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A Search for Primary Cosmic Gamma-Radiation. I

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A search has been made for primary cosmic gamma-radiation in the energy range 3.4 to 90 Mev. The apparatus was a counter telescope in which ionizing rays were excluded by anticoincidence and γ-rays detected by their conversion products in lead. The apparatus was carried above the atmosphere in a V-2 rocket launched at White Sands, New Mexico. The recorded γ-ray counting rate is reduced about a factor of 2 by corrections of various sorts. The variation of detection efficiency with energy permits the results to be stated in terms of the energy crossing unit horizontal area in unit time. The result is 1.4 Mev/cm^2/sec. This is 1300 times less than the corresponding figure for the total cosmic-ray energy at this latitude. Considering the smallness of the result and the nature of the corrections, it is possible that the result is actually a null one.

I. INTRODUCTION

It is generally believed that energetic gamma-rays cannot constitute more than a very small fraction of the primary cosmic radiation. Millikan and co-workers[1] have shown that sixty-five percent of the incoming energy is sensitive to the earth's magnetic field and hence is due to charged particles. Most of the remainder must be attributed to similar primaries of higher energy. A considerably lower limit to the gamma-ray intensity can be deduced from a recent cloud chamber measurement,[2] which demonstrates that at an atmospheric depth of 20 g/cm^2, the small number of electrons present with energies greater than 1 Bev sets an upper limit to the primary *electron* intensity of a few tenths percent of the total charged primary intensity. Since 20 g/cm^2 is an appreciable fraction ($\sim\frac{1}{2}$) of a radiation length, we may infer that primary photons of comparable energies are comparably rare.

No experiment reported to date however has established the absence of *low* energy primary gamma-rays. At balloon elevations, the soft-component produced in the remaining atmosphere makes any such measurement subject to difficulties of interpretation. We have therefore attempted to make a direct measurement by use of a rocket. Essentially three experiments were done. In the first we looked for gamma-rays in the energy interval 3.4 to 90 Mev, in the second for lower energies, down to 0.1 Mev, and in the third for a diurnal effect of the latter radiation. This paper reports on the first experiment. This was done in a V-2 at White Sands, New Mexico, on January 28, 1949.

II. THE EXPERIMENTAL METHOD

Figure 1 shows the apparatus schematically. Anticoincidences $AB-(C+D)$ were the primary data telemetered[3] from the rocket. Coincidences AB were telemetered for reference. The action of the counter trays and absorbers is as follows:

(1) A gamma-ray from above is distinguished from a similar ionizing ray by its failure to trip any counter in tray C.

(2) The gamma-ray produces electronic conversion products in the 6.3-mm lead annulus S_1, and these are detected by coincidence between the thin-walled counters A and B.

(3) A 1.9-mm Cu absorber S_2 between A and B insures that the recorded electron has energy >3.2 Mev and its parent γ-ray >3.4 Mev (if Compton effect is the conversion process).

(4) The electrons are absorbed in the 2.42-cm lead annulus S_3 whose existence is justified by its permitting the use of anticoincidence tray D. The latter rules out ionizing rays from below which might stop in S_1 and record as an apparent γ-ray from above. S_3 sets an upper limit on the energy. According to Snyder[4] a photon initiated cascade, developing through the combined thickness of S_1 and S_3, will degenerate to an average number of electrons $\bar{N}\leq 1$ emerging below if the photon energy was originally ≤ 90 Mev. It suffices in the present work to consider 90 Mev as the upper cutoff of the instrument.

The rocket was launched at 10:20 A.M., MST. For reasons not associated with the experiment the jet was turned off by radio signal before complete exhaustion of the fuel. The rocket rose to a peak altitude of 61 km above sea level corresponding to an atmospheric pressure of 0.16 mm Hg. This occurred 149 seconds after take-off. By this time the rocket zenith angle had advanced to about 20 degrees toward the north. The data taken between 90 and 167 seconds have been lumped together as being "above the atmosphere." The atmospheric pressure for this interval was less than 1.3 mm Hg and the zenith angle less than 45°.

