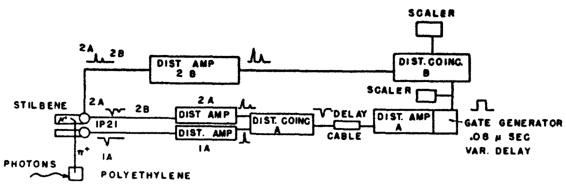


FIG. 1. Block diagram of electronics.

(Fig. 1). The amplifiers and coincidence circuits are of a distributed type.[4] The gate generator is a non-symmetrical cathode coupled multivibrator using miniature tubes.

In order to determine the detection efficiency, the meson counting rate was measured as a function of pulse height for (1) the $\pi^+$ meson pulse in the first crystal, (2) the $\pi^+$ meson pulse in the second crystal, (3) the $\mu^+$ meson pulse in the second crystal. Curves for the $\pi^+$ meson pulses are of the same type as those of Steinberger.[3] A plateau was obtained for the $\mu^+$ meson pulse (Fig. 2) by varying the gain of the amplifier providing the signals for the $\pi-\mu$-coincidence circuit. This plateau shows that all $\mu^+$ mesons, which stop in the crystal during the time the gate is open, are counted.

With delayed coincidence detection, the accidental background is proportional to the length of gate used. Since the ratio of the $\pi^+/\mu^+$ mean lives is of the order of 0.01, the accidental background is reduced by going to the faster decay scheme. With the present apparatus, the background is reduced only by a factor of 10 from that of reference 3. This is due to the larger ratio of pulse width to half-life and the difficulty of discrimination with narrower pulse widths. To lower the background further, a triple delayed coincidence involving $\pi^+-\mu^+-\beta^+$ decay has been used. This requires that the $\mu^+-\beta^+$ decay as well as the $\pi^+-\mu^+$ decay must take place in the second crystal. The background and counting efficiency are both lower when the $\pi^+-\mu^+-\beta^+$ detection scheme is used, but the ratio of counting efficiency to background is increased.

As an application of this method, the $\pi^+$ meson mean life[5-7] was measured by varying the gate delay. The delay was increased and decreased in cycles to minimize the effect of beam fluctuations and detection sensitivity changes. In order to obtain the accidental delayed coincidences, the gate is delayed for a time long compared to a $\pi^+$ mean life. The finite length of the gate does not need to be taken into account, since this does not affect the slope of the curve. Calculations show that the effect of the decay of the $\mu^+$ mesons into positrons can be neglected. This is owing to the fact that only a small fraction of the positrons occur at each delay; in addition, only about 30 percent or less of these positrons lose sufficient energy in the crystal to be counted.

Eight lengths of RG 63/U cable were used to provide the variable delay. The delay of each cable was measured, using a synchroscope, by photographing the reflections of pulses sent down the cable. Cable delays were measured to 2 percent.

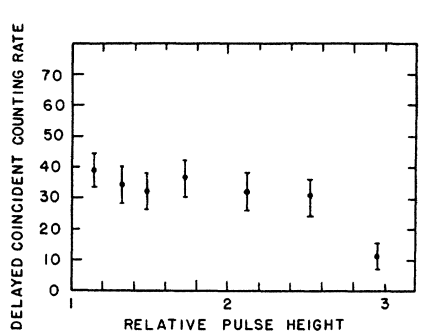


FIG. 2. Pulse 2B plateau. Plot of delayed coincidence counting rate against the relative height of a pulse required to make a delayed coincidence. Obtained by counting the number of delayed coincidences for different gain settings of amplifier 2B.

