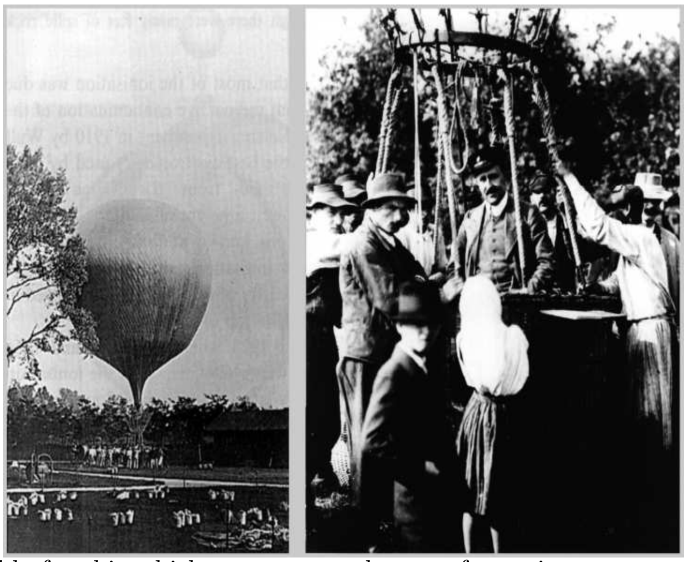
Chapter 7

Cosmic Rays

7.1 Introduction



In August 1912, Austrian physicist Victor Hess made a historic **balloon flight experiment** that opened a new window on matter in the universe. What he discovered is that there has been some reading of current in circuit. Earlier people thought that the reason for this is the **earth's radioactivity**. As there are radioactive materials present in core so the particle emitted from there must have ionised the atmospheric molecules and hence there has been a current. But the same balloon experiment at different heights ie at different altitudes have shown different readings. In fact they have found that at higher altitudes the current reading is more which is contrary to the fact that it should go down since the ionisation radiation from the earth's core should decrease as there are collisions with atmospheric molecules which will result in losing kinetic energy and also there will absorption present in the medium. So people thought that earth is not the origin.
So they looked up and thought that **sun** may be responsible for this which turns out to be true for various reasons that the sun is emitting all possible radiations. But then during night time when the sun is not in the sky over a particular place the reading should go to zero. But to their surprise the reading continues to be exsisting. This then leads to the conclusion that sun is not the only culprits for this, rather there are more things to analysed and explored.
Q. So, what are the cosmic rays?
Ans. Cosmic rays are energetic, subatomic particles that arrive from outside the Earth's atmosphere. The lowest energy cosmic rays are produced by ordinary stars like the Sun. They blaze at the speed of light and have been blamed for electronics problems in satellites and other machinery.

7.1.1 Origin of Cosmic rays

It is argued that there are three 'origins' of cosmic rays; **The origin of the particles**, **the origin of the energy** and **the site of the acceleration**. The particles of Galactic origin where the energy comes mainly (but not exclusively) from supernova explosions, the site of the acceleration is at strong collisionless shock waves, and the accelerated particles come from the interstellar and circumstellar material swept over by these shocks. If these shocks are capable as indicated by recent observations and theoretical work of significantly amplifying magnetic fields this picture appears capable of explaining the cosmic ray particles at all energies below 3×10^{18} eV. The particles above this energy are generally taken to be of extra-galactic origin.
However recently proposed origin of cosmic rays can be explained as arising from three sources
• Supernova explosions into the interstellar medium
• Supernova explosions into a predecessor stellar wind
• The hot spots of giant powerful radiogalaxies
The origins makes specific and quantitative predictions as to the origin of the energies of the particles, to the spectrum, and to the chemical composition.

7.1.2 Classification of Cosmic rays

Cosmic rays can be divided into two types. **Primary cosmic rays** and **Secondary cosmic rays**.
• **Primary cosmic rays:** Primary Cosmic Rays are stable charged particles that have been accelerated to enormous

energies by astrophysical sources somewhere in our universe. They must be stable (lifetimes greater than a million years), in order to survive the long trips through interstellar (or intergalactic) space. They are charged because the accelerating mechanism is probably electromagnetic and because their charge is what interacts with matter and produces the effects that we can easily see here on earth.
The most common primary cosmic ray particle is mainly proton or hydrogen nucleus. **95%** of all cosmic rays are **protons**, **4%** are **helium nuclei**, and the **1%** balance is made up of **nuclei from other stellar-synthesized elements up to iron.**
Primary cosmic rays come from a variety of sources. For example, they might come from solar flares or from explosions on the Sun. The particles emitted from the sun are often referred to as solar energetic particles. Particles can also come from stellar explosions such as novas and supernovas, which are mostly from within our galaxy. Moreover, Neutron stars, Pulsars, Active Galactic Nuclei (AGN), Quasars, and the Big Bang itself, all have also been implicated.