Figure 2 shows the counting rates of coincidences and

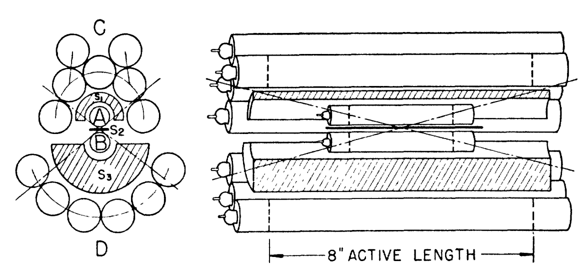

FIG. 1. Diagram of the apparatus. S_1 and S_3 are 6.3 mm and 2.42 cm of lead, respectively. S_2 is 1.9 mm of copper. Counters C and D have 0.8-mm copper walls. A and B have 0.15-mm aluminum walls.

[1] Bowen, Millikan, and Neher, Phys. Rev. **53**, 855 (1938). Millikan, Neher, and Pickering, Phys. Rev. **61**, 397 (1942). Millikan, Neher, and Pickering, Phys. Rev. **66**, 295 (1944).
[2] Critchfield, Ney, and Oleksa, Phys. Rev. **79**, 402 (1950).
[3] N. R. Best, *Electronics* August, **23**, 82 (1950).
[4] H. S. Snyder, Phys. Rev. **76**, 1563 (1949).

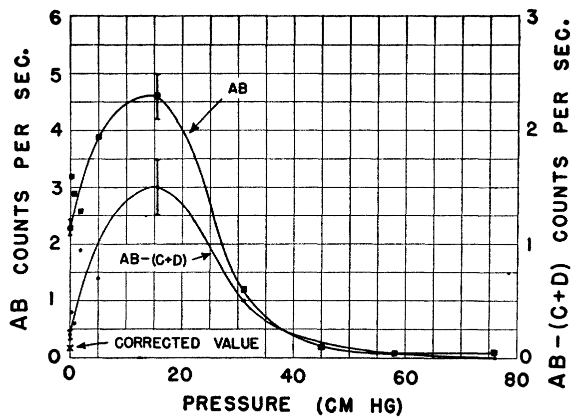

FIG. 2. Counting rates of coincidences and anticoincidences as a function of pressure altitude.

anticoincidences as a function of pressure altitude. Within the meager accuracy of this part of the data the gamma-radiation and the ionizing radiation peaks occur at the same altitude. The curves are uncorrected. The corrected value (discussed below) for the γ-ray point at "zero" pressure appears on the counting rate axis. The corrections are important only for this and neighboring points. The rate of coincidences AB corresponds to a particle intensity of 0.155 particle/cm²/sec/steradian. This is about a factor of two higher than what is believed on the basis of other measurements[5] to be the correct value; but it is not surprising when one considers the vulnerability of the AB rate to showers in the lead. The influence of this type of event on the anticoincidence rate is not large, and is considered in Appendix A.

Table I represents the data and corrections above the atmosphere. The uncorrected ratio $AB-(C+D)\div AB$ is 8.7 percent. Application of the corrections reduces this to 3.9 percent. Applying the telescope geometrical and efficiency factors (Appendix B) we arrive at an incoming γ-ray energy flow in this interval of 0.46 Mev/cm²/sec/steradian. If isotropy is assumed in the upper hemisphere, we have finally that the γ-ray energy flow across a horizontal surface in the energy range 3.4 to 90 Mev is 1.4 Mev/cm²/sec. The corresponding energy for the total radiation at this latitude as deduced from the ionization integrals[1] is 1.8×10^3 Mev/cm²/sec, or 1300 times greater. Considering the nature of the corrections discussed below and the smallness of the answer, there is a question as to whether our result is not actually a null one. In any case it is not far from being an upper limit.

Because of the recently renewed interest in the sun as a source of cosmic radiation, it is worth noting that there was no significant difference in counting rate during the interval in which the sun lay inside the solid angle of the telescope compared to that in which it lay outside. At the time of the launching on January 28 there was a large spot on the west limb of the sun. It had been active on January 24, 25, and 26 but was no longer so. Another smaller spot was also present and inactive.[6]

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APPENDIX A. CORRECTIONS TO THE ANTICOINCIDENCE RATE

(1) Twofold accidentals of type AB. This is readily shown to be negligible with the coincidence resolving time of 5×10^{-6} second.

(2) Circuit and dead time of the anticoincidence trays. There was a dead time of 60 μsec associated with each C or D count. This was inherent in the electronic design. There was also a counter dead time of 200 μsec associated with each counter. There are many different ways in which these can conspire to make an AB event appear as $AB-(C+D)$, but the saving feature is that, since most of the rays above the atmosphere are penetrating,[7] if the C tray is dead, the D tray will generally suffice and *vice versa*. The result is that an inefficiency of 0.5 percent exists. This fraction applied to the AB counting rate gives the rate of spurious anticoincidences due to this cause.