The 5641 meson counts, with a background of 398 at each of the seven points (Fig. 3), give for the mean life

$$\tau_m = 2.54 \pm 0.11 \times 10^{-8} \text{ sec.} \quad \text{(Standard deviation.)}$$

The corresponding half-life is $\tau_{\frac{1}{2}} = 1.76 \pm 0.08 \times 10^{-8}$ sec. This value agrees with that of reference 5 but lies outside the standard deviations of previous measurements.[6,7]

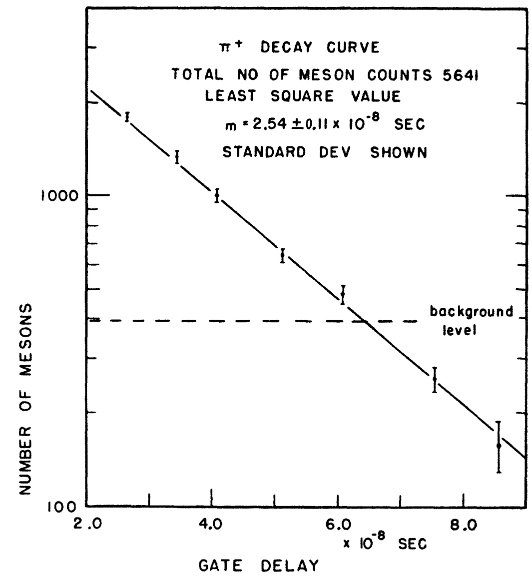


FIG. 3. The number of $\pi^+$ mesons at each gate delay plotted against the gate delay.

We wish to thank Professor E. McMillan and Professor O. Chamberlain for their encouragement and advice. Thanks also are due to Dr. Leininger for kindly providing the crystals and to the synchrotron crew for aid in carrying out the bombardments.

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## The Neutrons from the Nucleonic Component as an Indicator of Changes in Primary Intensities*

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TWO important factors in the selection of a suitable secondary component for low altitude observation of the changes and fluctuations of the primary cosmic-ray intensity are (a) uniqueness of interpretation of the observed intensity changes and (b) response of the secondary component to changes in the primary intensity. In this note the meson component and the neutrons from the nucleonic component will be compared briefly with respect to these factors.

*Interpretation.*—It has been shown that, owing to the short mean lives of the $\pi$ and $\mu$ mesons, the temperature expansion and contraction of the atmosphere, especially in the 50 to 150-mb region,[1] where the meson production is large, has a pronounced effect on the meson intensity observed at greater atmospheric depths; hence, it is difficult to distinguish between changes of secondary intensity caused by the atmosphere and changes caused by primary intensity.

Along with meson production, the primary radiations also generate a nucleonic component composed of high energy nucleons which, in turn, produce stars throughout the atmosphere of intermediate and low energies. These stars emit neutrons with energies up to the order of 10 to 30 Mev which are readily detected. It can be shown that almost the entire yield of atmospheric neutrons arises from star production by nucleons.[2] Since the nucleons have long mean lives, the neutron intensity is a function of the total mass of air above the point of observation, and temperature effects are negligible. The barometric coefficients for neutrons can be determined from absorption measurements[3] at $\lambda=0°$ to 54° N magnetic latitude.

*Response.*—At a given pressure altitude the response of a secondary component to changes in primary particle intensity can be defined for any geomagnetic latitude as the ratio of the percentage change in the secondary intensity to the percentage change in primary intensity. The production of mesons, having sufficient range to penetrate of the order of one-half the atmosphere, does not become appreciable until reaching proton cut-off energies corresponding to $\sim\lambda=45°$ or less. Even then, the contribution of charged mesons produced by all primary particles with momenta below about 15 Bev/c does not represent more than approximately 50 percent of the total meson production. However, the latitude dependence[3] of the fast or slow neutron intensity shows that between $\lambda=0°$ and 54° there is more than a 400 percent increase in neutron production in a column of atmosphere, owing to the primary radiations below about 15 Bev/c, and that nearly one-half of this fourfold increase comes from particles with momenta below about 8 Bev/c. Thus, the ratio of the cross section for processes leading to neutron production to that for meson production increases rapidly with decreasing primary particle energy. This was discussed by Simpson[3] and, more recently, by Forbush, Stinchcomb, and Schein.[4] Hence, the nucleonic component appears most suitable for measurement of changes in low energy primary particle intensity.

