

ELEMENTARY PARTICLES PHYSICS

THE THEORETICAL INTERPRETATION OF SOME COSMIC
RAYS REACHING THE SEA-LEVEL AND THE MESON
THEORY*

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Abstract. In keeping with the current interest in studies of the cosmic rays, this paper give, among other things, a picture of the characteristics of cosmic radiation. Firstly, I calculated the inclined intensities of the hard, the soft and the total components of the sea - level cosmic rays, with: $I(\theta) = I_0 \cos^2 \theta$, at an angle $\theta < 80^\circ$ to the vertical direction, and I neglected the muon decay ($E_\mu > 100 / \cos \theta$ (GeV)). Secondly, various properties of the cosmic rays are reviewed, and, I calculated the angular distribution of some mesons as function of the various muons energy, in view of the fact the contribution of the π and the charged K - meson.

Finally, in the summary I concluded that, the hard component of meson at sea – level is about 72.81 per cent of the total component of secondaries cosmic rays at sea – level.

Key words: cosmic rays, fast nucleons, angular distributions of mesons.

1. INTRODUCTION

The cosmic rays were discovered as a result of a large number of investigations of the conductivity of gases. In the 1912 year, Hess discovered that the air ionization increases with increasing height altitudes in comparison with the sea-level. Most of the cosmic rays, both primary and secondary particles must be due to an extra-terrestrial origin radiation. Hess (1926) concluded that the increase of the ionization with height must be due to cosmic rays coming from outside space. The studies of the cosmic rays performed by researchers as: C.T.R. Wilson, Ester, Geitel, Hess, Bothe and Kolhorster, Compton, Johnson and Street, Anderson, Blackett and Occhialini and will be continue interpreted all the time by many other workers.

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In keeping with the current interest in studies of the cosmic rays, this study provides a rich array of material of exploring both the discovery of the cosmic radiation and how the primaries and the secondary particles are able to reach sea – level.

The primary cosmic rays (as electrons, protons, neutrons, and nuclei such as Helium, Carbon, Oxygen, Iron) interacts with the interstellar gas and appear the secondary particles as: muons, pions, kaons, antiprotons, positrons, and nuclei as Lithium, Beryllium, Boron. Most of the primaries in the upper atmosphere are protons; the baryons with momenta to rise above 1 GeV/c are fast protons.

At sea-level are reaching most the leptons, (mainly the muons with mass, $m_{\mu} \cong 0.106 \text{ GeV}/c^2$, mean life time, $\tau \cong 2.19 \times 10^{-6} \text{ s}$; and $J = 1/2$). The cosmic rays reaching near the sea-level contains the charged particles (e^{\pm} , positive and negative mesons and protons), non-ionizing agencies (photons and neutrons), and the neutrinos.

Only the cosmic rays with the energy exceeding 1GeV interacts with the atomic nuclei by the terrestrial atmosphere, to give raise both the fast and the slow secondary particles in extensive air showers. It is seen that the velocity of particle of charge $Z e$ in air is by $v = 0.96c$. The masses and life time of elementary particles is a question of fundamental interest.

The properties of a body depend on the system of reference in which they are measured. Many measurements are made with respect to the earth (or in the laboratory system, L-system) and in the centre of mass system (C-system)⁽¹⁾. One of the purpose of present work is to determine the connexion between the calculated inclined intensity of muons at sea-level and the observed vertical intensity of muons at sea-level.

2. MESON THEORY

The nucleons are sources of a meson field, similar to the electromagnetic field. Primary particles in high-energy collisions emit in the first instance pions. The pion is an unstable particle, it decays emitting the muon. The pion is believed to be one of the particles responsible for nuclear forces. The pion unlike the muon shows a strong interaction with nucleons.

$e_{\pi} = 115 \text{ GeV}$ is the critic energy of pions. For pion of energy 115 GeV, the rates of loss due to ionization and due to radiation are about equal. Below the numeric value of critic energy the loss due to ionization becomes predominant than that due to radiation.

