The author is indebted to Dr. E. O. Salant and Dr. J. Hornbostel of the Brookhaven National Laboratory for making these plates available. He wishes to express his thanks to Dr. B. T. Feld for suggesting this experiment and contributing to the analysis of the data. The author wishes to express particular gratitude to Mrs. T. Kallmes and Mr. I. L. Lebow for help in scanning and analyzing the plates.

APPENDIX

We have calculated the average angle of dispersion for mesons emitted in the collision of two nucleons if the mesons are produced in the center-of-mass system of the two nucleons with a single energy and an angular distribution corresponding to the $2n$th power of the sin or cos.

β = velocity of meson in c-of-m system.
β_0 = velocity of c-of-m system.
θ = angle of meson emission in c-of-m system.
ψ = angle of meson emission in laboratory system.

We assume a distribution in the center-of-mass system

$$\text{if} \quad N(\theta)\sim\cos^{2n}\theta\sin\theta d\theta,$$

then,

$$\bar{\psi}=\int_0^\pi \cos^{2n}\theta\psi(\theta)\sin\theta d\theta \Big/ \int_0^\pi \cos^{2n}\theta\sin\theta d\theta,$$

$$\psi(\theta)=\tan^{-1}[(1-\beta_0^2)^{\frac{1}{2}}\sin\theta/(\beta_0/\beta)+\cos\theta].$$

This expression can be integrated exactly

$$\bar{\psi}=(\pi/2)+(\pi/2)(1/\beta_0)(1/\alpha_1-\alpha_2)[G(\alpha_1)=G(\alpha_2)] \quad \beta_0<\beta,$$
$$\bar{\psi}=(\pi/2)(1/\beta_0)(1/\alpha_2-\alpha_1)[G(\alpha_1)-G(\alpha_2)] \quad \beta_0>\beta,$$
$$\alpha_{1,2}=(1/\beta_0\beta)\{1\pm[(1-\beta_0^2)(1-\beta^2)]^{\frac{1}{2}}\},$$
$$G(\alpha)=\left(-\frac{\beta_0}{\beta}\alpha+1\right)\left[\alpha^{2n}+\tfrac{1}{2}\alpha^{2n-2}+\cdots+\frac{1\cdot3\cdots(2n-1)}{2\cdot4\cdots2n}-\frac{\alpha^{2n-1}}{(\alpha^2-1)^{\frac{1}{2}}}\right].$$

We can find $\bar{\psi}$ for a distribution, $\sin^{2n}\theta$, from the corresponding $\cos\theta$ moments. For instance,

$$\bar{\psi}(\sin^2\theta)=\tfrac{1}{2}[3\bar{\psi}(n=0)-\bar{\psi}(\cos^2\theta)].$$

For the case $n=0$ (spherical symmetry)

$$\bar{\psi}=[1-(1-\beta^2)^{\frac{1}{2}}](1-\beta_0^2)^{\frac{1}{2}}/\beta\beta_0 \quad \beta_0>\beta,$$
$$\bar{\psi}=1-\{[1-(1-\beta_0^2)^{\frac{1}{2}}]/\beta\beta_0\} \quad \beta_0<\beta.$$

To obtain the curves of Fig. 4, we have assumed various total energies, ϵ, for the mesons in the center-of-mass system. Assuming then a given nucleon total energy, U_0, (laboratory system), we find the velocity of the center-of-mass, β_0,

$$1-\beta_0^2=2Mc^2/(U_0+Mc^2), \quad M \text{ is the nucleon mass.}$$

We find the total energy available in the center-of-mass system and divide by the meson energy to obtain the multiplicity, M_0

$$M_0=[2Mc^2(U_0+Mc^2)^{\frac{1}{2}}-2Mc^2]/\epsilon,$$
$$\epsilon=mc^2/(1-\beta^2)^{\frac{1}{2}}=\alpha mc^2,$$
$$m=\text{meson mass.}$$

The values of $\bar{\psi}$ for the $d\epsilon/\epsilon$ spectrum are obtained by an integration of the above expressions for $\bar{\psi}$ over the center-of-mass meson energy. The resulting curves of M_0 vs $\bar{\psi}$ are shown in Fig. 4.

