exponential expansion. The extra term involves no further empirical coefficients, since the 0.63 is merely (1/2)/0.7935.

In his letter[4] the 20th of April, 1946, to *The Physical Review*, written before the author had seen our publication, Good suggested the formula

$$\bar{\nu}=0.7932-0.0048(J^2+J-K^2)+0.0020K^2.$$

The expression now obtained by Good[1] is

$$\bar{\nu}=0.79347-0.005048(J^2+J)+0.007040K^2+0.00001546(J^2+J)^2-0.00004260(J^2+J)K^2+0.00002920K^4, \quad (3)$$

where all the coefficients are empirical. On multiplying out, (2) becomes

$$\bar{\nu}=0.7935-0.0050_5(J^2+J)+0.0070_4K^2+0.000016_1(J^2+J)^2-0.000044_9(J^2+J)K^2+0.000031_2K^4. \quad (2a)$$

It is surprising that Good made no comment on the close agreement between the two expressions. It should be noted that the accuracy of the measurement of frequency is the same in the two experiments, since the ±5. Mc/sec. claimed by Good corresponds to our ±0.02 percent. We did not feel justified, however, in evaluating the coefficients to greater accuracy, since even third-order terms would be appreciable for some lines.

2. The comparison of the relative intensities of the lines made by Good assumes that the widths of the different lines are all the same. The widths of 17 lines measured by us vary as $3[K^2/(J^2+J)]^{\frac{1}{2}}$, and from these widths the absolute intensities can be calculated. Our measured intensities agree with the calculated values within ±5 percent, while the intensities shown in Good's Fig. 5 are considerably smaller. For instance we find 0.044 db/meter for the line (6, 3), whereas Good's value appears to be less than 0.01 db/meter. The calculated value is 0.042 db/meter.

3. The following factors affect the change of intensity with temperature, in addition to those enumerated by Good.

(a) The change in the relative populations of the two levels of the inversion doublet causes the intensity to vary as $1/T$, corresponding to the fact that the cancellation of the absorption by induced emission is less at low temperature.

(b) At a given pressure the lines become broader, not sharper, as stated by Good, as the temperature is lowered, because the number of molecules per cc varies as $1/T$, while the molecular velocity varies only as $\sqrt{T}$.

4. Good suggests that the fall in intensity at low pressures shown in his Fig. 4 is owing to the interruption of the absorption by collision with the walls of the wave guide, which would ultimately cause the collision frequency to become independent of the pressure. At room temperature in a wave guide with the usual narrow dimension of 4.5 mm, however, an ammonia molecule would collide with the walls about $13\cdot 10^4$ times per second giving a line-breadth constant ($\Delta\nu$) of $13\cdot 10^4/2\pi\cdot 10^6=0.02$ Mc/sec. The value of $\Delta\nu$ for the line (3, 3), estimated from Good's Fig. 4a, is, however, 0.4 Mc/sec. which must therefore be attributed to collisions between molecules. This indicates that the collision cross section for this absorption is considerably greater than the kinetic theory value; our measurements of the width of this line show that the ratio of the two cross sections is actually 14.

5. We suggest that the diminution in the intensity as the pressure is reduced may be owing to disturbance of thermal equilibrium, as the absorption of energy tends to equalize the populations of the upper and lower levels. We have observed this effect by determining the absorption coefficient at various energy densities in a resonant cavity, and find that the reduction in the intensity is in close agreement with that calculated from the measured energy density. In a wave guide of cross-sectional area $A$ through which a power $W$ is flowing, the attenuation $\gamma$ should be less than that ($\gamma_0$), which would be observed if thermal equilibrium were preserved, by a factor

$$\gamma/\gamma_0=\frac{2}{a}\left(1-\frac{1}{(1+a)^{\frac{1}{2}}}\right),$$

where

$$a=\frac{16\pi(\mu mn)^2}{3(hc)^2(\Delta\bar{\nu})^2}\cdot\left(\frac{\lambda g}{\lambda}\right)\cdot\frac{W}{Ac}.$$

Inserting our measured value for the line breadth constant ($\Delta\bar{\nu}$) we find that a power of one milliwatt would be sufficient to reduce the intensity of the line (3, 3) by a factor of 3 at a pressure of $1.5\cdot 10^{-2}$ mm Hg. The usual types of oscillator give 20–30 mw; allowing 10 db of attenuation and 3 db for the division of power between the two guides, it would seem quite possible that a milliwatt of power was flowing through the ammonia. Thus the disturbance of thermal equilibrium appears a likely explanation for the drop in the intensity at low pressure and may also explain the abnormally low intensities shown in Fig. 5 of Good's paper.

[1] W. E. Good, Phys. Rev. **70**, 213 (1946).
[2] Hsi-Yin Sheng, E. F. Barker and D. M. Dennison, Phys. Rev. **60**, 786 (1941).
[3] B. Bleaney and R. P. Penrose, Nature **157**, 339 (1946).
[4] W. E. Good, Phys. Rev. **69**, 539 (1946).

