Distribution of Neutrons in the Atmosphere

H. M. AGNEW,* W. C. BRIGHT, AND DAROL FROMAN
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
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Measurements on the distribution of neutrons in the atmosphere have been made to an altitude of 36,600 feet. Observations were made with counters filled with boron trifluoride containing 82 percent of B^{10}. Information concerning the spectral distribution of the neutrons was obtained by using the counters in various shielding geometries. Counters were used bare (no shielding), cadmium-covered, boron-covered, and surrounded with a layer of paraffin. The counting rates of all counters varied in the same way with altitude in the pressure range from 20 to 50 cm Hg. Within this pressure range the intensity I is given quite accurately by the relation $I = I_0 e^{-0.083p}$, where p is expressed in cm of Hg. The counting equipment was carried in a B-29 type aircraft.

1. INTRODUCTION

SEVERAL previous experiments[1] have been performed to study the neutrons associated with the cosmic radiation, and some theoretical discussions[2] of their origin have been published. The purpose of the experiments described here was to observe the dependence upon altitude of the total neutron flux and of the general spectral distribution of these neutrons, in the range of altitudes easily accessible to the B-29 airplane in which the equipment was carried. Among other quantities, the "cadmium ratio" was measured at various altitudes. The cadmium ratio is the ratio of the neutron counting rate of a bare counter to that of the same counter, cadmium-shielded, under otherwise identical conditions. Thus, this ratio is a measure of the fraction of neutrons in the thermal region of energy.

2. APPARATUS AND EXPERIMENTAL METHOD

The neutron detectors were proportional counters, $1\frac{1}{2}$ inches in diameter and 11 inches in effective length, constructed with thin brass walls and a 0.0025-inch center wire. The counters were filled with BF_3 to a pressure of 20 cm of Hg. Some counters were filled with BF_3 enriched to 82 percent in the B^{10} isotope, while others were filled with gas containing boron of normal isotopic constitution.

All counters gave counting rates essentially independent of voltage when operated in the region of 1550 to 1650 volts and, since they contained equal quantities of boron, counting rates in a given flux of slow neutrons were in the ratio of the B^{10} contents. Those counters containing 82 percent of B^{10} had an efficiency of about 2 percent for thermal neutrons. Within the statistical counting errors in the experiments described here, all of the counters containing enriched boron showed equal efficiencies for the detection of slow neutrons in the laboratory. The counters containing ordinary BF_3 were used in the flights only to check the assumption that all counts above background were produced by neutrons and not by other cosmic-ray phenomena such as showers. It was assumed that the effects of processes other than neutron capture were negligible if counters in identical geometries gave counting rates proportional to their B^{10} contents at all altitudes.

* Now at the University of Chicago.

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Four counters were used in different geometries during each flight in order that a rough determination of the energy distribution of the neutrons might be made. One counter was used without shielding. Its response was expected to vary in the same way with neutron energy as the B^{10} capture cross section, i.e., the sensitivity was expected to be approximately inversely proportional to the velocity of the neutrons. Another counter was covered with 0.030-inch cadmium sheet. This shield absorbed neutrons with energies less than about 0.4 ev but had little effect on the response of the counter to neutrons of greater energy. A third counter was surrounded by a layer one inch thick of B_4C (normal boron) packed to a specific gravity of 1.3. Because this shield exhibits an absorption inversely proportional to neutron velocity, the enclosed counter was effectively protected against neutrons of energies less than several tens of electron volts. The fourth counter was enclosed in a cadmium-covered cylindrical shield of paraffin with 2-inch wall thickness. This counter was primarily a fast neutron detector since its sensitivity was roughly independent of neutron energy in the range from a few electron volts to about a million electron volts.

Precautions were taken to insure that the counters were influenced as little as possible by their surroundings in the airplane. The bare, cadmium-shielded and boron-shielded counters were placed in the pressurized tail gunner's compartment of the B-29. All gunnery equipment and hydrogenous material were removed from this section, and the armor glass of the observation ports was replaced by Duralumin and steel. The effects of the counters on each other were minimized by spacing them about 2 feet apart. A small high voltage battery and preamplifiers for the counter signals were the only other pieces of apparatus in the tail compartment. Removal of the kapok insulating layer from the tail resulted in rather low temperatures in this section of the plane during flight. In order to insure that the counter voltage remained constant, the battery was enclosed in a steel box lined with hair felt and heated electrically from the plane's 28-volt line. The counters themselves were checked in the laboratory and found to be insensitive to temperature in the range from $-55°C$ to $25°C$.

The paraffin-covered counter could not be placed near any of the others during the experiment because of the effect of the paraffin on

TABLE I. Neutron counting rates observed during flights.