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A Search for Cosmic-Ray Diurnal Effects at Balloon Altitudes

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In two balloon flights in Minnesota a search was made for diurnal effects in the cosmic radiation at altitudes above 50,000 feet. Measurements were made simultaneously of the total ionizing radiation, γ-radiation in the energy range of approximately 0.75 to 5 Mev, and fast neutrons. The ionizing radiation and γ-radiation component was measured by means of a central horizontal counter tube surrounded by a closely packed ring of horizontal counters. Coincidences between the central counter and the outer ring determined the ionizing radiation, while anticoincidences gave the intensity of the γ-radiation. The neutron flux was measured by two BF_3 counters, one filled with enriched BF_3, mounted side by side in a vertical paraffin cylinder eight inches in diameter surrounded by Cd. One flight was launched at 12:30 A.M. LCT and remained aloft until 8:30 A.M. The other flight was launched at 6:00 P.M. and landed at 10:00 P.M. No diurnal effects were observed. The statistical accuracy of this measurement is on the order of 1 percent for the total ionizing radiation, 3 percent for the γ-radiation, and 2 percent for the neutron measurement.

I. INTRODUCTION

THE possible existence of a diurnal variation in the cosmic-ray intensity is of considerable interest, since it bears both on the matter of a permanent solar magnetic moment[1] and on the energy spectrum of the primary cosmic radiation. A solar magnetic moment of adequate magnitude to account for the apparent "knee" in the cosmic-ray latitude curve[2] should also give rise to an appreciable diurnal effect.[3,4] Measurements of this effect may provide evidence to aid in the resolution of the present doubtful status of the solar moment. If the absence of a diurnal effect can be established, some other mechanism will be required to explain an energy cut-off at high latitudes.

The relatively low energy particles of 3 Bev or less which would be affected by the solar field contribute very little to the intensity at ground level. These

[1] P. M. S. Blackett, Phil. Mag. 40, 125 (1949).
[2] L. Jánossy, Z. Physik 104, 430 (1937).
[3] M. Vallarta, Nature 139, 839 (1937).
[4] P. S. Epstein, Phys. Rev. 53, 862 (1938).

particles would also be excluded by the earth's magnetic field at low latitudes. From this it appears that measurements at high altitude and at least intermediate latitude should be most favorable to the detection of this variation.

We carried out a search for the diurnal effect at balloon altitudes in Minnesota (magnetic latitude 56°) in June of 1949. Identical equipment was carried in each of two balloon flights, the first of which was launched at 12:30 A.M. and remained aloft to 8:30 A.M. local civil time. The second flight was flown from 6:00 P.M. to 10:00 P.M. local civil time. Measurements were made of the intensity of the total ionizing radiation, of gamma-radiation in the energy range 75 kev to 5 Mev, and of fast neutrons. No diurnal variation was found in any of the three measurements. The statistical probable error for the total ionizing particle measurement was of the order of 1 percent, for the gamma-radiation of the order of 3 percent and for the neutrons about 2 percent.

II. EXPERIMENTAL APPARATUS

Figure 1 shows the Geiger counter arrangement used for measuring the total ionizing particle intensity and the intensity of the gamma-radiation. This is similar to that used by Perlow[5] in rocket experiments. It consisted of a single horizontal counter (A) surrounded by a closely packed ring (B) of five counters in parallel. A particle penetrating the center counter resulted in a coincidence ($A\cdot B$) between the center counter and the outer ring. An anticoincidence ($A-B$), in which the center counter was discharged but no counter in the outer ring was discharged, would result from a gamma-ray in the energy range 75 kev to 5 Mev approximately.

Figure 2 shows a cross section of the neutron counter. The two proportional counters 1 and 2 were physically identical. Counter 1 was filled to 25 cm pressure with BF_3 enriched to 96 percent of B^{10}. Counter 2 was filled to the same pressure with normal BF_3. The counters were sealed with paraffin into a removable aluminum cylinder as shown to provide for interchangeability of the counters. The large paraffin cylinder, 8 inches in diameter, was covered with sheet cadmium to stop thermal neutrons. The two counters, differing only in the concentration of B^{10}, were used to correct the neutron counting rate for spurious counts due to highly ionizing events not necessarily associated with neutrons in the energy range considered. Preflight calibration with a Ra-Be source was used to establish the ratio of the efficiencies of the two counters for neutrons. Actually, it proved unnecessary to make this correction.

