The Specific Ionization of the Cosmic Radiation above the Atmosphere*

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A DIRECT measurement of the average primary specific ionization of the cosmic rays above the atmosphere has been conducted in order to gain more information about the nature of the primary radiation. The results presented are based on one rocket flight and are of preliminary character.

A counter telescope (Fig. 1) containing a low efficiency counter was installed in a V-2 rocket launched at the White Sands Proving Ground ($\lambda = 41°$) on February 17, 1949. The low efficiency counter B' had an effective length of 14.5 cm, an effective diameter of 2.38 cm, and was filled with pure hydrogen to a pressure of 5 cm Hg; it required an external quenching circuit. The other counters in the telescope were constructed similarly, but filled with a standard mixture of argon and alcohol. Their measured efficiency was better than 99.3 percent. The following triple coincidences were telemetered: telescope counts (ABC), ($AB'C$), and guard counts (ACG). The solid angle of the telescope was covered by about 1 g/cm^2 of aluminum. The same telescope had been installed in an Aerobee rocket in November 1948 in a much "cleaner" environment but was transferred to the V-2 after postponement of the Aerobee firing.

The efficiency of a G-M counter is given by the well-known expression

$$\eta = 1 - \exp\{-(\text{prim. spec. ioniz.}) \times (\text{path length through counter}) \times (\text{counter pressure})\}.$$

This dependence of efficiency on primary specific ionization has been used in cosmic-ray investigations at low altitudes.[1-3] In the present experimental arrangement, the efficiency of counter B' for single particles is the ratio $ABB'C/ABC$.** At Silver Spring (altitude 120 m) and at White Sands (altitude 1200 m), the experimental efficiency was 0.585 ± 0.019.*** The rocket spent 238 seconds on the high altitude cosmic-ray plateau (above 55 km).[4] The measured efficiency on the plateau was 0.689 ± 0.027. The guard count correction in the high altitude case was about 40 percent; however, we believe that the shower protection was adequate since most of the material near the telescope was disposed at its side. Furthermore, with all guard counts subtracted out, the telescope counting rate yielded an average intensity above the atmosphere $j = 0.10$/sec.$-$cm$^2-$steradian, in substantial agreement with previous measurements.[4] In any case, leaving in all shower counts did not appreciably affect the value for the high altitude efficiency. However, the following corrections need to be considered:

(i) A geometrical correction has to be made to the efficiency since the average path length through counter B' increases in going above the atmosphere, as the zenith angle distribution of the radiation changes from a $\cos^2\theta$ dependence to a more nearly isotropic distribution. This correction for our particular case is less than 0.02.
(ii) The knock-on correction amounts to about 0.01 but is already present in the low altitude value for efficiency.
(iii) The burst correction has been estimated from the transition curve of the primaries in aluminum[5] to be less than 0.01. We can safely assume that most bursts tripped a guard counter and have, therefore, been already subtracted.

On the basis of these considerations, the best value for the high altitude efficiency is 0.670 ± 0.027, compared to a low altitude value of 0.585 ± 0.019.

Insofar as we can believe in the validity of these results—and indeed it seems reasonable to do so in view of the arguments advanced earlier, in spite of the large shower correction—their interpretation leads to rather interesting consequences:

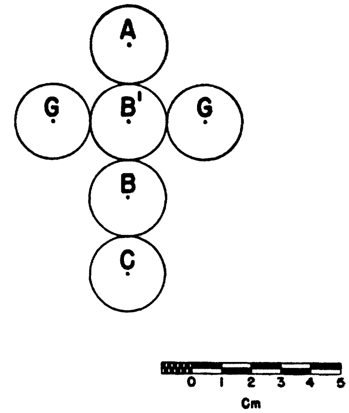

FIG. 1. Inefficient telescope.

(i) The principal conclusion one can draw is that the *ionizing radiation above the atmosphere* is predominantly *singly charged* and has an average primary specific ionization appreciably higher than minimum.

On the over-simplified assumption (see below) that the radiation above the atmosphere consists exclusively of primary rays, we can estimate from the theoretical geomagnetic cut-off and the observed latitude effect an average momentum for any assumed type of particle.

