Notas de Física Vol. III, Nº 5

DIRECTIONAL INTENSITIES OF POSITIVE AND NEGATIVE MESONS IN THE ATMOSPHERE * +

I. Escobar V.

Laboratorio de Física Cósmica, La Paz, Bolívia

and

F. B. Harris

Utica College of Syracuse University, Utica

New York, U.S.A.

(August 8, 1956)

I. INTRODUCTION

In an earlier work[1], the authors described an experiment performed at Chacaltaya, Bolívia, in which the intensities of positive and negative mesons were measured at various angles in the east-west planes. It was found possible to explain the observed counting rates at 45° east and west and at the vertical by a μ-meson production spectrum of the form.

---

* Submitted for publication to The Physical Review

+ This research was supported by the U.S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command. The data obtained at Echo Lake and Chacaltaya, referred to herein, were obtained with the support of the joint program of the Office of Naval Research and the U.S. Atomic Energy Commission.

$$G(R') = A\left[R' + a(M_c)\right]^{-n} , \qquad (1)$$

where M_c is the effective cutoff magnetic rigidity at the latitude, longitude, and direction of incidence of the primary particles under consideration.

The excellent agreement between theory and experiment mentioned above necessitated the introduction of corrections due to the following effects: (1) spurious counts, (2) equipment normalization, (3) lack of collimation in the production of π mesons, and (4) finite solid angle of the equipment In large part, the corrections were evaluated using certain of the data themselves, and the remaining data were then found to be perfectly consistent with the theory.

Additional data, for zenith angles of $22\frac{1}{2}^{\circ}$ and $67\frac{1}{2}^{\circ}$, obtained in the course of the same experiment, offer a means for a more rigorous check of the theory, since the various corrections for these angles may now be based on the results of the earlier, 0° and 45° data.

The same equipment was operated at Echo Lake, Colorado during the summer of 1951, at 45° east and west. These data permit a separate test of that part of the theory which refers to the curvature of mesons in the atmosphere after production, since at that latitude there is practically no asymmetry in the primary radiation.

II. TEST OF THE THEORY AT LOW LATITUDE

The $22\frac{1}{2}^{\circ}$ counting rates obtained at Chacaltaya were corrected downward by an assumed spurious counting rate of 0.81 ± 0.20 hr^{-1}. This figure was arrived at by assuming that the spurious rate for a given zenith angle followed the same rule here as was found for 0° and 45°, i.e. that it was proportional to the sum of the four counting rates at that angle, positive and negative, east and west. The resulting rates were then multiplied by the normalization factors found in that analysis.

If one uses the curve obtained in reference 1, and M_c = 11.7Bv (west), 17.2 Bv (east), one finds for the parameter a of the theory[1] 620 and 686 g cm^{-2} for $22\frac{1}{2}^{\circ}$ west and east, respectively. The theoretical counting rates were computed, using these values of a . They were then corrected for the spreading in π -meson production (rms angle of 14°, as in ref. 1), and for the finite solid angle of the equipment.

The experimental rates were used to find the observed positive excesses ϵ , and from them the corresponding positive excesses at production δ . As noted in ref. 1, the latter quantities are of somewhat doubtful reliability, due to their dependence on small and perhaps neglected terms in the expressions for the intensities. Both the ϵ's and the δ's have been shown in Table I. The subscripts refer to the two different momentum channels in the equipment.

TABLE I - Positive excesses observed (ϵ) and at production (δ) at Chacaltaya.

Direction	ϵ_1	δ_1	ϵ_2	δ_2
$22\frac{1}{2}^\circ$ W	+0.063±0.012	+0.041±0.012	+0.071±0.027	+0.041±0.027
$22\frac{1}{2}^\circ$ E	-0.072±0.013	+0.019±0.016	-0.048 0.028	+0.064 0.030

Computation of the positive excess essentially removes one degree of freedom from the data in a given direction. Therefore, for the purpose of comparison with the theory, positive and negative counting rates have been combined in each direction. This procedure has the additional advantage that the sum of the two rates is extremely insensitive to the value of positive excess, and therefore provides a good test of the theory regardless, of erros in the latter quantity. Table II shows that experiment and theory agree closely.

TABLE II- Comparison of experimental and theoretical counting rates for zenith angle $22\frac{1}{2}^\circ$ at Chacaltaya. All rates are in hr^{-1}, and refer to the sum of positives and negatives.

