over a broad spectrum extending to unbelievably large values as shown in Fig. 2.1 (20) Energies of between 10^9 and 10^{11} ev were obtained from balloon measurements of the geomagnetic latitude effect. Observations with nuclear emulsions exposed at balloon altitudes have provided some data in the energy region between 10^{11} and 10^{13} ev (the particle energy being estimated from the characteristics of their nuclear interactions). All data beyond 10^{15} ev come from experiments on air showers. The energy spectrum of primary cosmic rays varies from about 1 Gev (10^9 ev) to about ten billion Gev (10^{19} ev). Actually, the largest energy recorded, as of August, 1962, was 6×10^{19} ev (20).

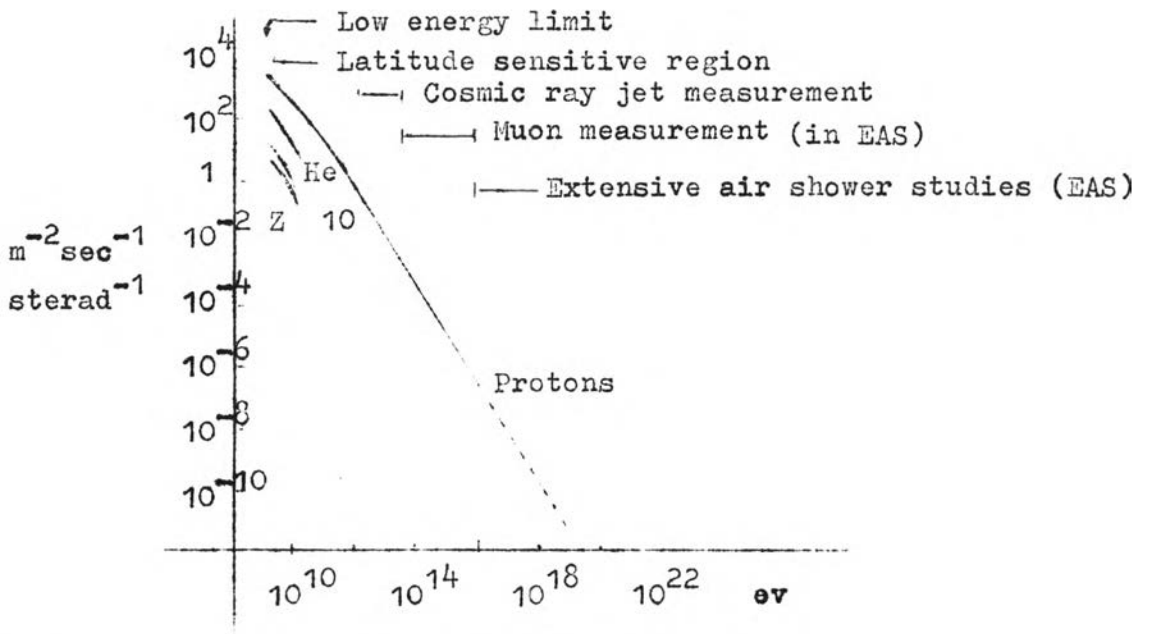

Fig. 2.1 Integral energy spectra of primary cosmic rays.

2:2 SECONDARY COSMIC RAYS

Secondary cosmic radiation is the radiation produced by nuclear reactions between the primary rays and nuclei in the atmosphere. These secondary cosmic rays consist of three separate components: the meson component, consisting of muons, the nucleonic component, comprising protons and neutrons, and the soft component, consisting of electrons and γ-quanta. Fig. 2.2 illustrates in a schematic way the generation of the secondary components.