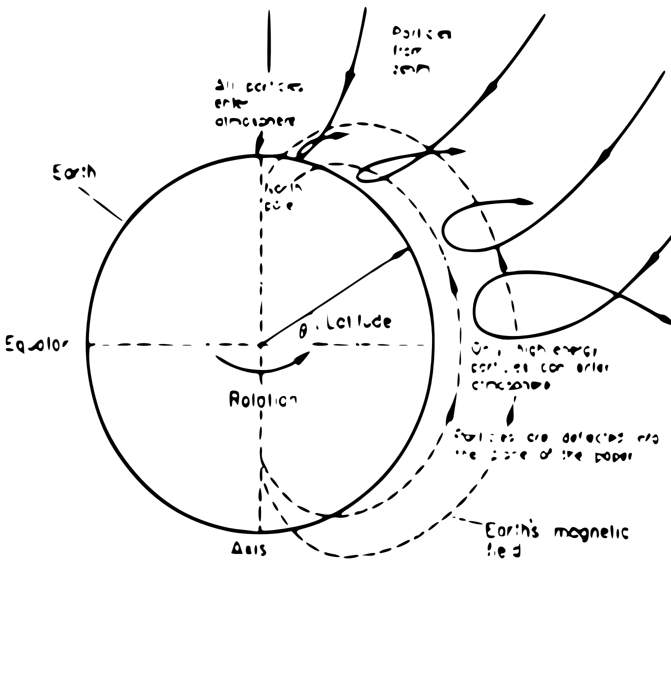
• **Secondary cosmic rays:** When primary cosmic rays enter the Earth's atmosphere they collide with atoms and molecules, mainly oxygen and nitrogen. This shatters the nuclei of the gases into smaller pieces, the process is called spallation and thereby produces a cascade of lighter particles which travel down through the earth's atmosphere towards the earth's surface. These cascade of lighter particles are called secondary cosmic rays. Secondary cosmic rays consist of gamma rays and a large variety of elementary particles, including mesons, protons, neutrons, electrons, and positrons. Many of the secondary cosmic ray particles initially produced go on to split more nuclei and decay into more particles. This means that the number of particles increases rapidly as the shower of particles moves downward through the atmosphere. But with each interaction, the particles lose energy. Eventually, they are not able to create new particles. This means that only a small fraction of secondary cosmic ray particles reach the Earth's surface.

7.2 Other Studies of Cosmic Rays

Studies of cosmic rays have been made with a variety of detection devices. The earliest studies were made with electroscopes; later such instruments as cloud chambers and Geiger-Mller counters were used. Today, instruments called scintillation counters are commonly used. A scintillation counter contains a fluorescent material that produces a flash of light when struck by radiation such as cosmic rays. An electronic device called a photomultiplier tube converts the flash of light into an electrical signal that is recorded by the counter. With an array of scintillation counters, the direction and energy of the radiation in terms of intensity can be determined which can be of course placed at various places (ie changing the latitude & longitude), at various heights over a place (at different altitudes) and placing in different directions (either towards east or west but never along north-south because of earth's magnetic field). Based upon these studies scientists have seen different responses of the cosmic rays. Following are the effects what have been observed.

7.2.1 Latitude Effect

The experiments to study the variation of cosmic ray intensity (I) with geomagnetic latitude (θ) showed that the intensity is maximum at the poles ($\theta = 90^o$), minimum at the equator ($\theta = 0$) and constant between latitudes of 42^o and 90^o. The variation of cosmic ray intensity with geomagnetic latitude is known as latitude effect and is shown in Fig. The decrease in cosmic ray intensity at the earth's equator is explained by the magnetic Lorentz force given by $F_B = q\,(\vec{v} \times \vec{B})$ since there is an earth's magnetic field. The charged particles approaching the earth near the poles doesn't feel any deflecting force since the angle between $\vec{v}$ and $\vec{B}$ is either zero or close to zero. So such cosmic ray partcles travel almost along the direction of the magnetic lines of force and easily reach the surface of the earth and hence maximum intensity at poles. But the charged particles that approach at the equator have to travel in a perpendicular direction to the field and are deflected away as they experience maximum deflecting force since the angle between $\vec{v}$ and $\vec{B}$ is 90^o. Only particles with sufficient energy can reach the equator, while the slow particles are deflected back into cosmos and hence minimum intensity at the equator.