(3) Lack of complete solid angle coverage of the telescope AB by the trays C and D. Presumably this is mainly so for rays of extreme obliquity. The effect has been estimated by plotting the anticoincidence rate on the ground as a function of the converter thickness and extrapolating to zero thickness. The converter is not entirely absent even when the lead S_1 is removed, since there

TABLE I. Experimental counting rates and corrected values.

Event	Counts/sec above atmosphere	Counts/sec sea level
AB	2.30±0.11	0.110 ±0.002
$AB-(C+D)$ (uncorrected)	0.20±0.04	0.0124±0.0005
Corrections to $AB-(C+D)$		
Accidentals	0.000	
Dead time	0.010	
Leakage	0.070	
Stars	0.025	
Showers	0.005	
Total	0.110	
$AB-(C+D)$ (corrected)	0.09±∼0.05	
Geometrical* factor	14.8 counts = 1 count/cm²/ster	
Efficiency factor	1 count = 75 Mev (approx.)	
"Vertical" γ-ray energy flow		0.46 Mev/sec/cm²/ster
γ-ray energy flow across 1 horizontal cm² from upper hemisphere		1.4 Mev/cm²/sec
Total primary energy flow (Millikan, *et al.*)		1800 Mev/cm²/sec

* Computed from curves in H. E. Newell and E. Pressly, Rev. Sci. Instr. **20**, 568 (1949).

[5] J. A. Van Allen and S. F. Singer, Phys. Rev. **78**, 819 (1950). Winkler, Stix, Dwight, and Sabin, Phys. Rev. **79**, 656 (1950).

[6] We are indebted to A. Shapley of the National Bureau of Standards for this information.

[7] G. J. Perlow and J. D. Shipman, Jr., Phys. Rev. **71**, 325 (1947).

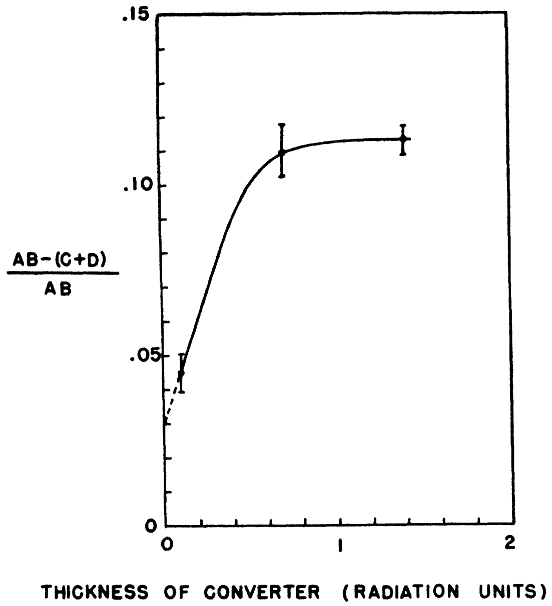

FIG. 3. Effect of varying converter thickness at sea level. The anticoincidence rate is expressed as a fraction of the coincidence rate obtained with full converter thickness.

remain still the counter walls and 3 mm of aluminum structure. In Fig. 3 this is taken into account by using as abscissa the thickness in radiation units of the total material lying between the active volumes of counters C and counter A. The curve rises steeply with thickness reaching a plateau in the neighborhood of 1 radiation unit. The extrapolation to zero thickness gives a leakage effect of about 3 percent of the AB counts. The number should possibly be increased when applied to the flight data, because the radiation is then more nearly isotropic. Counterbalancing this, however, is the circumstance that a considerable fraction of the AB rate is due to locally generated multiples. Thus, use of the observed AB rate over-emphasizes the intensity of the radiation available for the "leakage" effect. The difficulty in making a more precise correction for this effect causes the largest uncertainty in our final result.

(4) The anticoincidence rate is sensitive to stars produced in the region adjacent to counters A and B. The star production rate in a rocket has been determined by the plate measurements of Yagoda and co-workers[8] made in a V-2. Although the rate is dependent on the disposition of neighboring materials, we shall assume their figure of 5000/day/cm^3 of emulsion. This figure is quite high, so that we are not likely to be underestimating the influence of stars.