Output pulses from the Geiger counters were fed to diode coincidence and anticoincidence circuits.[6] The ($A\cdot B$) output of this circuitry was scaled by a factor of 16 and the ($A-B$) output by a factor of 8. The proportional counter pulses were amplified and also fed to scaling circuits. A scale factor of 16 was used for the enriched BF_3 counter and a factor of 8 for the normal BF_3 counter.

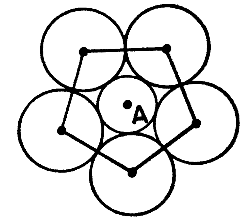

FIG. 1. Geiger counter arrangement for measuring total ionizing particle intensity and the intensity of gamma-radiation.

The counter data after scaling was totalized on four telephone message registers and time reference was provided by a clock. Ambient atmospheric pressure was measured by two mercury manometers, one having a range from zero to 10 cm, and the other calibrated over a range from 5 cm to 76 cm. A photographic type thermometer was used to determine the temperature within the gondola. The entire instrument group was photographed with a 16-mm gunsight camera modified for continuous film motion. Exposures were made at approximately 20-sec intervals by flashing four bulbs mounted in a reflector. The time interval between exposures was set by a cam operated switch driven by the camera gear train.

The entire equipment assembly including electronics and batteries was enclosed in a 30-in. pressure-tight aluminum sphere consisting of two hemispherical sections spun out of 0.030-in aluminum. Prior to flight the sphere was covered with a two-inch blanket of glass wool to prevent excessive temperature changes. By this means the temperature inside the gondola was held within the range of 70° to 80°F during the entire flight.

Both flights were made from Camp Ripley at Little Falls, Minnesota. Two 70-ft General Mills polyethylene cells were used to carry each experiment. The balloons and flight services, including tracking and recovery, were provided by Project Skyhook. Tracking of the

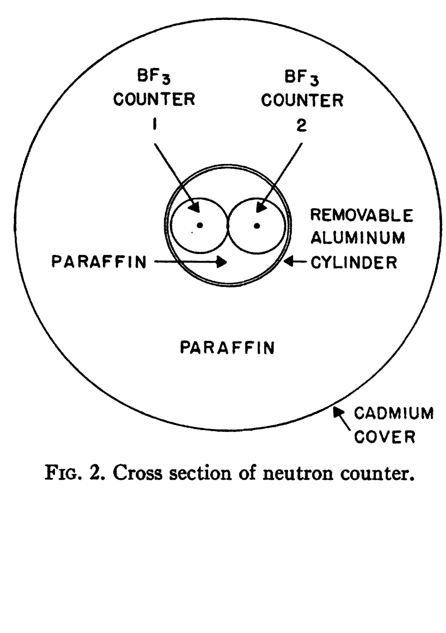

FIG. 2. Cross section of neutron counter.

[5] Perlow, Kissinger, and Schroeder, Phys. Rev. **76**, 164 (1949).
[6] Howland, Schroeder, and Shipman, Rev. Sci. Instr. **18**, 551 (1947).

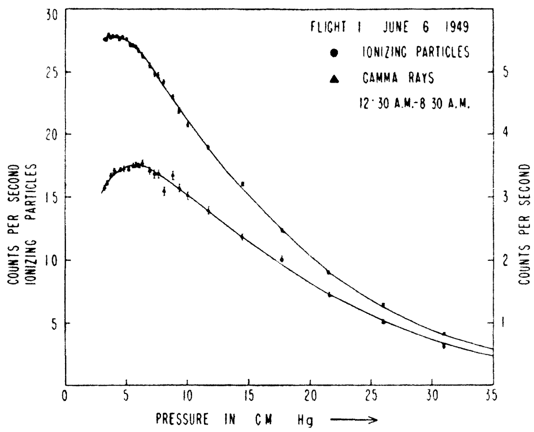

FIG. 3. Intensity of ionizing particles and of gamma-radiation *vs* pressure for Flight 1.

balloons was accomplished by means of theodolites and by a Radio sonde in conjunction with the radar. The Radio sonde also provided altitude data, but the pressure data from the mercury manometers was used for all calculations.

