Nuclear Evaporations Produced by Cosmic Rays

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WITH the photographic emulsion technique,[1] the well-known processes discovered by Blau and Wambacher,[2] i.e., the so-called "stars" produced by cosmic radiation, were investigated.

The experiments, which were performed partly at the Laboratorio della Testa Grigia (3500 m.s.l.) and partly with balloon flights,[3] have yielded results which, though provisional, are, we feel, not without significance.

In a first series of experiments (carried out at 3500 m.s.l.) the plates were exposed under varying thicknesses of several materials. Up to now 10 plates exposed under lead have been completely scanned. The results concerning those stars, which show at least three clearly observable prongs, are summarized in Table I.

Table I.

cm of Pb	0	2	9	13
No. of stars / $cm^3\cdot$day	15.3 ± 1	18.0 ± 0.9	13.1 ± 1.15	9.7 ± 1

These results are perhaps consistent with the assumption that there is a small transition effect in the first two centimeters of lead. This is also borne out by the results reported by Heitler, Powell, and Heitler[4] in connection with single proton tracks.

From the data summarized in Table I it is also possible to give a rough estimate of the absorption coefficient of lead for the radiation which produces the stars. Neglecting the transition effect, we find an absorption coefficient

$$K_{\mathrm{Pb}}=1/300\ \mathrm{g}^{-1}\cdot\mathrm{cm}^2.$$

To take into account the finite size of the lead blocks, this value should be enlarged by about 20 percent.

Let us now turn to the results of the balloon flights. The first of these balloons reached an altitude of about 18 km and the second 22 km. In the plates exposed during these balloon flights (see Fig. 1) we found π- and σ-mesons, and a relatively great number of stars.

We have attempted to evaluate the absorption coefficient for the star-producing radiation, comparing the number of stars in the first balloon flight plates and in the L.T.G. ones. We obtained an absorption coefficient for air:

$$K_A=1/(141\pm12)\ \mathrm{g}^{-1}\cdot\mathrm{cm}^2.^5$$

This result is in quite good agreement with that of Perkins from single proton tracks.[6]

In Fig. 2 the stars are classified according to the number of their prongs. In spite of the large statistical errors there is reasonable evidence for saying that the shape of the distribution does not vary greatly in the very different cases represented by the histograms.[7] This appears to support the assumption that the processes by which the stars arise are roughly independent of the energy of the radiation which produces them.

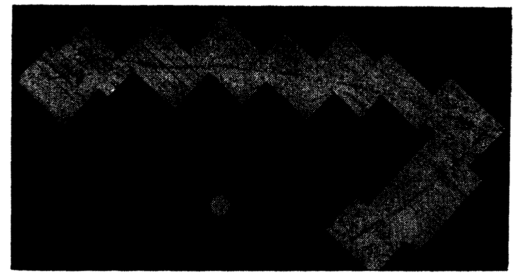

Fig. 1. Mosaic of photomicrographs of a $\pi\rightarrow\mu$-disintegration process, observed in one of the balloon plates.

It is quite evident that there is a close correlation between the observations concerning stars and the burst experiments.[8] As a matter of fact, below 200 g/cm² under the top of the atmosphere, the curve of the burst rate *versus* depth is very well represented by the relation

$$I=I_0\exp[-Kx]$$

with

$$K=1/138\ \mathrm{g}^{-1}\cdot\mathrm{cm}^2$$

in very good agreement with our result.

The relatively low absorption coefficient in lead excludes the possibility that any appreciable fraction of the stars are due to the electron-photon component. The same conclusion is reached by considering the lack of maximum in the burst curve obtained in the atmosphere.

