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Mesotron Studies with Dual Telescope

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A description of a large area dual telescope for mesotron studies is given. Continual check on operation is obtained by constant ratio of counts of upper to lower telescope within the natural statistical fluctuations. Correlations have been made between mesotron intensity and mass temperature of various fractions up to 0.2 of the daily atmosphere; air data being obtained by sounding balloon flights at Lakehurst, New Jersey. Thus, temperature coefficients from 0.37 to 0.46±0.03 percent per degree Centigrade were obtained. It is shown that the temperature coefficient varies as dz/dT when increasing fractions are taken, as expected. Correlations have also been made for the same mesotron intensities with change of height of two levels of the daily atmosphere. The assumption that mesotrons are produced throughout the atmosphere according to the distribution of the air mass leads to a mean rest lifetime rather smaller than that obtained by other methods.

In a previous article[1] a preliminary analysis was made of mesotron intensity correlations with the temperature of various fractions of the *standard* atmosphere. It is the purpose of this article to present a description of the cosmic-ray telescope used in this investigation, and to submit further developments in the analysis of the data.

GENERAL DESCRIPTION OF THE TELESCOPE AND RECORDERS. TESTING

The telescope, devised by Professor W. F. G. Swann and one of us (V.F.H.), combines the features of large, well-defined sensitive area with moderately small solid angle. The complete assembly consists of six trays of Geiger counters arranged in vertical train; alternate trays are so connected for coincidence counting that in reality there are two independent but interposed telescopes of three trays each. The screening for vertical rays is provided by lead plates totaling ten centimeters between the first and second trays, and additional lead plates totaling twelve centimeters between the second and third trays of the telescopes. It is evident that by this arrangement in which both telescopes are subject to the same events a self-monitoring system is obtained; reliability of operation was guaranteed by the fact revealed by the tests that the two counters gave a constant ratio within the limits of statistical fluctuation. In each tray are 16 counters so disposed as to overlap one another and provide a continuous sensitive area. Arrangement of counters, trays and absorbers is illustrated in Fig. 1.

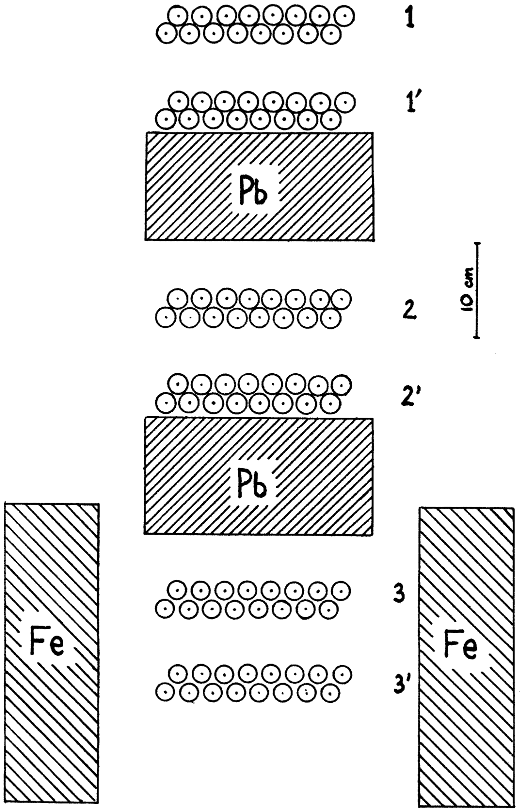

Fig. 1. Arrangement of counters, counter trays, and absorbers.

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[1] V. F. Hess and F. A. Benedetto, Phys. Rev. **40**, 610 (1941).

TABLE I. r and α for temperature variations at indicated km levels and for $\bar{\theta}_{16}$.

	i vs. θ_0	i vs. θ_3	i vs. θ_6	i vs. θ_9	i vs. θ_{12}	i vs. $\bar{\theta}_{16}$	I vs. $\bar{\theta}_{16}$
$-r$	0.76±0.04	0.73±0.05	0.71±0.05	0.70±0.05	0.24±0.10	0.73±0.05	0.79±0.04
$-\alpha$	0.40±0.02	0.36±0.02	0.31±0.02	0.29±0.02	0.16±0.07	0.59±0.04	0.70±0.04

Note: The temperatures of the 0 km level ranged between 27 and −1°C, for 3 km between 13 and −21, for 6 km between −3 and −41, for 9 km between −24 and −52, for 12 km between −44 and −69 and the average temperature up to 16 km ranged between −18 and −37°C. α is given in percent per degree C.