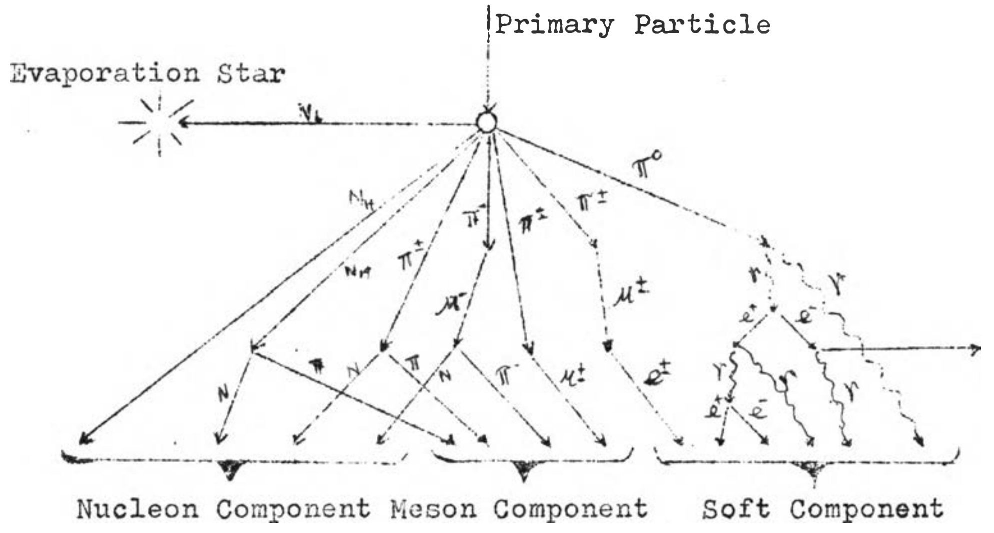

Fig. 2.2 The Nuclear Reactions of Cosmic Rays.

The various processes begin with a few primary particles of **high** energy colliding with the nuclei in the air which gives birth to a large **number** of secondary particles of lower energies. Owing to the very high energy of the primary particle, most of the secondaries are propagated in a forward direction.

The disintegration particles (secondary particles) consist of a mesonic component and a nucleonic component. These particles may come from the p-p interaction (21) as follows:

$$p + p \longrightarrow K^+ + K^+ + p + p \,,$$

$$\text{or} \longrightarrow \Xi^- + K^0 + K^0 + 2\pi^+ + p \,.$$

Most of these disintegration particles are unstable, short life, particles. For exsample, K^+, positive K-meson, can decay into several modes with a mean life time of 1.22×10^{-8} second. The decay modes of K-meson are as follows:

$K^+ \longrightarrow \mu^+ + \nu_\mu$	59 %,
$\longrightarrow \mu^+ + \nu_\mu + \pi^0$	4 %,
$\longrightarrow e^+ + \nu_e + \pi^0$	2 %,
$\longrightarrow \pi^+ + \pi^0$	27 %,
$\longrightarrow \pi^+ + \pi^+ + \pi^-$	6 %,
$\longrightarrow \pi^+ + \pi^0 + \pi^0$	2 %.

K^0, neutral K-meson, has a mean life time of 6×10^{-8} second. The decay modes are as follows:

$K^0 \longrightarrow \pi^+ + \pi^-$	40 %,
$\longrightarrow \pi^0 + \pi^0$	10 %,
and $K^0 \longrightarrow \mu^+ + \nu_\mu + \pi^-$	,
$\longrightarrow \mu^- + \bar{\nu}_\mu + \pi^+$	,
$\longrightarrow e^+ + \nu_e + \pi^-$	,
$\longrightarrow e^- + \bar{\nu}_e + \pi^+$	,
$\longrightarrow \pi^+ + \pi^- + \pi^0$	,
$\longrightarrow \pi^0 + \pi^0 + \pi^0$	.

Ξ^-, negative Ξ hyperon, has a mean life time of 1.3 X 10^{-10} second. The decay mode is as follows

$$\Xi^- \dashrightarrow \bar{\Lambda} + \pi^- \quad ,$$

and $\quad \bar{\Lambda} \dashrightarrow P + \pi^-$ with a mean life time of 2.2 X 10^{-10} second.