The muon decay at the end of their range into at least three products: an electron and two neutrinos. Although the muon have all the properties predicted by Yukawa, investigations of these mesons show that the plausible assumption is that the pion is Yukawa's particle. The majority fast particles from cosmic radiation induced nuclear interactions and electromagnetic interactions (the ionization processes).

The electromagnetic force acts between all charged particles and between gamma rays and charged particles, the nuclear force acts strongly between a nucleon and a baryon or hyperon [1].

3. ANALYSIS OF THE FAST NUCLEONS OF COSMIC RAYS

To describe the spectra of the hadron component of the cosmic rays I assumed that the production of secondary cosmic rays in the atmosphere depends on the intensity of nucleons per energy-per – nucleon. The intensity of any component of the cosmic rays in the GeV range depends both on the location and time. At energies much smaller than 10 GeV, the cosmic rays are affected by the geomagnetic field. Between their source of high energy particle and their arrival at some point of detection, the cosmic rays are acted on by a variety of forces. Between all charged particles acts the electromagnetic force, or the Coulomb force and between a nucleon and a hyperon acts strongly the nuclear force or the short range force. The fast nucleon interacts with the nuclei in atmosphere. Their loss energy by ionization for energy smaller than that the value of the critic energy, and losses energy by radiative collisions for energy much greather than that the value of its critic energy. For critic energy the processes the ionization is to equal of the radiative processes.

3.1. THE VERTICAL INTENSITY OF NUCLEONS IN AIR

In this paper I shall discuss the significance of the general flux and energy spectra of the cosmic rays. Because the protons constitute a source of high energy particles, it can be used to perform the information in the study of the cosmic rays. The following formula can be used to evaluate the differential vertical intensity of nucleons at atmospheric depth, X :

$$I_N(E, X) \sim I_N(E, 0) e^{-X/\Lambda}, \quad (1)$$

where $\Lambda = 123 \text{ g/cm}^2$ is an attenuation length of nucleons in air, X is the atmospheric depth [g/cm^2] and $I_N(E, 0) = 0.9 \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ is the integral intensity of vertical protons at sea-level at momentum $\sim 1 \text{ GeV}/c$. The units of differential intensity, I , are [$\text{cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1}$].

I calculated the vertical intensity of proton as a function of atmospheric depth X . The variation of the proton intensity with atmospheric depth follows the approximate curve given in Fig. 1, where errors on the points are statistical.

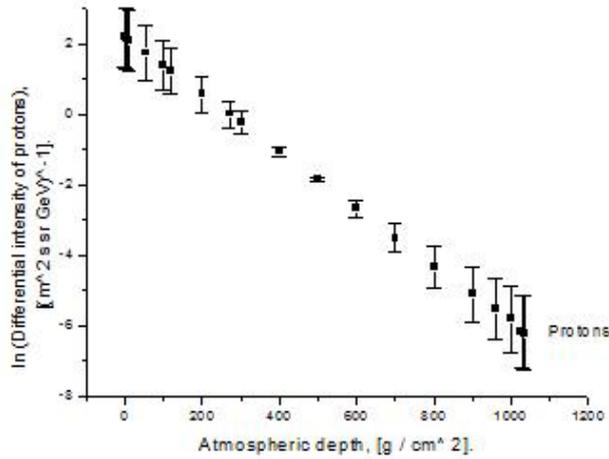


Fig. 1 – The variation of the proton intensity with atmospheric depths.

The intensity of the protons rises rapidly with atmospheric depth and the absorption of the proton in the atmosphere is exponential. At lower regions arises very small number of nucleons, those who do not interact with the atmospheric nuclei on one's way to earth. As is known that the average level for muon production is in region of atmospheric depth (120-200)g/cm², and beyond this level, most muons decay into electron and specific neutrinos and at sea-level the intensity of cosmic radiation decreases.