TABLE II. r_f and α_f as functions of $T_f \cdot [\partial z/\partial T]_f$ and average $[\partial z/\partial T]_f$ for corresponding fractions.

	r_f	α_f	$[\partial z/\partial T]_f$ $m/°\mathrm{C}$	Av. $[\partial z/\partial T]_f$ $m/°\mathrm{C}$
I vs. $T_{1/5}$	−0.71±0.05	−0.37±0.03	13.3±2.2	17
I vs. $T_{2/5}$	−0.70±0.05	−0.40±0.03	21.8±1.8	18.5
I vs. $T_{3/5}$	−0.72±0.05	−0.41±0.03	29.7±0.5	20.5
I vs. $T_{4/5}$	−0.75±0.05	−0.46±0.03	49.3±0.9	24

The counters, 19.3 cm×2.0 cm, are of the glass envelope, copper cylinder, argon-oxygen type, and were constructed under the supervision of Mr. W. E. Ramsey of the Bartol Research Foundation. Anti-coincidence tubes are used across the ends of the counters of the top and bottom trays of each telescope to avoid difficulties due to slight changes in longitudinal sensitivity of the counters. The sensitive area thus defined is 321 cm^2. The distance between top and bottom trays is 65.7 cm, thus the solid angle subtended is 0.297 steradian or 4.7 percent of the total hemisphere. All amplifying tubes and connections are well shielded against stray electrical fields.

The lowest tray of each telescope is screened against side showers by an iron "wall" of four inches thickness. This "wall" weighs approximately one ton and is built on two L-shaped trucks mounted on rollers to facilitate periodic inspection of apparatus. Location of apparatus is in a basement laboratory beneath three floors and roof; with vertical rays screened by this and the 22-cm lead absorber of the apparatus the average rate of counts is ~10 counts/min.

The recorders are of a new type recently developed by Professor W. F. G. Swann. They consist essentially of a wheel on whose inside rim are milled a series of teeth; a magnetically operated plunger records a count by being pulled up against the sloping edge of a tooth and returning to its initial position against another sloped tooth, thereby rotating the wheel one division. Though in the special arrangement used by us the recorders are not to be considered *fast* they are certainly sufficiently fast for this type of counting. Their particular advantage is that overshooting is impossible, and reliability is insured by their sturdy construction.

In a device of this sort where many Geiger counters are employed, in this application 108 altogether, it is essential that operation be checked periodically since it is possible for failure of a single counter to go undetected for some time. A special test set was constructed by which it is possible to plug into a whole tray of 16 counters and test them simultaneously for paired coincidences. For routine checking however it is found that satisfactory results are obtained much more rapidly by checking each counter visually with an oscilloscope. Only four tubes have failed over a period of seven months operation.

CAMERA AND POWER SUPPLIES

Photos of recorder dials are taken at two-hour intervals by means of a small camera. Sufficient illumination is afforded by a No. 1 Photoflood lamp at about $\frac{1}{5}$-sec. exposure to give detailed records on Eastman Kodak "Insurance Bromide paper." A small Syncron motor takes up the paper continuously and controls the impulse commutator. At two-hour intervals an auxiliary motor (1 r.p.m.) is triggered by the impulse commutator; a cam device on this auxiliary motor operates two spring switches, one serving to keep the auxiliary motor running until the end of the cycle, the other allowing a momentary current to pass through the series connected photoflood lamp and magnetic device for the camera shutter.

The high voltage, −1012.5 v, is furnished by a set of B-batteries and is common to both telescopes. Likewise all filaments are supplied from a storage battery which is on floating charge. Two separate power packs are used for the thyratron plate supplies and two neon stabilized packs furnish all bias potentials and plate current for the two telescopes, it being found necessary to have separate sources for the two telescopes to avoid electrical interaction.

OBSERVATIONS

Various Temperature Correlations

Most of our effort has been directed towards correlating ground mesotron intensity with temperature variations of different fractions of the atmosphere.[1] Data for 12-hr. (6 P.M.–6 A.M.) mean values of mesotron intensity observed between March 23 and July 31 (1941) are given in Table I. Mesotron data for the interval April 3 to August 21 were later recomputed according to 24-hr. means (6 P.M.–6 P.M.) and gave a more symmetrical distribution around the times of the Lakehurst sounding balloon flights, 4–6 A.M. For this latter analysis average *mass*[1] temperatures of the daily atmosphere were used; these latter results are given in Table II.

The following symbolism is used in Tables I and II:

i = 12-hr. mesotron mean values (6 P.M.–6 A.M.).
I = 24-hr. mesotron mean values.
θ = temperature *at* levels indicated by subscript (in km).
$\bar{\theta}_{16}$ = spatial average temperature up to 16 km.
T = *mass* temperature for fractions indicated by subscript $= [\int_{P_1}^{P_2} \theta dp]/[\int_{P_1}^{P_2} dp]$.
r = product-moment correlation coefficient.
α = temperature coefficient.

Table I indicates that there are increasingly good correlations as temperatures *at* levels approaching ground are used. The reason for this is principally meteorological: Temperature changes of the atmosphere occur primarily and more intensely near ground, particularly as far as changes from day to day are concerned. The temperature at the height of 12 km bears very little relation to day-to-day changes of the lower atmosphere, hence poor correlation with cosmic-ray intensity and a low temperature coefficient are obtained. From these values no preponderance of mesotron production at any specific level can be deduced.