(ii) *The data are then in clear disagreement with the hypothesis of a pure electronic primary radiation.* Hereford[6] has demonstrated experimentally the rise in primary ionization for electrons of energy higher than 1.5 Mev. 10-Bev electrons should be detected with an efficiency of about 0.80 by our arrangement. It may be remarked that, aside from the general burden of other evidence against this hypothesis, there are the recent balloon cloud-chamber results of the Minnesota group that electrons do not represent more than 1 percent of the primary beam.[7]
(iii) *The data are not consistent with the assumption of a pure proton beam of primaries.* Since the primary ionization of a 10-Bev proton is about the same as the average sea level meson (about 1 Bev) there should have been no appreciable difference between low altitude and corrected high altitude values of efficiency.

We can finally proceed to examine the consequences of a mixture of particles in the primary radiation:

(iv) *For an assumed proton-electron mixture the data require the electron intensity to be 41+6 percent of the primary beam.* This possibility is excluded on other grounds, as under (ii).
(v) *For an assumed proton-alpha-particle mixture the data give an alpha-particle intensity of 20±8 percent.* This fraction is consistent with the estimate made by the Minnesota group based on cloud-chamber data at balloon altitudes.[8]

The data obtained in the present experiment do not furnish a basis for excluding more complex mixtures. More importantly, there is evidence that secondary radiation from the earth's upper atmosphere contributes significantly to the intensity observed above the atmosphere. Thus, it is more realistic to attribute the measured average specific ionization to a mixture of primary and secondary particles. The zenith angle dependence of the efficiency may make possible a separation of primary and secondary contributions. The subject is being pursued in further experiments using different telescope arrangements and counters of different efficiencies.

At any rate, conclusion (i) is independent of detailed assumptions and may be regarded as the principal result of this preliminary work.

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[1] W. E. Danforth and W. E. Ramsey, Phys. Rev. **49**, 854 (1936).
[2] M. G. E. Cosyns, Bull. Acad. Belg. **5**, 498 (1937).
[3] F. L. Hereford, Phys. Rev. **75**, 923 (1949).

** More precisely

$$\eta=\frac{(AB'C)\cdot(ABC)-(AB'C)\cdot(ABC)\cdot(ACG)}{[(AB'C)\cdot(ABC)-(AB'C)\cdot(ABC)\cdot(ACG)]+[(ABC)-(ABC)\cdot(ACG)]}.$$

*** All errors quoted are standard errors.

[4] Gangnes, Jenkins, and Van Allen, Phys. Rev. **75**, 57 (1949).
[5] Fraser, Ostrander, Van Allen, Echo Lake Conference (June 1949).
[6] F. L. Hereford, Phys. Rev. **74**, 579 (1948).
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Spontaneous Neutron Emission from Uranium and Samarium

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EXPERIMENTS with 200-micron Ilford C2 plates show that about 15 mg of B^{10} and 2 mg of Li^6 can be incorporated per ml of emulsion after soaking for 2 hours in a solution containing 10 g of lithium borate and 3 ml of glycerine per 100 ml without causing appreciable loss in sensitivity for densely ionizing particles.[1,2] The high concentration of B^{10} and Li^6 nuclei, coupled with the large cross section for slow neutron capture, provide an exceedingly sensitive recording medium for the measurement of slow neutron flux. Thus, a detector plate situated 1.3 cm from a ~4-mc Po-Be disk enclosed in the paraffin cylinder described in Fig. 1 recorded a population of 8.38×10^3 tracks per ml of emulsion originating from the $B^{10}(n,\alpha)Li^7$ reaction after only a 15-min. exposure. Counts of proton recoil tracks show that the source emitted a total of 3.85×10^6 fast neutrons during the same interval, indicating the registration of 1 $(B^{10}+n)$-track per ml of emulsion per 460 ± 24 fast neutrons generated.

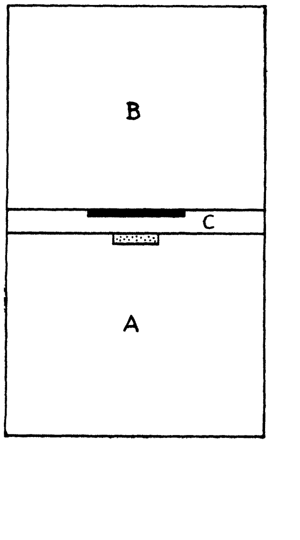

FIG. 1. Paraffin cylinder for slow neutron measurement. Two 1-lb. iron tobacco cans are each filled flush with 1450 g of molten paraffin. *A* serves as a sample holder and *B* as a neutron reflector. The plate holder *C* is a paraffin disk 16 mm thick carrying a 1×2-inch plate wrapped in paraffined-black paper. The cylindrical arrangement was chosen for convenience, and its efficiency has not been compared with a cubical or spherical disposition.