The stars can similarly not be produced in an appreciable measure by mesons of mass 200. In fact, the ratio between the number of stars registered at 3500 m and at s.l. is

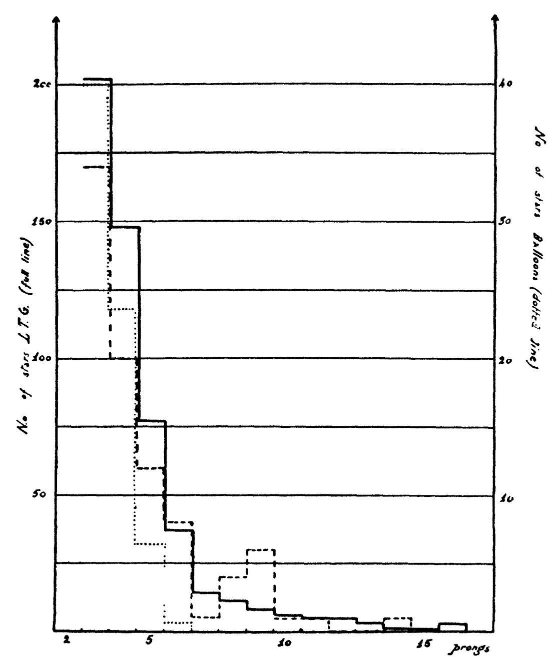

Fig. 2. The full line refers to the L.T.G. plates. The dotted line refers to the balloon plates. The finely dotted line describes the stars produced by 400-Mev α-particles (see reference 7)

about 15/1, while the corresponding ratio of meson intensity is only 2/1.

Hence we may say that it appears almost certain that high energy nucleons and σ-mesons play the principal role in the creation of these stars. The latter may be spoken of as "local indicator" of these components of cosmic radiation.

If this assumption is justified, we may deduce, by comparing the measurements under air and lead, the following value for the total cross section of this component:

$$\sigma \cong 3A^{\frac{2}{3}} \times 10^{-26}\ \text{cm}^2.$$

[1] C. F. Powell, G. P. S. Occhialini, and C. M. G. Lattes, Nature **159**, 186 (1947); **159**, 694 (1947); **160**, 453 (1947); **160**, 486 (1947).
[2] H. Wambacher, Sitz. Akad. Wiss. Wien, IIA, **149**, 157 (1940).
[3] We are very indebted to Dr. A. Persano for his invaluable help in the performance of the flights.
[4] W. Heitler, C. F. Powell, and H. Heitler, Nature **146**, 65 (1940).
[5] G. Cortini, A. Manfredini, and A. Persano, Nuovo Cimento, in press.
[6] D. H. Perkins, Nature **160**, 707 (1947).
[7] Communication by Professor L. W. Alvarez at the Zurich Congress, July 1948.
[8] H. Bridge and B. Rossi, Phys. Rev. **71**, 379 (1947); H. Bridge, B. Rossi, and R. Williams, Phys. Rev. **72**, 257 (1947); H. E. Tatel and J. A. Van Allen, Phys. Rev. **73**, 87 (1948).

Preliminary Analysis of the Microwave Spectrum of Ethylene Oxide*

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FOUR strong lines of the pure rotational spectrum of the asymmetric rotor, ethylene oxide, have been observed in the region near 24,000 Mc/sec. (see Table I). The frequencies of the lines and their Stark effects allow identification of the transitions and determination of the moments of inertia of the molecule.

The Stark splitting is of the form $\Delta\nu = \mu^2E^2(A+BM^2)$ where $\Delta\nu$ is the difference between the frequencies of the Stark component and the undisplaced line. The number of components and their relative spacings allow a determination of the lower value of J involved in each transition.

Table I. Ethylene oxide absorption lines.

Frequency Mc/sec.	Designation
23,160	3_1-3_3
23,614	$3_{-1}-3_1$
24,855	4_0-4_2
24,948	$2_{-2}-2_0$

Relative intensities of the components are proportional to M^2, which indicates that $\Delta \cdot J=0$ for all four transitions.[1]

For $\Delta J=0$, $\nu_{J\tau;J\tau'} = (a-c)/2(E_\tau{}^J - E_{\tau'}{}^J)$, where $E_\tau{}^J$ is a tabulated function[2] of J, τ, and κ. Only values of $\kappa = \pm 0.395$ allow fitting the observed lines in frequency, and the Stark effect shows that $\kappa = +0.395$ is the correct choise between these two values. In addition to determining κ, the line frequencies give $(a-c)/2 = 0.1898$ cm^{-1}.