3.2. DIFFERENTIAL INTENSITY OF PROTONS

A power law in the energy range from 30 GeV to 100 EeV, is expressed as:

$$I_M(E) \sim 1.8 \times E^{-\alpha}, \quad (2)$$

where α denotes the differential spectral index of the cosmic ray flux at the top of the atmosphere, and E is the cosmic ray particle energy. Let $\alpha = 2.7$ for energy range from 30 GeV to 4×10^6 GeV, and $\alpha = 3.1$ for range energy from 4×10^6 GeV to 10^{11} GeV [10].

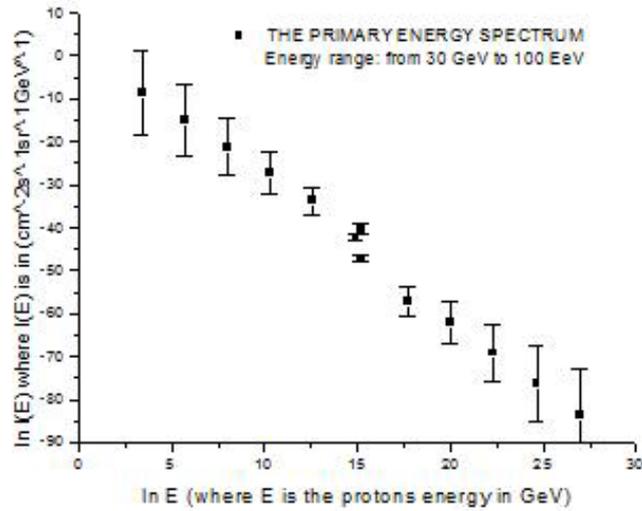


Fig. 2 – The cosmic ray proton energy spectrum in atmosphere.

By using the equation (2), the sea-level proton spectrum is calculated and the results compared with the absolute cosmic ray muon spectrum at sea-level of Allkofer *et al.*

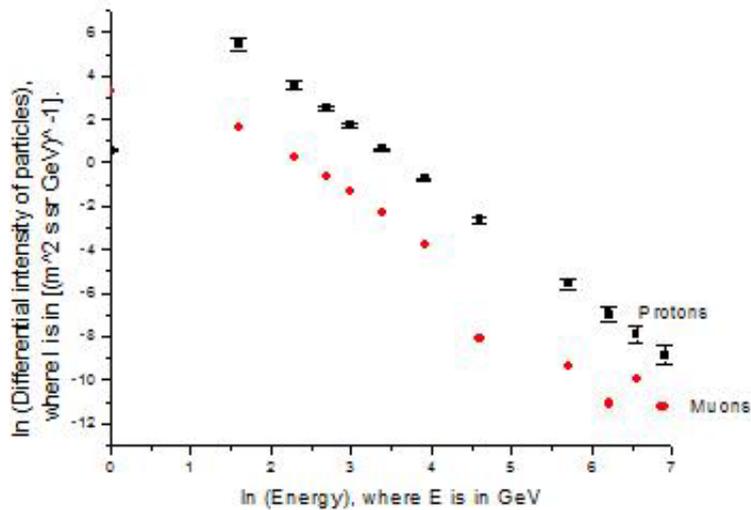


Fig. 3 – The absolute vertical particle spectra. Upper curve – differential intensity of protons in atmosphere $[(m^2 s sr GeV)^{-1}]$ is calculated with formulae (2) for $\alpha = 2.7$, and lower curve – differential muon intensity in atmosphere is from [13].