All these new generations are unstable particles. The pion (π - meson) with positive or negative charge whose mean life time is 2.55 X 10^{-8} second, decays into a muon (μ-meson) and neutrino as follows:

$$\pi^+ \dashrightarrow \mu^+ + \nu_\mu \quad ,$$
$$\pi^- \dashrightarrow \mu^- + \bar{\nu}_\mu \quad .$$

The neutral pion, which is assumed to exist in an intermediate state between the penetrating and soft components of the secondary rays, with a mean life time of 2 X 10^{-16} second, has several modes of decay. The two most probable decay processes proposed for theoretical reasons (Heisenberg 1953) are:

$$\pi^0 \dashrightarrow \gamma + \gamma \quad ,$$
$$\pi^0 \dashrightarrow e^+ + e^- + \gamma \quad .$$

The first type of decay is about 100 times more probable than the second one.

The γ-quanta play an important role in the production of the electrons of the soft component by the pair production process:

$$\gamma \dashrightarrow e^+ + e^- \quad .$$

Muons, $\mu^{\pm}$, positive or negative mu-mesons, whose mean life time is 2.212 X 10^{-6} second, have two decay modes.

$$\mu^+ \text{----} \; e^+ + \nu_e + \bar{\nu}_\mu \quad ,$$
$$\mu^- \text{----} \; e^- + \bar{\nu}_e + \nu_\mu \quad .$$

The positrons from the positive muons will disappear through annihilation processes with the emission of γ-quanta.

Most of the nucleonic component of the disintegration particles are protons and neutrons. The proton will lose its energy rapidly by ionizing the atmospheric air. But the neutron will be absorbed by N^{14} if its energy is in the kiloelectron-volts range. The process is as follows:

$$N^{14} + n \dashrightarrow C^{14} + p.$$

The neutron also decays into a proton, an electron and an anti-neutrino with a mean lifetime of 770 seconds as shown in the following equation,

$$n \dashrightarrow p + e^{-} + \bar{\nu} \quad .$$

Then it can be concluded that the cosmic ray particles near sea level contain the following kinds of particles;

a. Charged particles: mesons, protons and electrons.

b. Nonionizing particles: neutrons, photons and neutrinos.

2:3 COSMIC RAY INTENSITY VARIATION

Several types of cosmic ray intensity-time variations have been observed, e.g. diurnal variation, seasonal variation, Forbush decrease and 27 days sun rotation period variation. The variations are effected by the temperature and pressure of the atmosphere around the earth and the variation of the primary cosmic rays. These variation effects are now listed.

1. The variation of terrestial origin, which occurs in interplanetary space, due to superimposed cosmic rays or the result of modulation process, effects only a part of the radiation.

2. The variation of cutoff rigidity with locality produces a series of geomagnetic effects. These effects are recognized as the latitude effect, the longitude effect, the zenith angle effect, and the azimuth effects.

3. The variation due to solar flares, which can be said to be a radiation superimposed upon the quiescent cosmic rays. Thus it differs in character from other kinds of intensity-time variation which have the character of being due to the modulation effects.

4. Periodic variation of the cosmic radiation due to the sun spot cycle, the cosmic radiation will decrease when the sunspots increase (16).

5. A common non-periodic intensity variation is Forbush decrease. This event cosnists of a more or less sudden drop of the intensity closely associated with geomagnetic disturbances. It displays a certain recurrence tendency with the 27 day sun rotation period.

6. If the observation is made at sea level, most cosmic ray intensity variations are due to atmospheric effects. They are the temperature effect and barometric effect.

2:4 ATMOSPHERIC EFFECTS

It follows from the discussion in section 2:2 that the disappearance and reproduction of secondary cosmic rays is a function of the temperature distribution in the atmosphere and the mass of the atmosphere, or atmospheric pressure. Consequently atmospheric effects give rise to part of the variations in the ground level cosmic ray intensity. Here we shall see how the atmosphere effects the neutron counting rate.

2:4:1 TEMPERATURE EFFECT

The change of neutron counting rate as a function of room temperature was studied at Climax, U.S.A., by J.A. Simpson in 1953 (11). The result gave a temperature coefficient of only 0.000 ± 0.04 per cent / ^{o}C. The pile interior did not vary more than 5^{o}C, because of its large heat capacity. Hence the average temperature of the thermal neutron within the pile remained essentially constant. Therefore the temperature effect is neglegible.

2:4:2 Barometric effect

The local neutron production rate in a pile at a given geomagnetic latitude and atmospheric depth is a function of the mass of air X above the pile, which can be determined from a measurement of the local atmospheric pressure. Although the pile is an omnidirectional detector, the incident nucleonic component is peaked around the vertical direction, for large X.