The slow neutron intensity is generally measured isotropically by detectors sensitive only to the disintegration of $B^{10}$. This discrimination against unrelated charged particle events and the lifetime of slowed neutrons increases the statistical accuracy of neutron measurements.

As an example, the measurement of the neutron intensity changes at 30,000-feet pressure altitude[5] (312 g cm$^{-2}$ air) can be compared with concurrent measurements of charged particle intensity. In independent experiments in the same aircraft, Biehl and Neher[6] measured the total ionization and vertical charged particle intensity with and without lead at the same time the neutron measurements were obtained, both in 1948 and 1949. The observed intensities at $\lambda=56°$ N are given in Table I for June, 1948, which was a quiet day, and for October, 1949 flights during solar disturbances. Prior to both sequences of flights the neutron counting rates were normalized at the geomagnetic equator. It is seen that the response of the neutron component for singly charged primary particles of momenta $<2$ Bev/c is at least an order of magnitude greater than the response of the meson component. Owing to atmospheric absorption, this neutron intensity increase could not have been observed at sea level.

Adams and Braddick[7] have recently described a sharp increase of neutron intensity at sea level following a solar flare.[4] It is evident from their results that the primary particles producing the increase must have had higher energies than those associated with the measurements in October, 1949. They observed a response for the neutron component at least a factor of 40 greater than for the corresponding $\mu$-meson increase of intensity measured by Elliot.[8]

TABLE I. Data for $\lambda=56°$ N geomagnetic latitude and 30,000-feet pressure altitude comparing concurrent measurements of the neutron and charged particle intensities. Neutron intensities were normalized at the geomagnetic equator in 1948 and 1949.

| Observation | Neutron intensity[a,b] (counts per minute) | Total ionization[c] (ions cm$^{-3}$ sec$^{-1}$ (atmos of air)$^{-1}$) | Vertical charged particle intensity without lead[c] |
|---|---|---|---|
| Flight June, 1948 (quiet day intensity) | 660 | 106 | 775 |
| Flight October 27, 1949 (disturbed day intensity) | 850 | 106 | 775 |
| Percent change between 1948 and 1949 | +30 | 0 | 0 |
| Percent of shift of "knee" between October 27 and 31, 1949 | $\sim+3$ | 0 | 0 |

[a] Reference 3.
[b] Reference 5.
[c] Reference 6.

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## Magnetic Moment of the Deuteron

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A PRECISION measurement of the ratio of the magnetic moment of the proton to that of the deuteron has been carried out using the magnetic resonance method. The apparatus was that used by Anderson[1] in the measurement of the magnetic moment of $He^3$, with a number of improvements. Gas samples were used so that the magnetic shielding correction could be calculated in a reliable way.

The measurements were made using mixtures of $H_2$ and $D_2$ in a small volume (0.6 cm$^3$) at high pressure (100 atmos) in a region where the magnetic field inhomogeneity was less than $3\times10^{-6}$. Two r-f coils having rectangular cross sections were used. These were oriented at right angles to each other and to the magnetic field. The proton coil nested snugly inside the deuteron coil. The space exterior to the coils was filled with Teflon plastic, thereby confining the gas to the region inside the coils. The possible fractional difference in the central value of the magnetic field for the two substances in this arrangement was less than $2\times10^{-7}$.

The proton and deuteron resonances were observed at the same time on two Esterline-Angus recorders by slowly increasing or decreasing the magnetic field. In establishing the resonance frequencies, advantage was taken of the fact that their ratio is close to 13/2. A master crystal oscillator was used to generate a fundamental frequency $f_0$ near 2.36 Mc. The second harmonic of this was used to drive the deuteron coil. The proton frequency was obtained by amplifying the upper side band derived by mixing the thirteenth harmonic of the master oscillator with the output of a variable frequency oscillator operating at a frequency $f$ near 0.068 Mc. The ratio of the proton to the deuteron frequency is given by

$$R=\tfrac{1}{2}(13+f/f_0).$$

The relative error in the determination of $R$ by this method is only 1/450 of the relative error in the determination of either $f$ or $f_0$.