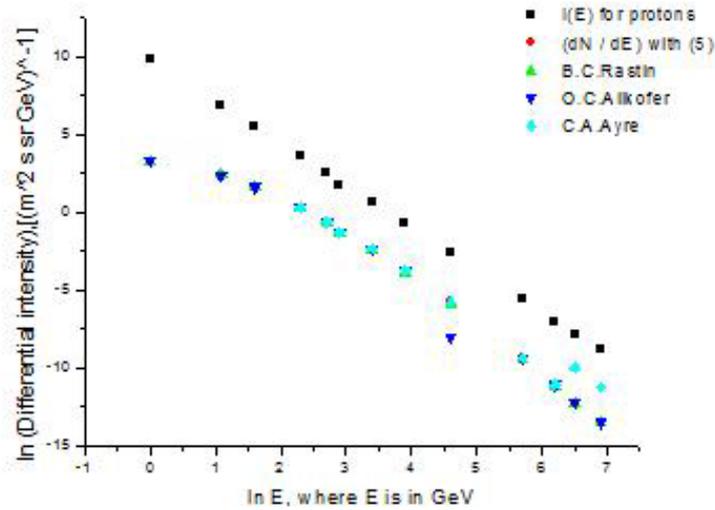


Fig. 4 – The absolute vertical particle spectra as a function of energy.

The differential intensities of C. A. Ayre et al (1975) are in agreement with the form fit spectrum.

The M.I.T. Group (Rossi) have taken an exponent for the region 4×10^{15} eV and give as the integral energy spectrum of proton:

$$F(> E_0) \sim 8 \times 10^{-11} (10^{15} / E_0)^{2.17} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}, \quad (3)$$

where E_0 denotes the proton energy in eV.

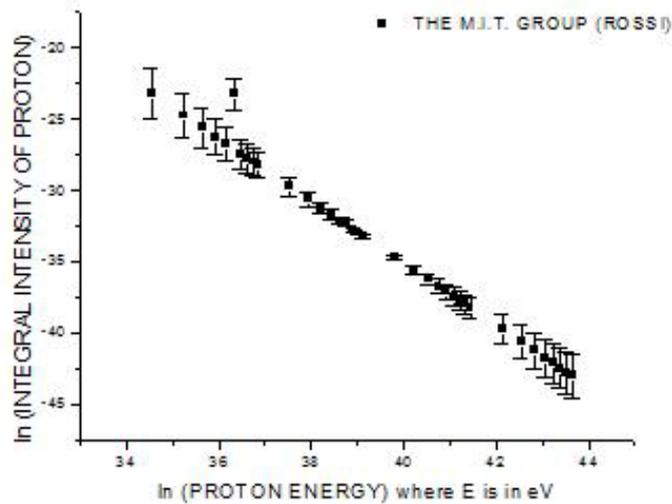
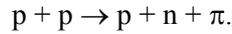


Fig. 5 – The proton energy spectrum in atmosphere (by Rossi).

The energy spectrum at the knee region ($\sim 4 \times 10^6$ GeV) is of astrophysical origin, not due to nonstandard hadronic interactions in the atmosphere [6].

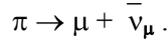
4. ANALYSIS OF THE COMPONENTS OF COSMIC RAYS ABOUT SEA-LEVEL AND AT SEA-LEVEL

Protons in collisions with atmospheric nuclei emit the particles responsible for nuclear forces, the pions. A fast proton interacts with a hydrogen nucleus at rest in the atmosphere and produces a positive charged pion:



The important quantity in this reaction is the threshold energy available in the C- system, much higher than that in the laboratory system (~ 11 MeV).

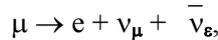
When a fast proton strikes a hydrogen nucleus, can occur the elastic scattering processes depending the energy of the nucleon, the size of the nucleus. Because in this process momentum and kinetic energy are conserved, the parent's muons are both pions and the charged kaons. The charged pion can decay into muon, as follows:



The mean life time of the pion is $\tau_{\pi} \sim 2.55 \times 10^{-8}$ s.

For energy greater than that 115 GeV, the pion tend to interact in the atmosphere before they decay. The pion is an unstable particle, it decays emitting the muon. The muon is a passive nuclear particle, their life time is $\tau_{\mu} \sim 2 \times 10^{-6}$ s. A cosmic ray muon loses about 2 GeV by ionization in traveling from its origin to sea-level.