Channel	Direction	Theoretical counting rate (corrected)	Experimental counting rate (corrected and normalized)
I	$22\frac{1}{2}^\circ$ west	45.85	45.46±0.36
I	$22\frac{1}{2}^\circ$ east	39.44	39.95±0.35
II	$22\frac{1}{2}^\circ$ west	9.54	9.47±0.30
II	$22\frac{1}{2}^\circ$ east	8.12	8.14±0.30

If one adopts the viewpoints of ref.1 and regards the "western" part of the a(M_c) curve (i.e. $M_c \leq 13.5$ Bv) as well established, one can normalize the eastern data to the western data. The parameter a at 22 $\frac{1}{2}^o$ east can then be computed from the experimental results to be 678 $\pm$ 5 g cm^{-2} for Channel I and 663 $\pm$ 18 g cm^{-2} for Channel II, as compared with 686 as read from the curve. This Channel I result has been shown on Fig. 1, along with the previous result for 45^o east, and the curve has been redrawn.

Data for 67 $\frac{1}{2}^o$ are available in the west only, as the mountainside at Chacaltaya interferes with the solid angle of the equipment in the east. The corrections for finite solid angle of the equipment and for non-collimation are so large at these zenith angles that computation is nearly impossible. About all that can be said is that theory and experiment agree in order of magnitude. The corrected and normalized experimental sum of positive and negative rates for Channel I was 4.36 + 0.18 hr^{-1}, while the theory, with approximate corrections, predicts 5.70 hr^{-1}.

III. APPLICATIONS OF THE THEORY AT HIGH LATITUDE

A. Approximations in the Theory

The effective critical rigidity at geomagnetic latitudes greater than about 40^o varies but little with zenith angle in the east-west plane. This fact leads to certain simplifications in the theory, due to the near constancy of a with direction.

The simplifications are brought about if the quantity a_1 of the numerical computations[1] is chosen equal to the vertical cutoff rigidity.

First, terms in the theoretical expression for the μ-meson intensities involving the quantity J_2, which describes the primary asymmetry, can be considered to be small quantities, and terms in the square of J_2 can be neglected. Second, terms in J_6, having to do with the variation of a along the meson trajectories, can be totally neglected. Third, since the primary spectrum is nearly the same in all directions, the positive excess at production, δ, can be considered to be the same in the east and west for a given zenith angle.

The authors have investigated the effect of the vertical component of the terrestrial magnetic field at these latitudes. It was found that only the horizontal component produced effects of first order in the magnetic field, the effects of the vertical component being of second order and smaller.

The above considerations make it possible to write the expression for the intensities at high latitude as follows:

$$i_\sigma(R, \Theta) = C \cos^{n-1} \Theta \quad J_1 \left[1 + \frac{1}{2}\sigma \bar{\delta} - (J_2/J_1)(\Delta/H) - \sigma \gamma \tan (J_4/J_1) - \frac{1}{2} \sigma \bar{\delta} \tan \Theta (J_4/J_1) \right] . \qquad (2)$$

B. The Average Secondary Asymmetry

The action of the magnetic field of the earth on the se condary particles produces, at high latitudes, an asymmetry of the positives favoring the west, and a very nearly equal asymmetry of the negatives in the opposite direction. The quantity J_4 of the theory, which expresses this effect, can best be compared with experiment through the measurement of a quantity which will be called the "average secondary asymmetry", defined for a given zenith angle as follows:

$$A_{Av} = \frac{2\,(i_{W+} - i_{W-} - i_{E+} + i_{E-})}{i_{W+} + i_{W-} + i_{E+} + i_{E-}} \tag{3}$$

where i_{W+} denotes intensity of positives from the west, etc. A simple substitution from Eq. (2) yields

$$A_{Av} = \frac{2\,\gamma \tan|\Theta|\,(J_4/J_1)}{1 - (1/2H)(J_2/J_1)(\,W + E\,)} \tag{4}$$

The (J_2/J_1) term in the denominator is quite small, making A_{Av} very insensitive to the values of Δ_W and Δ_E.

C. Comparison with Experiment

Numerical computations were carried out for a zenith angle of 45° at Echo Lake (geomagnetic latitude λ=48.4°N, geomagnetic longitude ω = 112.7°W, atmospheric depth H = 705 g cm^{-2}). The temperature variation with atmospheric depth was taken from the cur ve given by Olbert[2] for 40° geographic latitude. The horizontal magnetic field of the earth was taken to be 0.22 gauss[3], the corresponding value of γ being 3.9×10^{-2}.

The critical rigidity at Echo Lake is 2.7 Bv at the vertical, and 2.3 and 4.2 Bv at 45° west and east respectively. These figures were obtained from curves given by Vallarta[4], corrected according to the procedure given in ref. 1. The corresponding values of a are 522 g cm^{-2} for the vertical direction, and 519 and 538 g cm^{-2} for west and east.

The theoretical value of the average secondary asymmetry has been compared with the experimental value in Table III. It is seen that the theory is wholly adequate to explain the observed asymmetry.

TABLE III . Comparison of experimental and theoretical value of average secondary asymmetry for zenith angle 45° at Echo Lake.