The neutron counting rate, which varies directly with the production rate, according to the equation depends upon the atmospheric pressure

$$N_o = N \exp(\alpha \cdot \Delta p)$$

where N_o = pressure corrected counting rate,

N = uncorrected counting rate,

α = pressure coefficient,

$\Delta p = p_t - p_o$,

p_t = pressure reading at the station,

p_o = standard pressure.

2:5 FORBUSH DECREASE

The Forbush decrease is a non-periodic intensity drop; it consists of a more or less steep slope in the cosmic ray intensity- time curve. Such decreases were observed for the first time by Forbush in 1937, and latter several workers in the field were able to prove them to be worldwide, appearing simultaneously at all latitudes and longitudes. They are closely associated with geomagnetic disturbances, and display a certain recurrence tendency with the 27 days sun rotation period.

Some typical intensity variations of this kind are illustrated by the histograms in Fig. 2.3 (22). The decrease starts gradually but the gradient increases with time. Sometimes the slope ends abruptly. In other cases it displays a region with a less pronounced gradient before the intensity approaches a minimum. Magnitudes of the decrease of 15 to 20 per cent of the total intensity have been recorded. The recovery following upon the minimum can be comparatively rapid, but generally it is slow and extends over many days.

Very often decreases display a structure in the downward slope (Fig. 2.3). In some cases it can be shown that the structure is due to two or more decreases following closely one upon another. It happens also that small Forbush decreases appear during the recovery stage. Very often the latter is distinguished also by other kinds of big intensity fluctuations. Such a complicated structure leads to the conception of cosmic ray storms. The term has been employed indiscriminately as an appellation for Forbush decreases as well as for sets of decreases on other worldwide intensity variations constituting an extended period of disturbances.

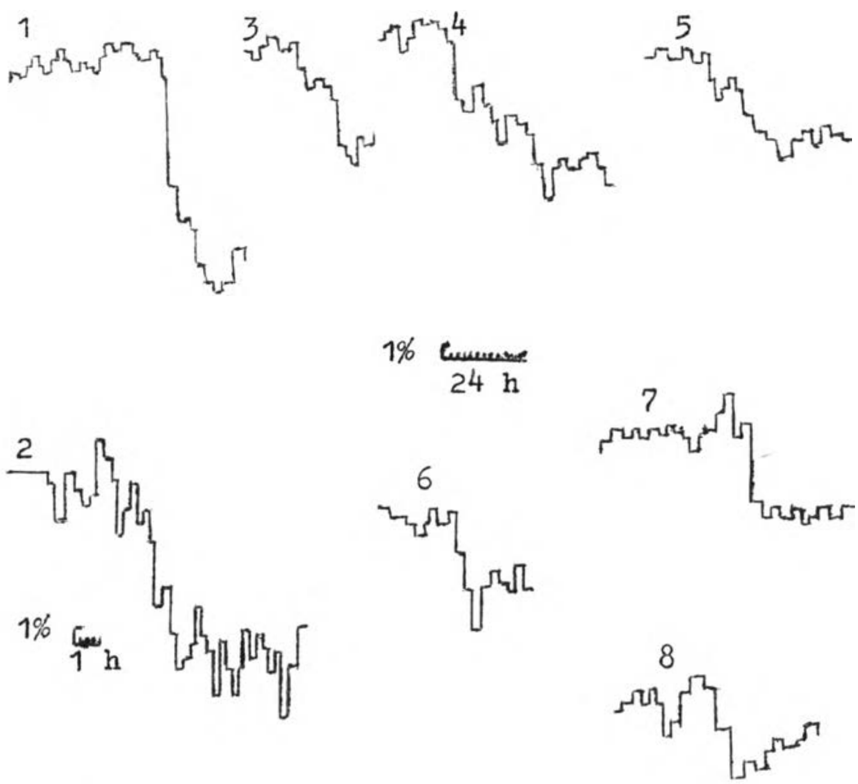

Fig. 2.3 Some types of Forbush decreases.