Muon decay into an electron, a neutrino and an antineutrino at the end of their range:



where the antineutrino is a particle of zero rest mass.

The muons with the total energy greater than that the $m_{\mu} c^2$ and $v \sim c$, are the fast muons.

The hard component of the cosmic rays contains the fast muons and the pions. The soft component of the cosmic rays is composed of the electronic component, photons and slow muons. The main processes responsible for the secondary soft component are the emission of decay electrons and the production of electron secondaries.

4.1. THE INCLINED DIRECTIONS OF SECONDARY COSMIC RAYS

The inclined intensity of the total component of the sea level cosmic rays decreases gradually with increasing the energy.

The probability of decay of muons with inclined directions is greater than for those incident in the vertical direction due to the larger path travelled if both are taken to have started at the same height, h [3].

In the first part of this work I shall reproduce the following numerical values of the Greisen's experiment. I note that these values are essentially to evaluate the numerical values of the inclined intensity of the components of secondary cosmic rays. Using Geiger counter arrangements at 50° geomagnetic latitude, Greisen has measured the vertical intensities, I_v , and flux, F , for the hard, the soft and the total components of the sea-level cosmic rays. To estimate the vertical intensity of the total component, Greisen measured the vertical intensity of the hard component plus the vertical intensity of the soft component and obtained: $I_v = 1.14 \times 10^{-2} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ [3].

In consequence of results of the Greisen's experiment, I calculated the inclined intensity of the hard, the soft and the total components of the sea-level cosmic rays. The intensity in a direction inclined at θ to the vertical can be defined to be proportional to:

$$I(\theta) = I_v \cos^2 \theta, \quad (4)$$

where I_v is the vertical intensity for the component of cosmic rays, and θ ($^\circ$) is the angle of inclination to the vertical.

For $\theta = 50^\circ$ geomagnetic latitude the inclined intensity of fast muons is $I_{\text{Hard}} = 3.4 \times 10^{-3} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ and for the soft component of secondaries is $I_{\text{Soft}} = 1.3 \times 10^{-3} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. The angular distribution of muons, with $E_\mu \sim 3 \text{ GeV}$, at the low altitude is proportional to $\cos^2 \theta$, where θ is the angle of inclination to the vertical [2].

The vertical intensity of the hard component is about (72.81 ± 0.07) per cent of the total vertical component of secondaries cosmic rays, and $p \sim 0.05 \%$, where $p = 0.6745 \sigma$ is the accuracy degree.

The inclined intensity of the hard component is about 72.34 per cent of the total inclined component of secondaries cosmic rays.

4.2. THE ANGULAR DISTRIBUTION OF THE MUONS

I calculated the angular distribution of the muons as a function on the various energies and various zenith angles, for energy range $(1 - 1000) \text{ GeV}$ and $0^\circ < \theta < 70^\circ$. For mathematical convenience I shall disregard the contribution of the π and the charged K-meson, for low energy range ($E_\mu < 100 \text{ GeV}$), because this will cause errors in the calculated distribution of low-energy particles.

The following formulae can be used to evaluate numerically the overall angular distribution of muons at sea-level [9]:

$$E_{\mu}^{2.7} dN_{\mu}/dE_{\mu} \sim 0.14 \{ [1/(1+9.6 \times 10^{-3} E_{\mu} \cos\theta)] + [0.054/(1+1.3 \times 10^{-3} E_{\mu} \cos\theta)] \} \quad (5)$$

where E_{μ} is the muon energy and θ is the zenith angle.