Channel	Theoretical asymmetry	Experimental asymmetry
I	0.162	0.141 ± 0.023
II	0.208	0.153 ± 0.088

1. F. B. Harris and I. Escobar V., Phys. Rev. 100. 255 (1955).
2. S. Olbert, Phys. Rev. 92 454 (1953).
3. F. E. Fowle, Smithsonian Physics Tables (Smithsonian Institution, Washington, 1934), eight revised edition, p. 593
4. M. S. Vallarta, Phys. Rev. 74 1837 (1948).

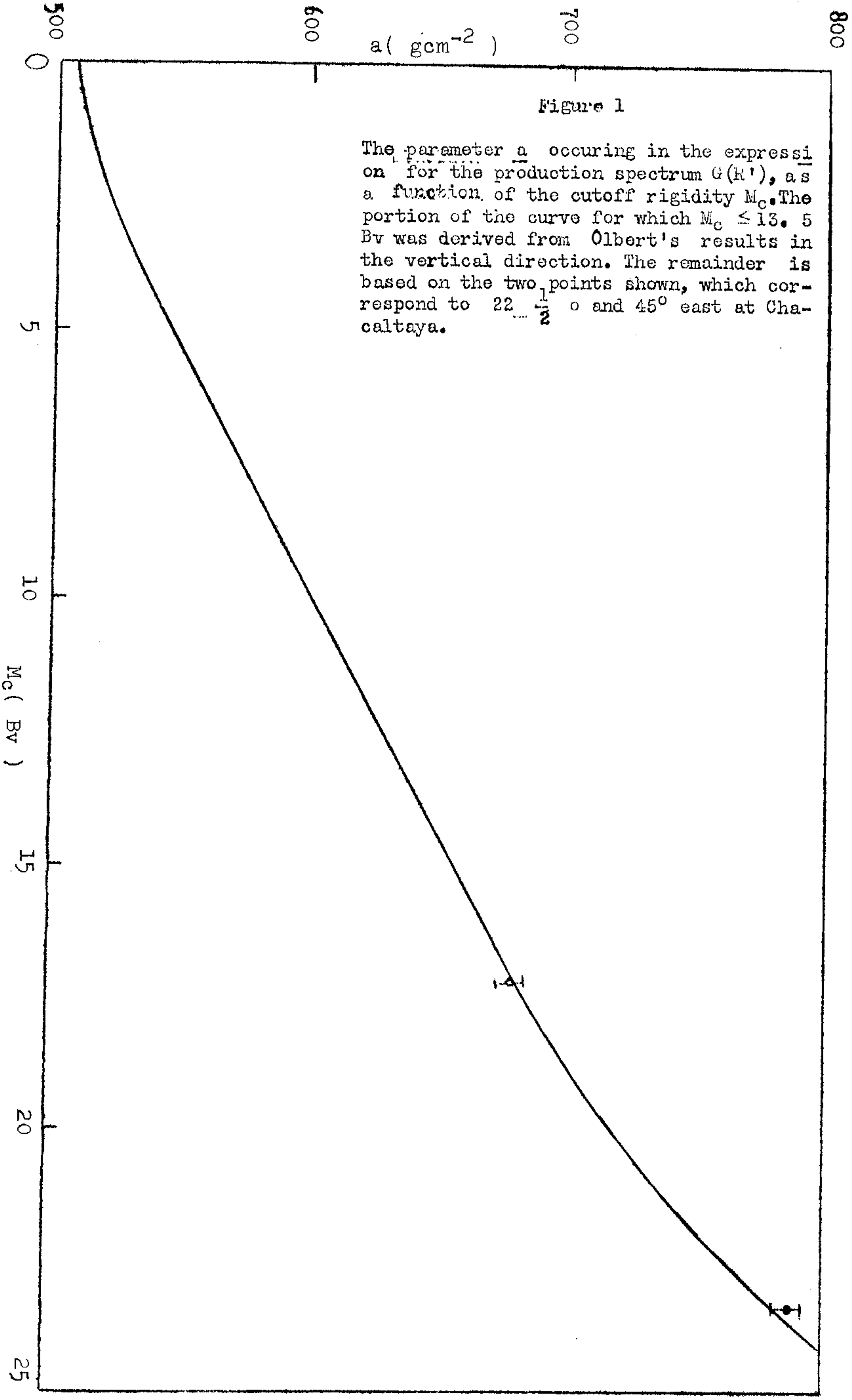

Figure 1

The parameter $\underline{a}$ occuring in the expression for the production spectrum $G(R')$, as a function of the cutoff rigidity M_c. The portion of the curve for which $M_c \leq 13.5$ Bv was derived from Olbert's results in the vertical direction. The remainder is based on the two points shown, which correspond to $22\frac{1}{2}$ o and 45° east at Chacaltaya.