Date of flight	Atmospheric condition	Altitude (ft.)	Pressure (cm Hg)	Counts per minute corrected for background $A(E)$	$Cd(E)$	$B_4C(E)$	$A(N)$	$B_4C(N)$	$P(E)$	Enriched to normal ratio $A(E)/A(N)$	Cadmium ratio $A(E)/Cd(E)$
5/8/46	Clear	36,650	16.6	25.37	—		—	—	332	—	
		34,700	18.1	21.57	—		5.06	—	301	4.30	
		29,700	22.9	15.37	—		3.86		216	3.98	
		*24,850	28.4	9.67	—		2.56	—	150	3.78	
		20,100	34.8	5.45	—		−0.95	—	82	—	
										$B_4C(E)/B_4C(N)$	
5/21/46	Clear	33,630	19.1	18.47	9.14	6.45		1.59	322	4.06	2.02
		*29,770	22.9	15.53	6.74	4.35		1.23	217.3	3.54	2.31
		24,830	28.3	11.25	4.84	2.39		0.46	159	5.18	2.32
		*19,940	35.0	6.32	2.84	1.59		0.39	87	4.07	2.22
		*15,000	43.0	2.97	1.13	0.72		0.32	—	2.25	2.63
		14,840	43.2	2.54	1.02	−0.005		0.01	42.6	—	2.49
		*9,980	52.5	0.57	0.7	0.05		−0.37	16	—	0.81
4/11/46	Clear	29,900	22.8	17.67	7.93				250		2.22
		*26,900	26.0	12.47	5.96				184		2.09
		24,780	28.5	9.97	4.79				154		2.08
		*22,000	32.0	7.41	3.65				113		2.03
		19,800	35.2	6.25	2.45				85.8		2.55
		*17,000	39.7	4.01	1.93				59.2		2.08
		*12,000	48.4	1.34	0.77				26.2		1.74
3/20/46	Clouds at 22,000	29,800	22.8	16.97	8.84	3.74			252		1.92
		24,930	28.3	12.67	6.21	2.74			164		2.04
		14,930	43.2	4.74	2.05	1.02			45		2.31
4/5/46	Cloud up to 25,000 ft., flying 200 ft. under toward hole	10,000		10.07	6.91	7.08			20.6		1.45
		10,300		3.37	1.97	1.92			25.6		1.71
		10,300		4.57	1.77	1.92			24.0		2.58
		10,380		2.97	0.97	1.52			24.0		3.06
		10,420		2.27	1.17	1.52			19.2		1.90

*Coming down.

Note: Counter filling indicated by
(E) = enriched boron
(N) = normal boron

Counter shielding indicated by
A = bare (no shield)
Cd = cadmium shield
B_4C = boron carbide shield
P = paraffin shield

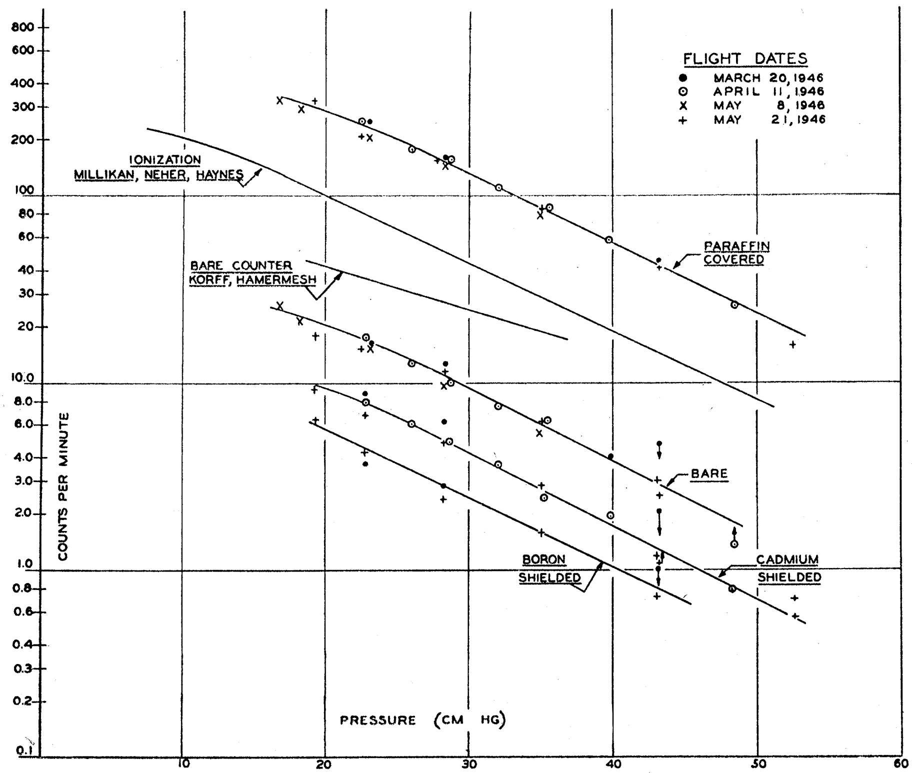

FIG. 1. Neutron distribution in the atmosphere.

