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# Variation of the Position of the Cosmic-Ray Neutron Intensity Maximum with Geomagnetic Latitude*

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It has been experimentally demonstrated that there exists a maximum in the cosmic-ray neutron intensity when plotted as a function of altitude or pressure. The position of this maximum at various geomagnetic latitudes in the northern hemisphere has been measured by experiments which used balloon-borne unshielded $BF_3$ counters with various enrichments of the $B^{10}$ isotope. It has been found that the position of the maximum varies approximately parabolically when plotted as a function of geomagnetic latitude. The range of variation is from about 120 millibars at the equator to about 70 millibars at the north geomagnetic pole. The experimental results are compared with theory.

IT is now known that there exists a maximum in the cosmic-ray neutron intensity when measured as a function of altitude or pressure. The position of this maximum has been measured at various geomagnetic latitudes in the northern hemisphere. The experimental technique used was to fly boron trifluoride counters and associated circuitry by means of large plastic balloons. This apparatus and the method of interpreting the raw data has been previously described.[1–3]

It was found that the position of the neutron intensity maximum varies with geomagnetic latitude. Data are available for six different latitudes.[2–6] These data were plotted and a curve was sought which would be the best fit to all the experimental points.

Messel[7] has calculated the dependence of the atmospheric depth of the maximum number of nucleons involved in a nucleonic cascade on the minimum energy of the incident primaries. He obtained a relation of the form:

$$\theta_{\max}=\alpha \ln(\beta E_{\min}), \tag{1}$$

where $\theta_{\max}$ is the atmospheric depth of the maximum of the cascade; $E_{\min}$ is the minimum energy of the incident primaries; and $\alpha$ and $\beta$ are constants which depend on the type of cascade being considered. From the papers of Johnson[8] and Alpher[9] on the geomagnetic cutoff values for primaries incident at various angles, it was found that these cutoff values can be reasonably approximated for protons and alpha particles which are incident at almost any particular angle by a Gaussian distribution of the form:

$$E_{\min}=\gamma \exp(-\delta\lambda^2), \tag{2}$$

where $\lambda$ is the geomagnetic latitude, and $\gamma$ and $\delta$ are constants which depend upon the type of primary considered and also upon the angle of incidence assumed. If we now substitute this approximation into Eq. (1), we obtain a relation between the depth of the cascade maximum and the geomagnetic latitude. That is,

$$\theta_{\max}=C-D\lambda^2, \tag{3}$$

where $C$ and $D$ are constants which are determined by $\alpha$, $\beta$, $\gamma$, and $\delta$. This is the equation for a parabola.

At first glance it appears difficult to relate the neutron intensity which is detected by a $1/v$ detector such as an unshielded $BF_3$ counter with the nucleons involved in a nucleonic cascade whose energies may be of the order of several Bev. However, as Cocconi *et al.*[10] have shown, in every nuclear process, disintegration nucelons which result from evaporations and slow recoils are produced, and these can be used as indicators of the development of the nucleonic cascade. Since the average distance that an evaporation neutron will diffuse in the atmosphere is equivalent to only about 100 millibars,[2,11] it can be seen that the neutron intensity maximum

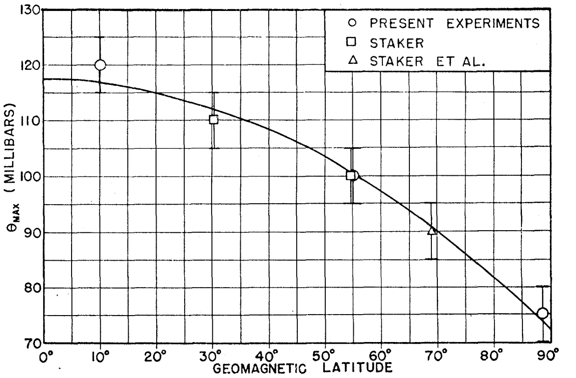

FIG. 1. Position of the neutron intensity maximum *versus* geomagnetic latitude.

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which would be measured by a $1/v$ detector would occur not far from the maximum of the nucleonic cascade and would be expected to vary in the same way, with geomagnetic latitude. With the above reasoning in mind, a parabola was fitted to the six points by the method of least squares (see Fig. 1). It can be seen that the curve falls within all of the estimated probable errors.

An interesting point about the above theory is that the geomagnetic cutoff ($E_{\min}$) is different for primary protons than for alpha particles. This might seem to predict the existence of a double maximum in the neutron intensity curves due to nucleonic cascades which are originated by these different primaries. A close look at the experimental data, particularly those which were obtained at $\lambda = 10.1°$ where the effect would be more pronounced, indicates that perhaps such an effect does exist and what we commonly think of as the neutron intensity maximum may be the composite of two such maxima. More accurate data in the vicinity of 100 mb are needed before anything further can be said about this point.

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# Cosmic-Ray Electrons Near Sea Level and at Mountain Altitudes*

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A cloud chamber containing aluminum and lead plates has been used to study the intensities and energies of cosmic-ray electrons as a function of altitude and zenith angle. The energy distribution is found to be approximately independent of altitude and zenith angle. The decrease of electron intensity with zenith angle is found to be much less than has been reported by investigators using counter telescopes. The increase of the vertical intensity with altitude is found to be slightly smaller than previously reported. The numbers of electrons resulting from decay and collision processes of $\mu$ mesons have been calculated and subtracted from the observed numbers. The residual electrons have an exponential altitude dependence with an absorption length of $135 \pm 15$ g cm$^{-2}$, and a zenith-angle dependence which is much less steep than would be expected if they preserved the directions of the primary particles from which they originate.

## INTRODUCTION

OBSERVATIONS of cosmic-ray electrons are of interest in order to provide information for comparison with suppositions concerning the origin of electrons in the atmosphere. At sea level, most of the observed electrons can be explained in terms of decay and collision processes of $\mu$ mesons. At higher altitudes electrons resulting from nuclear interactions, primarily through the decay of $\pi^0$ mesons, become increasingly important.

A number of measurements have been made of the intensities and energy distributions of electrons at various altitudes and zenith angles,[1–5] with results which are not entirely consistent, especially with regard to the variations with zenith angle. The most extensive surveys[1,3] were made with counter telescopes and absorbers. In this way, good statistical accuracy can be obtained but accurate identification of individual events is not possible. In order to obtain better information about the electron intensities, the present experiment was undertaken. A cloud chamber containing metal plates and triggered by a narrow-angle telescope was used. This method has several advantages over methods using counters alone. All electrons which reach the visible region of the chamber can be counted, regardless of how they scatter in the plates. Side showers can easily be recognized. Energetic electrons can be distinguished from heavier particles by the showers they produce in a series of lead plates, and their energies can be estimated from the development of the showers. A few aluminum plates, above the lead plates, serve to stop slow electrons, whose energies can be determined from their ranges. Stopped heavy particles can be recognized by their large ionization. With this type of apparatus, measurements were made at Ann Arbor (altitude 280 m), Echo Lake (3260 m), and Mt. Evans (4300 m).

## APPARATUS

The main body of the cloud chamber was a Pyrex cylinder of inside diameter 29 cm. The average thickness in the region below the counters was 0.63 cm. Eight absorbing plates were used in the chamber. The top plate was 0.32 cm of aluminum (alloy 24S), the

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