## Additional Cosmic-Ray Measurements with the V-2 Rocket

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ANOTHER cosmic-ray experiment has been done in a V-2 rocket, fired on October 10 at White Sands, New Mexico (Geom. λ = 41°N). Measurements were made with the counter arrangement shown in Fig. 1, of the ratio of total intensity as measured in the threefold telescope 1, 2, 3, to the intensity below 15.2 cm of lead as measured by the fourfold coincidences 1, 2, 3, (6+7+8). The quantities included in the parentheses were electronically paralleled for this measurement. Because of space limitations, it was not possible to make the solid angle of the fourfold set completely include that of the threefold. The ratio of these solid angles was determined to be 0.37 by a ground calibration. A third channel measured sixfold coincidences 1, 2, 3, 6, 7, 8. Each of these three channels was protected against the shower rays found in a previous experiment[1]

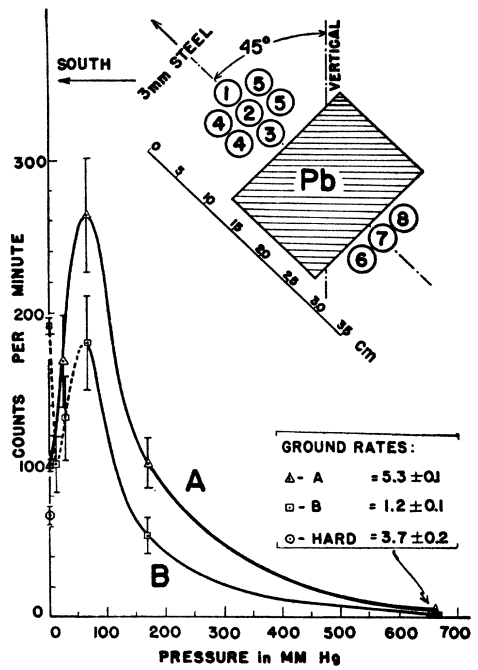


FIG. 1. Curve $A$, total intensity. Curve $B$, shower intensity. Circled points, intensity of penetrating component.

by anticounters 4 and 5 all operating in parallel. In a fourth channel, unprotected coincidences 1, 2, 3 were transmitted. The differences between these data and the similar, protected data give a measure of the showers.

The counters used had 0.8-mm brass walls. Resolving times for each channel were $\sim 5\times 10^{-6}$ sec. Data were transmitted to ground by the same radio system used in the previous flight. The altitude attained was in excess of 160 km.

The telescope axis pointed south at a zenith angle of 45° through a 3-mm steel "window." Both zenith angle and azimuth were preserved through the atmosphere, but the telescope axis precessed about the zenith in free space. "Free space" is taken as the region of less than 2 mm Hg pressure.

Curve $A$ in Fig. 1 shows the altitude dependence of the protected total intensity. It is seen that the counting rate in free space (based on 252 counts) was about $\frac{1}{3}$ that at the maximum (based on 22 counts). For the hard component, however, the counting rate within the atmosphere was too low to permit drawing a curve. Only two points are shown; the ground point determined by several hours of calibration, and the point in free space for which 150.6 seconds of operation (63 counts) was used. It is seen that the penetrating component amounts to about 70 percent of the total radiation. The shower rate in free space (480 counts) was again high as may be noted by curve $B$ which is the difference between the unprotected and protected coincidences 1, 2, 3. The validity of the dip in this curve at 12 mm Hg is questionable. Of the 63 hard counts in free space 13 were associated with showers below the lead.

In the experiment of Schein, Jesse, and Wollan,[2] it was reported that very few of the particles penetrating 4 cm of lead produced showers under 2 cm. The present results would appear to be consistent with that data if the non-penetrating radiation were fairly soft. Further experimental work is in progress.

The writers wish to acknowledge the aid of their colleagues in the Rocket Sonde Research Section of the Naval Research Laboratory, and are especially indebted to Professor J. A. Wheeler, Princeton University, for helpful discussion.

[1] S. E. Golian, E. H. Krause, and G. J. Perlow, Phys. Rev. **70**, 223 (1946).
[2] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).

## The Magnetic Field of the Galaxy

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THE force which galactic radiation pressure exerts on minute dust grains in interstellar space will give these grains a drift velocity of about $10^4$ cm/sec. relative to the interstellar atoms.[1] On the average, this velocity should be directed away from the galactic center. The Coriolis force of galactic rotation will deflect these grains, and give them also a drift velocity at right angles to the direction of the galactic center. Thus the dust grains rotate more slowly about the galactic center than do the interstellar atoms and electrons. It is believed that each dust grain has an electric charge of roughly 100 electrons. Therefore, the differential rotation of the dust grains produces an electrical current circling the galactic center. This result requires that the number of dust grains per $cm^3$ be constant in the galactic plane along any circle of constant radius about the galactic center. While most of the observed galactic dust is concentrated in isolated clouds, present evidence indicates a "substratum" of more nearly uniform distribution.[2] On the assumption that the density of this substratum is $6\times 10^{-26}$ gram/$cm^3$, the primary galactic current, computed without regard to the important secondary effects discussed below, is about $10^{17}$ amperes. Since the effective radius of this circular current is between 5000 and 10,000 parsec., the magnetic field resulting is between $10^{-5}$ and $10^{-6}$ gauss.

This computed field is so large that secondary effects of the magnetic field on the primary galactic current must be taken into account. A field of $10^{-5}$ gauss would provide a deflecting force on the dust grains which would be about $10^6$ times as great as the Coriolis force. A detailed study of this interaction is still in progress, but preliminary results indicate that the magnetic field in most of the galaxy will be no greater than is required to nearly cancel the Coriolis force, thus reducing the primary galactic current to a low value. Secondary effects on atomic ions must also be considered. The computations show that the resultant magnetic field is probably in the general neighborhood of $10^{-12}$ gauss. This tentative result is subject to very considerable revision as more complete information on the interstellar medium becomes available.