Examination shows that the stars observed by Yagoda, *et al.*, have about the same distribution in regard to number of prongs as those observed by the Bristol group[9] at 11,000 ft, thus establishing their origin as secondaries for the most part. We have therefore used the latter data to obtain the distribution of the number and energy of particles in the stars. The class of star we must consider (0_n in the Bristol notation) is produced by neutral radiation and contains a variable number N of heavily ionizing particles. We may disregard those produced by a charged primary as well as those emitting fast "shower" particles, since these will almost always trip trays C or D. On the basis of the data of reference 9, it is convenient to divide the N particles in a star into two groups, g particles consisting mainly of protons averaging about 100 Mev, and $N-g$ particles consisting of protons and heavier fragments averaging about 10 Mev. The first group of particles is able to penetrate the 1.9 mm of copper separating counters A and B, while the second group is not.

The nature of the calculation may be illustrated by reference to the effect of stars in the copper absorber S_2. We consider a strip on either side of the copper of a thickness equal to the range of a 10-Mev proton and calculate the probability that a star with $N-g$ assumed protons will produce a count in the adjacent counter. This is multiplied by the probability for the star to contain just N particles and then by the probability that at least one of the g particles will strike the other counter. The product is summed over N. Similar calculations are made for the other material surrounding counters A and B. Multiplication by the production rate in the strips gives the required anticoincidence rate.

(5) Another effect is due to primary particles striking the lead pieces S_1 or S_3 obliquely and producing a narrow angle shower which trips A and B without C or D. Assuming a particle intensity of 0.07 particle/sec/cm^2/steradian and a mean free path for interaction in lead of 160 gms/cm^2, one may make an estimate by considering the distribution in shower types as given by the high altitude Bristol data.[10] The correction is not to be trusted within perhaps a factor of three, but it is so small that it does not influence the results.

APPENDIX B. EFFICIENCY

The detection efficiency for γ-rays can be estimated fairly simply because of the circumstance that the converter S_1 is only slightly more than a radiation unit in thickness. It is therefore adequate to consider only the electrons of the initial conversion and not the further generations they would produce in greater thicknesses. Compton effect is not important except for the very bottom of the energy range and is therefore neglected.

A photon of energy W penetrates to a depth l (radiation units) and produces a pair in dl with probability $P(l, W)dl=\delta e^{-\delta l}dl$, $\delta=7/9$. For some energy $E<W$ the probability that at least one electron of the pair will have energy $>E$ can be shown to be

$$H(E, W)=\begin{cases} 2(1-E/W), & \text{for } E\geq W/2 \\ 1 & \text{for } E\leq W/2. \end{cases}$$

This assumes equal probability for any division of energy between the particles and $W\gg 2mc^2$. If we now take E as the energy necessary for an electron originating at l just to get through the remaining thickness l_0-l and after emerging to have enough energy left (3.2 Mev) to penetrate the copper absorber S_2, then the quantity,

$$\eta(W)=\int_{l=0}^{l_0} P(l, W)H(l_0-l, W)dl,$$

is the probability of a count and therefore the efficiency. The mean range of an electron in lead including radiation loss is obtained as a function of E from Heitler's tabulation.[11] We assume all electrons to have the mean range and neglect scattering and obliquity of path. $\eta(W)$ has been evaluated numerically. It is approximately proportional to W up to $W=35$ Mev and thereafter is constant at 70 percent. For photons of a given energy, W/η is the average energy corresponding to each count. If the ratio were a constant over the energy range of the instrument, the intensity of "counts" could be multiplied by W/η to give energy intensity. The ratio has the nearly constant value 50 Mev/count up to $W=35$ Mev. It then increases linearly to 125 Mev/count at $W=90$ Mev. A suitable average is 75 Mev/count, and this is the value used in calculating the incoming gamma-ray energy.

[8] Yagoda, de Carvalho, and Kaplan, Phys. Rev. **78**, 765 (1950).

[9] Brown, Camerini, Fowler, Heitler, King, and Powell, Phil. Mag. **40**, 862 (1949).

[10] Camerini, Coor, Davies, Fowler, Lock, Muirhead, and Tobin, Phil. Mag. **40**, 1073 (1949).

[11] W. Heitler, *The Quantum Theory of Radiation* (Oxford University Press, London, 1944), second edition, p. 223.