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.

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.

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 μ-meson increase of intensity measured by Elliot.[8]

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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 3×10^{-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 2×10^{-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.

The frequency at which the magnetic field was modulated was 25 cycles, large enough to affect the shape of the otherwise sharp deuteron signal by frequency modulation effects.[2] A study of these effects showed that our line shapes could be correctly described by applying the analysis of Karplus[3] to our arrangement. We were able to show that by operating with dispersion unbalance of the r-f bridge, use of the center of symmetry of the resonance pattern in making the frequency comparisons was justified. The strength of the r-f signal was kept well below the saturation level, and the amplitude of the magnetic field modulation was 0.024 gauss, small enough so that the line widths were not excessively broadened.

Results of seven independent measurements are given in Table I. The stated uncertainty is about twice the usual probable error.

TABLE I. Measured values of μ_H/μ_D.

Run	Pressure H_2	lb/in.[2] D_2	μ_H/μ_D
47	300	700	3.25719876
49	300	500	3.25719803
56	520	880	3.25719818
57	300	500	3.25720074
58	320	880	3.25720064
59	660	740	3.25719854 Coils rotated 90°
60	660	740	3.25719825 Coils rotated 90°
			Mean 3.25719902 ±0.00000060

In an earlier measurement with H_2O-D_2O mixtures, we obtained $\mu_H/\mu_D=3.25719986\pm0.00000045$.

The corrections for magnetic shielding calculated for H_2 and D_2 using Ramsey's formula[4] and new values for the rotational magnetic field[5,6] are very nearly the same. However, a difference in the magnetic shielding constant σ arises from changes in the amplitude of the molecular vibration.[7] For the first term in Ramsey's formula, Newell[8] has calculated that the contribution to σ is greater for D_2 by $(1.1\pm0.2)\times10^{-7}$. He points out that this change could be canceled by the effect of the molecular vibration in the second term. Accordingly, we give for the ratio of the magnetic moments

$$\mu_p/\mu_d=3.2571990\pm0.0000010.$$

This result is in agreement with, but ten times more accurate than that obtained by Levinthal.[9] It lies outside the experimental error of the result of Lindström.[10]

This result is comparable in accuracy with the new measurements by Prodell and Kusch[11] of the hyperfine structure in hydrogen and deuterium. Taken together these measurements provide a critical test of the theory of the structure of the deuteron.[12]

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A Model for Photo-Nuclear Reactions

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MANY of the features of photo-nuclear reactions induced by gamma-rays from 6 to 100 Mev can be explained by using a model which assumes the gamma-ray to be absorbed by a single nucleon in a process similar to the photoelectric effect[1] and the photo-disintegration of the deuteron.[2]

In this process the cross section for the photo-nuclear absorption for one nucleon is

$$\sigma(W)=(8\pi^3e^2\nu/c)|z_{OE}|^2,$$

where

$$z_{OE}=\int U_0[(A-Z)/A]z\phi_E d\tau\cong\tfrac{1}{2}\int U_0 z\phi_E d\tau$$

for a proton, and

$$z_{OE}=\int U_0(-Z/A)z\phi_E d\tau\cong-\tfrac{1}{2}\int U_0 z\phi_E d\tau$$

for a neutron. All symbols have their usual meanings, and $A\cong2Z$. The energy of the outgoing nucleon, aside from a small correction for momentum conservation, is $E_N=W-\epsilon_N$, where ϵ_N is the binding energy of the nucleon, and $W=h\nu$ is the energy of the gamma-ray. The total cross section is $\sigma_T=A\sigma(W)$; and the sum rule gives for the integrated cross section

$$\int_0^\infty \sigma_T dW=\pi^2e^2\hbar A/2Mc=0.015A \text{ Mev-barn},$$

as given by Levinger and Bethe.[3] The cross section, $\sigma(W)$, as a function of W will depend on the wave functions, which are not known. However, from analogy with similar processes[1-4] one would expect a rise at the threshold, ϵ_N, a maximum at about $2\epsilon_N$, and then a tail-off. This explains why the cross section for photo-emission of one nucleon is larger than two, and so on.

The fate of the nucleon which absorbed the gamma-ray will be determined by the size of the nucleus. In light elements, the nucleon will probably escape without being very much disturbed, and $\sigma(\gamma, p)/\sigma(\gamma, n)\cong1$. In medium and heavy nuclei, the nucleon will collide with other nucleons and form a compound nucleus; protons will be affected by the potential barrier. In the compound nucleus the emission of neutrons is more probable than the emission of protons, and (γ, n) will be favored over (γ, p). If there is enough energy available, several nucleons can be emitted. All this is in agreement with the presence of high energy protons in gamma-ray bombardment,[5] and with the (γ, p) and (γ, n) yields.[6,7]

Even in the medium and heavy elements, the nucleon that absorbs the gamma-ray near the surface can escape. Therefore, in bombardments of medium nuclei with monoenergetic gamma-rays, one expects that the ratio $\sigma(\gamma, p)/\sigma(\gamma, n)$ is proportional to $A^{-\frac{1}{3}}$ as long as $E_N>B$, where B is the potential barrier; and this is in rough agreement with Wäffler's results.[8]

Empirically, $\sigma(W)$ can be found in the light elements from the energy distribution of nucleons from gamma-ray bombardments if the gamma-ray spectrum is known; and it is always possible to find $\sigma(W)$ if the cross sections for $\sigma(\gamma, p)$, $\sigma(\gamma, n)$, $\sigma(\gamma, pn)$, $\sigma(\gamma, 2n)$, etc., are all known as functions of W: their addition will give $\sigma(W)$. A crucial test of the model is the energy distribution of protons from light elements irradiated with high energy monochromatic gamma-rays.

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On the Branching Ratio of the π^+ Meson*

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EARLY experiments on π^+ mesons, using photographic emulsions as detectors, have seemed to show[1] that some of the π^+ mesons, upon stopping in matter, do not decay into μ^+ mesons.

These studies were concerned with mesons of fairly low energy so that the emulsion would be the only stopping material. Ilford