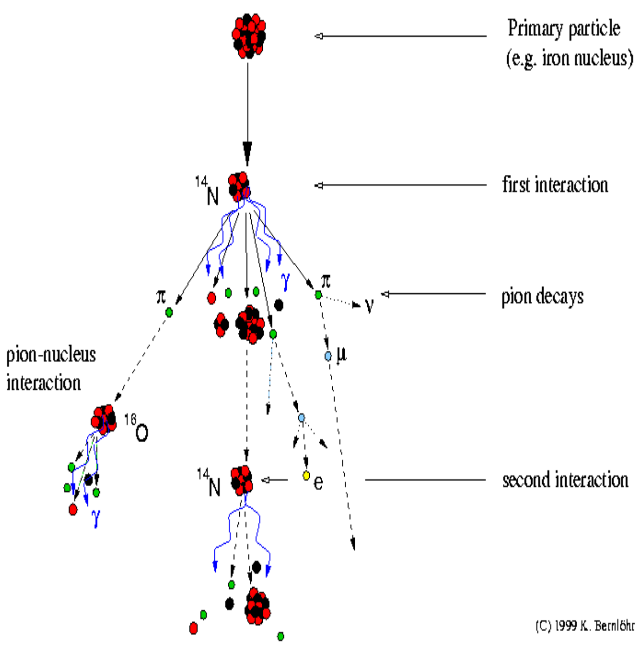


7.2.2 Longitude Effect

What people have observed in different voyages to study the latitude effect is that at different longitudes there has been a different intensity recorded for the cosmic rays. In fact the intensity is greater in the eastern than in the western hemisphere by an amount 5%. This was interpreted as saying that the earth's magnetic field in not symmetrical along the vertical axis connecting north and south poles. As the earth rotates along the vertical axis the flux lines passing from south to north gets distorted and because of which the possible symmetry is lost which have resulted in such observation.

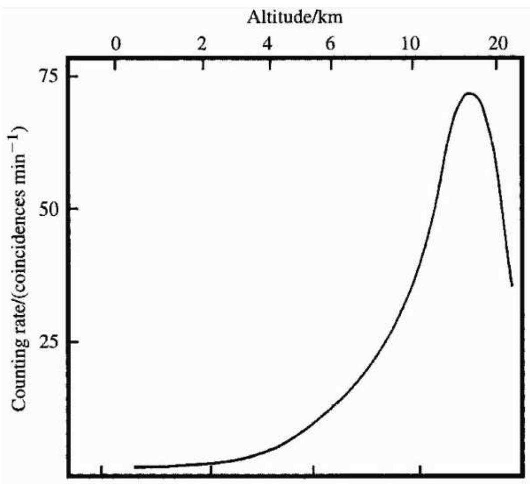
7.2.3 Extensive Air Shower: EAS

When a primary cosmic ray will collide (interact) with a nucleus of the air, such collisions results in the formation of many new particles and the colliding nuclei evaporate to a large extent and thereby producing many secondary particles, we call this an air shower. When many thousand (sometimes millions or even billions) of particles arrive at ground level, perhaps on a mountain, this is called an extensive air shower (EAS). The number of particles starts to increase rapidly as this shower or cascade of particles moves downwards in the atmosphere. On their way and in each interaction the particles loose energy, however, and eventually will not be able to create new particles. After some point, the shower maximum, more particles are stopped than created and the number of shower particles declines. Only a small fraction of the particles usually comes down to the ground. Most of the new particles are π-mesons (pions). Neutral pions very quickly decay, usually into two γ-rays. The γ-rays from the neutral pions may also create new particles, an electron and a positron, by the pair-creation process. Charged pions also decay but after a longer time. Therefore, some of the pions may collide with yet another nucleus of the air before decaying, which would be into a muon and a neutrino. The fragments of the incoming nucleus also interact again, also producing new particles.



7.2.4 Altitude Effect

The study of variation of cosmic ray intensity (I) with altitude (h) is known as altitude effect. It is seen that I the intensity increases with altitude and reaches a maximum at a height of about 15 km. Above this height there is a fall in intensity. The experimental results are similar at different places of the earth. It was explained that the detection method used was mainly detecting secondary particles rather than the primary particles reaching the Earth from space. The particle populations which has variation in terms of numbers in the shower, as one goes up in height the abundance of cosmic rays keep on increasing and once the production sites for secondary cosmic rays is crossed one encounters the primary cosmic rays which is very less in number compared to secondaries.



7.2.5 East-West Asymetry or Azimuth Effect

Due to the fact that the magnetic field of the earth deflects the cosmic ray particles, although some of then are still able to reach the earth , while others do not. Particles approaching the earth say in a vertical direction, if positively charged will be pushed according to Flemings' left hand rule towrads the east so that they will appear to come in a direction inclined to the west. Exactly opposite will happen to a particle which is negatively charged. Thus if somebody carrying out an experiment to detect +vely charged particle he has to face his detector towards the west and for -vely charged particle towards the east. This is called east-west asymetry.