TABLE I. $(B^{10}+n)$-track counts from U and Sm.

Experiment	Exposure hours	Volume surveyed	Track count	Counts per ml per day
A—Blank	449	0.0155 ml	19	66
B—36.4 g U	449	0.0216	111	276
C—18.6 g Sm_2O_3 powder	449	0.0126	16	68
D—18.6 g Sm_2O_3 pellet	689	0.0080	21	92
E—20 g rare earth oxide pellet	689	0.0089	16	63
F—31.8 g U metal	689	0.0085	55	227

The calibration data suggest that by extending the exposure to 500 hours flux of the order of 2×10^{-6} slow neutron per sec. per cm^2 could be measured with an uncertainty less than 20 percent. As a test, three identical paraffin cylinders were assembled. *A*—containing paraffin only served as a control for cosmic-ray neutrons, *B*—contained a disk of uranium of approximately the same volume as the Po–Be source, and in *C*—a 25-ml cavity was filled with Sm_2O_3 powder. The units were stored in the subbasement of a sea level building in which prior measurements showed an evaporation rate of 0.29 star per ml per day.[3] The $(B^{10}+n)$ tracks were counted with a 98× fluorite objective and 7.5× compensating oculars. High magnification is essential in order to discern the short tracks of 6- to 7-micron length at all angles of incidence and to differentiate them from occasional rod-shaped artifacts in the gelatin. The alpha-triton tracks from the $Li^6(n,\alpha)H^3$ reaction were noted, but were too few in number to constitute a quantitative check for the boron slow neutron reaction.

The differential counts between *B* and *A* (Table I) indicate the emission of 2660 fast neutrons per day per g of U. If this be attributed to spontaneous fission of U^{238} with one neutron released per fission, the count corresponds to a half-life of 1.8×10^{15} yr. This is in good agreement with the value of $(2.5\pm0.6)10^{15}$ yr. observed by Maurer and Pose[4] employing a cylinder of uranium weighing 8.82 kg.

As a check on the reproducibility of the method, the experiment was repeated with a smaller mass of uranium and an extension of exposure time. Also the samarium oxide was compressed into a pellet of 10-ml volume to provide better geometry, and a similar pellet of mixed rare earth oxides from Norwegian gadolinite was employed as a monitor. This measurement showed the emission of 2370 fast neutrons per day per g of U corresponding to a half-life of 2.0×10^{15} yr. The deviation from the mean value of $(1.9\pm0.1)10^{15}$ yr. indicates a reproducibility of about 5 percent.

Compression of the samarium oxide powder increased the track count by 39 percent. If this be attributed to fast neutron emission from the samarium preparation, the half-life of the process is estimated at 10^{16} yr. In view of the small differential count and that neutrons may have originated by interaction of samarium alpha-particles with light nuclei impurities in our preparation, confirmation of the effect must be made using larger quantities of samarium specifically purified from beryllium, boron, and other elements with a large cross section for (α,n) interaction. The observed neutron production, if attributed to $Be^9(\alpha,n)C^{12}$, would necessitate the presence of about 1 percent BeO as impurity in the Sm_2O_3. This degree of contamination is improbable in a rare earth preparation isolated from monazite sand.

Estimate of cosmic-ray neutron contribution to observed neutron emission from uranium.—An analysis of one of the $Li_2B_4O_7$-loaded plates from the same batch employed in the measurements revealed a B^{10} concentration of 9.3×10^{20} atoms per ml. The plate exposed in the blank cylinder (*A*) exhibited 66 tracks per ml per day arising from the $B^{10}(n,\alpha)Li^7$ reaction. This affords a measure of the average cosmic-ray slow neutron flux in our laboratory during the period of the exposures:

$$\text{slow neutron flux}=\frac{66}{3525\times10^{-24}\times9.3\times10^{20}}=20.1\ \text{cm}^{-2}/\text{day}.$$