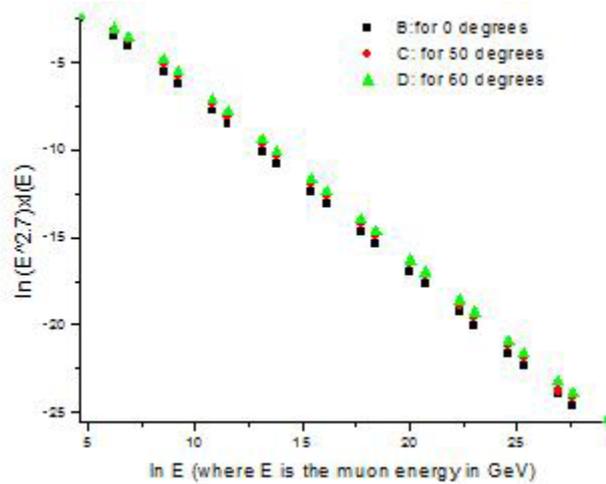


Fig. 6 – Angular distribution of muons as function of muon energy.

The results for the differential muon intensities obtained (as calculated with formulae 5) in the present work have been plotted in Fig. 6. The interpretation is that, for higher energies the angular distribution of the muons decreases slightly with increasing the muons energy. At big angles and low energy, the muons decay before reaching the sea-level [9].

5. EFFECTS OF METEOROLOGIC PARAMETERS

The vertical flux of cosmic ray muon at sea-level in the low momentum region is an important physical quantity which depends on the geomagnetic latitude level [14].

The elements as atmospheric pressure, the altitude and the temperature play a prominent part in changing the intensity of the cosmic rays in air.

The temperature distribution of the atmosphere is not uniform⁽³⁾.

The relationship between atmospheric pressure, altitude, temperature and variation intensity is

$$\Delta I / I = \alpha_p \Delta P + \alpha_H \Delta H + \alpha_T \Delta T, \quad (6)$$

where α_p is the pressure coefficient, α_H is the height atmospheric coefficient and α_T is the positive temperature coefficient.

In the (100–200) mbar pressure range the density decrease and the atmospheric temperature increase. In this region many pions decays and a small fractions interacts with atmospheric particles.

In the top of the atmosphere muons decay into electrons and the characteristic neutrinos.

The atmospheric pressure is varying as function of the altitude, the temperature and the time. When increase the atmospheric pressure, many muons at low energy are absorbed in the atmosphere, before reaching the sea-level and the intensity decrease. The probability of surviving muons at sea-level is the exponential form: $P = \exp(-t/\gamma\tau_0)$.

I shall thus base further calculations on the following probabilities. The quantity t depends on altitude. Depth - height relation can be obtained directly by logarithm of exponential equation.

Let

$$h = h_0 \ln(t_0 / t), \quad (7)$$

where t is the atmospheric depth, in $[\text{g}/\text{cm}^2]$, h is the height above sea-level (km), and t_0 is the atmospheric depth at sea-level, $t_0 = 1,033 \text{ g}/\text{cm}^2$.

Table 1

The atmospheric depth as function of the height above sea-level

t (g / cm^2)	h_0 (km)	$\ln(t_0 / t)$	h (km)
10	6.94	4.64	32.18
100	6.37	2.33	14.84
200	6.37	1.64	10.45
300	6.70	1.24	8.31
500	7.36	0.72	5.30
700	7.83	0.39	3.05
900	8.21	0.14	1.15
1030	8.43	0.0029	0.0244

6. CONCLUSIONS

The aim of this paper is to provide information on the angular distributions from muons near sea-level and at sea-level. The energies of muons and their overall angular distribution reflect a convolution of production spectrum and the many processes in atmosphere. The properties of the cosmic rays particles are connected with observations of their basic processes (the inelastic collision, the radiative collision, the emission of bremsstrahlung by mesons) and their impact on

the structure of the Universe. The inclined intensity of the total components of the sea – level cosmic rays decreases gradually with increasing the muon energy. The hard component of mesons at sea-level is about $(72.81 \pm 0.07)\%$ by the total component of secondaries cosmic rays at sea-level. It should be taken into account here that the radiation level at sea-level is insignificant than that near of the top of the atmosphere.

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