The correlations in the last two columns of Table I are interesting for purposes of comparison with other authors but the spatial average temperatures as used there have no importance for the expected "air mass effect;" also total changes of temperature are diminished by the constancy of the temperature of the upper region which in turn makes the value of α unduly high.

When daily atmosphere values are used, α appears to be a slightly increasing function with increasing fractions of the atmosphere as in Table II. In all cases so far considered the fractions are taken from ground upward. The correlation coefficients for all these fractions are remarkably high and indicate that the values of α are fairly reliable. Increase of α with increasing fractions must be expected from the following consideration. By definition $\alpha = -[1/I][\partial I/\partial T]$, and if it is assumed that an increase of intensity is linearly proportional to a downward shift of air mass, α can be expressed $\alpha = [1/L][\partial z/\partial T]$ where L is a constant, corresponding to the average path length of the mesotrons from their points of origin until decay ("life range"). Thus average values of $[\partial I/\partial T]_f$ over certain fractions (f) of the atmosphere should be proportional to the corresponding *average*[2] $[\partial z/\partial T]_f$, as well as to α_f. Table II shows the values actually obtained. Some discrepancy from proportionality is to be expected as the number of data collected so far is rather small for this particular analysis.

CORRELATIONS WITH HEIGHT VARIATIONS OF ATMOSPHERIC CENTER OF GRAVITY

From the ordinary expression for the temperature coefficient

$$\alpha = -(1/I)(\partial I/\partial T) \equiv -(1/I)(\partial I/\partial z)(\partial z/\partial T) = (1/L)(\partial z/\partial T),$$

it follows that

$$L = -1/[(1/I)(\partial I/\partial z)] \equiv -1/\beta, \qquad (1)$$

where ∂z is the average variation in height of the region where mesotrons are produced. This region would be beneath the top of the atmosphere by some distance of matter traversed.

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[2] *Average* $[\partial z/\partial T]_f$ values were obtained by plotting the actual values of $[\partial z/\partial T]_f$ for the upper boundary of f against the pressure and graphically integrating over the fraction in question.

However, since the barometer effect (total mass above the apparatus) probably affects both the distribution of production as well as that of absorption of mesotrons it was thought best to associate production levels with definite fractions of the prevailing atmosphere.

As a starting point, therefore, in our studies of mesotron variation as a function of changes of height of assumed mean production levels, the center of gravity of the daily atmosphere was first taken as the production level. Mesotron readings were the same 24-hour mean values as in the temperature correlation series; daily height variations of the center of gravity were taken from the height *vs.* pressure curves. It is seen from Eq. (1) that temperature does not enter into consideration in this correlation. Results for the level of the center of gravity gave:

$$r=-0.70\pm 0.04$$

and

$$\beta=-17.5\pm 0.9 \text{ percent/km.}$$

By taking a higher level, $p=400$ mb, we obtain the following

$$r'=-0.64\pm 0.05$$

and

$$\beta'=-13.3\pm 0.7 \text{ percent/km.}$$

To reduce β' to changes of height as they occur at the center of gravity, β' is multiplied by the inverse ratio of the mean heights of the two levels, so that

$$\beta'_{\text{red}}=(7.4/5.7)\beta'=-17.3 \text{ percent/km}$$

quite within the range of β, as given above.

The average path length L of the mesotrons can be computed from Eq. (1)

$$L=-1/\beta=5.7\pm 0.4 \text{ km},$$

provided that the average production level is not too far from the atmospheric center of gravity. For a mesotron spectrum of only 1 Bev mean energy, $\gamma=12.5$; and taking the above value for L we have $\tau_0\gamma=1.9\times 10^{-5}$ sec. and $\tau_0=1.5\times 10^{-6}$ sec. From $\partial z/\partial T=-\alpha/\beta$ we may also obtain an independent determination of the change of the height of the atmospheric center of gravity with the lower mass temperature. The value obtained, 22.5 meters/°C, checks with our study of the meteorological data which gave for the height variation of the center of gravity, $h_{\text{cg}}\backsimeq 5.7$ km, a value of $\partial z/\partial T=23$ meters/°C.

CONCLUSION

Since it is rather probable that the mean energy of the mesotrons registered by this apparatus is considerably greater than 1 Bev, it would seem difficult to reconcile the above results with the heretofore accepted mean lifetime, $\sim 2\times 10^{-6}$ sec., of the mesotron at rest, unless one is willing to assume that the mesotrons are exclusively produced in the uppermost fifth of the atmosphere. That the production of mesotrons probably extends throughout the total atmosphere is indicated by our results as well as those of previous workers.[3-5]

ACKNOWLEDGMENTS

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[3] M. Schein, E. O. Wollan, and G. Groetzinger, Phys. Rev. **58**, 1027 (1940).

[4] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).

[5] N. F. Beardsley, Phys. Rev. **59**, 402 (1941).