their counting rates. Thus, this counter was suspended from the ceiling of the radar room near hydrogeneous material whose geometry did not remain constant during a run. However, the 0.030-inch cadmium cover surrounding the paraffin shield rendered this counter insensitive to neutrons thermalized in the vicinity. Initially it was feared that the gasoline carried by the plane (some 6500 gallons) would affect the counting rates. However, measurements taken at the same altitude at the start and at the end of a flight, after the gas load was some 3,500 gallons less, gave the same results even for the paraffin-shielded counter in the radar room. The radar room is much nearer the gasoline tanks than is the tail compartment. Consequently, it is believed that the counters in the tail compartment can be considered to be in free space, except for the dural tail structure.

The recording equipment consisted of preamplifiers placed near their respective counters and linear amplifiers, scalers, and mechanical registers. The filament supply lines for the preamplifiers and the co-axial signal leads were strung from the tail compartment to the recording equipment which was placed in the radar room. Only four sets of recording equipment were used, so that it was not possible to use both the enriched and normal counters with all types of shielding simultaneously. The normal boron counters were used only in replacement for the enriched bare counter and the enriched boron-shielded counter.

3. RESULTS AND CONCLUSIONS

The ratio of the slow neutron efficiencies of the enriched and normal boron counters was measured in the laboratory. This ratio was compared with that obtained at various altitudes for both the bare and the boron-shielded counters and was found to remain constant within the statistical counting errors. This meant that the counters were counting neutrons plus natural background at all times, and that the effects of showers were negligible. It is clear that, if one-inch thickness of B_4C did not produce enough showers to be detectable, a thickness of 0.030 inch of cadmium would not either. Hence, the cadmium-covered enriched boron counter was never replaced by a normal boron counter.

The observed counting rates obtained in five flights are given in Table I. In two of these flights the recording equipment for one of the counters failed, and in one flight counting rates were obtained with five counters by using the same recording equipment part time at each altitude for two different counters. The geometries used for each counter are indicated in the table. Each of the counting rates given in Table I is obtained from a run of about 30 minutes. The statistical error can be estimated in any particular case from the total number of counts obtained by multiplying the counting rates given in the table by a factor of 30. Figure 1 shows curves of counting rate plotted against atmospheric pressure for the four enriched counters. These curves are parallel within experimental error. The curve for the boron-shielded counter includes data from only two of the flights as indicated in Table I.

The two curves with titles to the left in Fig. 1 are included for comparison and are plotted to an arbitrary scale. The upper curve for ionization caused by cosmic rays[3] is parallel to the curves obtained in these experiments. The lower of these two curves represents recent data obtained by Korff and Hamermesh[1] by means of an unshielded BF_3 counter carried by an unmanned balloon. The difference in slope between this curve and the others shown may arise from the relatively poor statistical accuracy, especially at the lower altitudes, which is attained in balloon flights.

One flight was made during cloudy weather, and the condition of the aircraft kept it below the clouds. It was extremely difficult to note the plane's position relative to the main body of clouds, as it was about 200 feet beneath them at all times. The only data obtained were taken under an extremely thick cloud. Observations were continued while the plane flew toward an opening in the overcast. Directly under the body of the cloud, the counting rate was high, except in the paraffin-covered monitor. As the opening was approached, the counting rate in the other counters decreased. It is hoped that this effect can be checked in later experiments incorporating a humidity measuring device. Data from this flight are not plotted in Fig. 1.

Within the error of these experiments the cadmium ratio is found to be constant, with a value about 2.2, at all altitudes from 7000 to 34,000 feet above sea level. The value of the ratio at the lower of these altitudes was obtained in the laboratory and is not shown in Table I. It is clear from the slopes of the graphs shown in Fig. 1 that the neutron counting rate of all the counters varied in the same way with the altitude as does the total ionization produced by the cosmic radiation. Thus, no variation of spectral distribution with altitude was observed, although it is evident that the experiment was not designed to detect variations in the neutron energy distribution in the region above 100 ev or so. In the pressure range 20 to 50 cm of Hg the neutron flux, I, observed with all counters is quite accurately given by $I = I_0 e^{-0.083p}$, where p is the pressure expressed in cm of Hg.

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[3] R. A. Millikan, H. V. Neher, and S. K. Haynes, Phys. Rev. **50**, 992 (1936).