Flight 1 was launched at 12:30 A.M., local civil time, on June 6. This flight climbed to an altitude of approximately 55,000 feet and leveled off until sunrise, when heating of the gas caused a further slow ascent. The

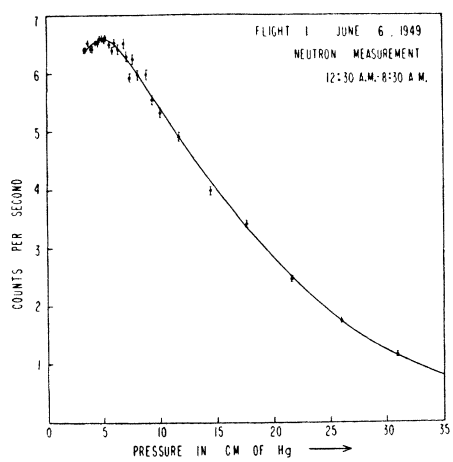

FIG. 4. Intensity of fast neutrons *vs* atmospheric pressure for Flight 1.

maximum altitude reached was 75,000 feet at 3.1 cm of Hg pressure. Data was obtained until 8:30 A.M. local time, and the equipment was dropped by means of a parachute. It was recovered immediately.

The second flight was launched at 6:00 P.M. on June 18. It rose to an altitude of 85,000 feet before sunset, and almost immediately began a steady rapid descent reaching the surface at about 10:00 P.M. local time. Weather and tracking difficulties caused recovery of the equipment to be delayed for several days. The film record was recovered in good condition.

III. RESULTS

The intensities of the three types of radiation which were measured are shown plotted as counting rates *vs* atmospheric pressure in Figs. 3–6. Figures 3 and 4 show the results for Flight 1, and Figs. 5 and 6 for Flight 2. The uncertainties indicated are the statistical probable errors.

The data shown for Flight 1 covers a time period of seven hours, approximately 1:00 A.M. to 8:00 A.M., local time. During this entire period the balloon was ascending. The rate of ascent through the pressure

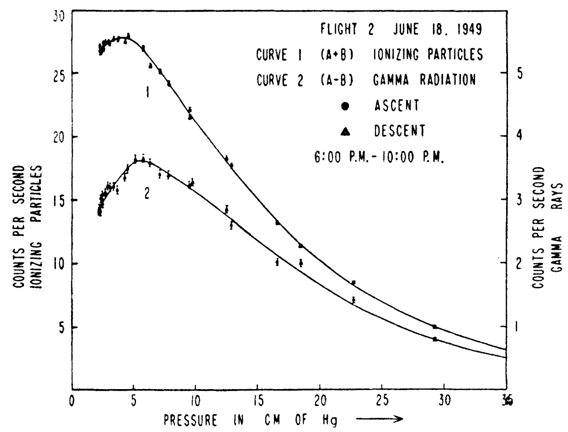

FIG. 5. Intensity of ionizing particles and of gamma-radiation *vs* atmospheric pressure for Flight 2.

interval 6.0 cm to 3.1 cm Hg was very slow, requiring 5 hours of the total period. Sunrise was approximately 0412 when the balloon was at an altitude of 18.5 km.

The curves for Flight 2 include data obtained over a 3-hr period from 6:40 P.M. to 9:40 P.M., local time. Apparently because of a break in one of the balloons, this flight did not remain at peak altitude for any extended period but descended at a rate comparable to the rate of ascent. Data were obtained throughout the

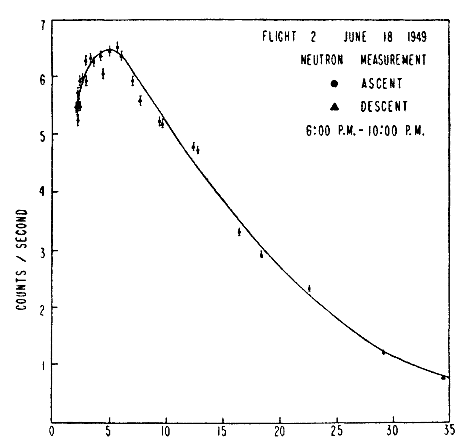

FIG. 6. Intensity of fast neutrons *vs* atmospheric pressure for Flight 2.

TABLE I. Data of Flight 1 corrected to constant pressure by means of the curves of Flight 2. The corrected counting rates are normalized to unity at the peak rate for each type of radiation.