The Stark pattern of the $2_{-2}-2_0$ transition is very sensitive to the ratio of $(a-c)/(a+c)$. Changes of 1 percent in the value of this ratio vary the ratio of the Stark effect coefficients A/B by 3 percent, giving $(a-c)/(a+c) = 0.2756 \pm 0.003$, and $(a+c)/2 = 0.689 \pm 0.007$ cm^{-1}.

For the analysis, ethylene oxide was considered to be rigid and the effective moments of inertia rather than the equilibrium moments are determined. They are:

$$I_A = 31.9 \times 10^{-40}\ \text{g cm}^2,$$
$$I_B = 36.7 \times 10^{-40}\ \text{g cm}^2,$$
$$I_C = 56.7 \times 10^{-40}\ \text{g cm}^2.$$

As a check on the structure, the Stark patterns of the 3_3-3_1, 3_1-3_{-1}, and 4_2-4_0 transitions were calculated and the ratios of various coefficients involved were compared with the experimental values (see Table II).

Table II. Ratios of Stark effect coefficients for observed lines. [Stark displacement $\Delta\nu = \mu^2E^2(A+BM^2)$.]

Ratio	Calculated	Observed
$A_{3_1-3_3}/B_{3_1-3_3}$	0.69	0.69
$A_{3_{-1}-3_1}/B_{3_{-1}-3_1}$	−0.20	−0.18
$B_{3_1-3_3}/B_{3_{-1}-3_1}$	0.67	0.66
$A_{4_0-4_2}/B_{4_0-4_2}$	0.002	0.01
$A_{2_{-2}-2_0}/B_{2_{-2}-2_0}$	0.233	0.233
$B_{4_0-4_2}/A_{2_{-2}-2_0}$	−0.62	−0.62

If the C−H distance is assumed to be 1.09A, then the H−C−H angle is 121°.

Further work is contemplated to study isotopic species and to obtain more accurate molecular constants.

* Work supported by the Signal Corps.
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[2] G. W. King, R. M. Hainer, and P. C. Cross, J. Chem. Phys. **11**, 27 (1943).

On the Production of Showers of Penetrating Particles

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THE purpose of the present experiments[1] was to study the cross section for the production of penetrating showers in various materials.

The penetrating showers were detected by a pair of "telescopes" shielded by lead from all sides (of the type used by G. Wataghin[2]). The registered radiation had a minimum range of 18 cm Pb. The telescopes were separated by 16 cm Pb.

Two series of measurements were planned. In the first one we distributed an equal number of nucleons (equal masses) of different materials in the same volume, and we obtained the frequencies of showers produced in these materials as the difference of the frequencies of the showers registered with and without the materials. In the second series (which is being performed) equal numbers of nuclei of two different elements are distributed in equal volumes. In this case the frequencies of the showers produced in the materials are proportional to the average cross sections of the respective nuclei.

In the present note we give the results of the first series, which consisted of experiments A and B. The shower-

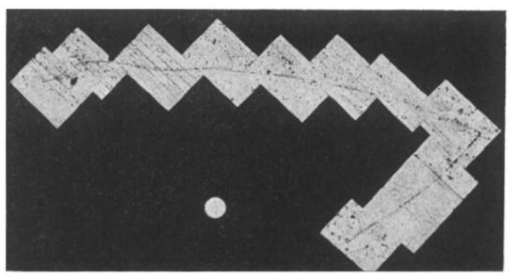

FIG. 1. Mosaic of photomicrographs of a $\pi \rightarrow \mu$-disintegration process, observed in one of the balloon plates.