Pressure altitude cm Hg	Local civil time	Normalized intensity Ionizing particles	Gamma rays	Neutrons
7.60 cm	0205	1.005±0.010	0.974±0.027	1.027±0.021
5.77 cm	0259	0.997±0.009	1.000±0.000*	0.979±0.020
5.37 cm	0405	0.993±0.009	0.969±0.022	
5.15 cm	0414			1.000±0.000*
4.70 cm	0454	0.994±0.008	1.018±0.022	1.003±0.015
4.00 cm	0549	1.000±0.000*	1.014±0.023	0.988±0.016
3.56 cm	0652	0.996±0.008	1.046±0.024	1.005±0.018
3.18 cm	0741	0.990±0.008	1.009±0.027	1.016±0.020

* Normalization point.

flight, and agreement between the counting rates for ascent and descent are satisfactory for all three measurements. Sunset occurred at approximately 1950 and an altitude of 21.5 km.

Since the balloons did not remain at a constant pressure level, the data of Flight 1 were corrected to constant pressure by means of the curves of Flight 2. The corrected counting rate was normalized to unity and is shown in Table I. The uncertainties shown are the statistical probable errors. The maximum correction for pressure difference is 15 percent. During the time interval from 2:00 A.M. to 8:00 A.M. on June 6, there was no variation in any of the three measurements which could be ascribed to a diurnal effect.

A comparison can also be made between the intensities of the ionizing radiation at widely separated times of day using ground calibration to correct for counter differences. Table II is a tabulation of the counting rates of ionizing particles for the two flights at an atmospheric pressure of 31 mm Hg, the maximum altitude reached by Flight 1, and at the Pfotzer maximum. The ratio of the effective volumes of the two counters was found by ground calibration to be 1.01 ±0.01. No difference as great as 1 percent was found in the ionizing radiation intensity between 7:40 A.M. and 7:40 P.M., and between 4:05 A.M. and 7:24 P.M., local time.

IV. DISCUSSION

Dwight[7] has recently published calculations on the expected magnitude of the diurnal variation. He assumed a power law spectrum for the incident cosmic

[7] K. Dwight, Phys. Rev. 78, 40 (1950).

TABLE II. Comparison of counting rates for ionizing radiation at different times of day. Corrected for counter differences by means of ground calibration.

	Pressure altitude cm Hg	Local civil time	Counting rate ionizing particles	Corrected counting rate	Ratio
Flight 1	3.18 cm	0741	27.52±0.12	27.52±0.10	1.009±0.012
Flight 2	3.18 cm	1942	27.50±0.19	27.77±0.26	
Flight 1	5.28 cm	0405	27.22±0.13	27.22±0.10	1.002±0.013
Flight 2	5.28 cm	1924	27.00±0.20	27.27±0.28	

radiation and an intensity in the "forbidden directions" of 90 percent of the full intensity.[8] For a solar magnetic moment of 10^{34} gauss-cm^3, he found that the vertical intensity should increase by about 7 percent between 4:00 A.M. and 8:00 A.M., local time, at 56° magnetic latitude. Both the magnitude and the phase of the variation are sensitive to the value of the assumed magnetic moment. When this was reduced to 0.42×10^{34} gauss-cm^3, a decrease of approximately 4 percent in the vertical intensity between 8:00 A.M. and 8:00 P.M. was predicted.

These calculations apply rigorously only to particles entering the earth's field in the vertical direction. Our measurements accepted radiation from all directions. Malmfors[9] has shown that when low energy charged particles are emitted from a sphere into the field of a magnetic dipole their final direction is practically independent of the direction of emission over a very large range about the vertical. The inclusion of a large solid angle should not seriously affect the results of the measurement.

The absence of an appreciable diurnal effect as indicated by these experiments places an upper limit on the value of the solar magnetic moment below that required for the latitude cut-off. Since no effect was noted in any radiation at the day-night line, the sun should not be a source of a significant portion of these radiations.

We wish to acknowledge the aid of our colleagues in the Rocket Sonde Research Branch of the Naval Research Laboratory, and of the personnel of Project Skyhook at Minneapolis. We are especially indebted to Dr. G. J. Perlow for many valuable suggestions on this problem.

[8] Kane, Shanley, and Wheeler, Revs. Modern Phys. 21, 51 (1949).
[9] Malmfors, Arkiv Mat. Astron. Fysik 30A, No. 12 (1944) and 32, No. 8 (1945).