one γ-ray only is produced per capture. Neglecting the capture cross section of oxygen we assume further that the cross section of deuterium is one-half of that obtained by Sargent and his collaborators[1] for the D_2O molecule (0.92 mb). For the cross section of aluminum we use the value 220 mb. From our measurements of the capture γ-ray spectrum of aluminum[2] we find that the 7.72-Mev γ-ray is radiated in 40 percent of the captures in that element. With these figures we find that the peak coincidence counting rate of the deuterium γ-ray should be about 0.07 of that of the 7.72 Mev aluminum γ-ray. The ratio observed was 0.08. The agreement is good but it may be accidental for such a calculation is difficult to make with precision. The error might amount to 30 percent.

In our method of measurement the energy of the γ-ray is determined from the end point of the coincidence peak. Near 6.2 Mev it seemed possible that the shape of the peak produced by that γ-ray was modified and the position of its end point was shifted by the presence of γ-rays produced by aluminum in the pile. To examine this possibility we have studied the spectrum produced by pure aluminum using the same resolving power. A part of this spectrum is shown by curve C in Fig. 1. The ordinates of this curve have been adjusted so that the peak coincidence counting rate for the 7.72-Mev aluminum γ-ray is equal to that produced by the aluminum in the pile. The difference between the two curves, given as curve B in Fig. 1, represents the contribution to the pile spectrum produced by neutron capture in deuterium and other constituents. It is clear that this subtraction does not shift the end point of the 6.2-Mev peak.

The binding energy of the triton, obtained by adding the recoil energy of that nucleus to the γ-ray energy, is 6.251 ± 0.008 Mev. This result is in good agreement with the binding energy obtained from disintegration data. According to Tollestrup, Fowler, and Lauritsen[3] the best value of the Q of the reaction $D^2(d, p)T^3$ is 4.032 ± 0.022 Mev. Adding to this the binding energy of the deuteron,[4] 2.230 ± 0.007 Mev the binding energy of the triton is 6.262 ± 0.023 Mev.

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[2] The details of this spectrum will be published shortly.
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Pressure Dependence of Resistance of Germanium*

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AN intrinsic semiconductor may exhibit a relatively large change in electrical resistivity with hydrostatic pressure due to the change in band structure which accompanies a compression of the lattice; the concomitant changes in Debye temperature and electron mass produce relatively small effects upon the resistivity. In germanium the application of hydrostatic pressure increases the forbidden band width, decreases the number of free holes and electrons and hence increases the resistivity.

The equations connecting the change in resistivity $\Delta\rho$ with the change in energy gap ΔE_G may be derived in the following way. It is known that the product of the electron concentration n_e and hole concentration n_h remains constant for fixed temperature and pressure as the concentration of impurity atoms is varied:

$$n_e n_h = C^2. \tag{1}$$

If one considers the dependence on gap width and temperature,

$$\begin{aligned} n_e n_h &= C' \exp(-E_G/kT), \\ C' &= 4(2\pi mkT/h^2)^3(m_e m_h/m^2)^{\frac{3}{2}}, \end{aligned} \tag{2}$$

where m_e and m_h are the masses of electrons and holes respectively, and the other symbols have their usual meaning. The resistivity is given in terms of the mobilities μ_e and μ_h by

$$1/\rho = e(n_e\mu_e + n_h\mu_h). \tag{3}$$

If one assumes that only E_G changes with hydrostatic pressure and that the number of impurity atoms which are ionized is constant, then at constant temperature

$$(\Delta\rho/\rho) = (\mu_e+\mu_h)n_e n_h \Delta E_G/(n_e+n_h)(n_e\mu_e+n_h\mu_h)kT. \tag{4}$$

This equation is very simple for the case of an intrinsic semiconductor (for which $n_e = n_h = C$):

$$(\Delta\rho/\rho)_{\text{pure}} = \Delta E_G/2kT; \tag{5}$$

but, as it is often necessary to make pressure measurements at temperatures below the intrinsic range owing to the impurity content of the material, the general form of Eq. (4) must be retained. However, it may be expressed in terms of more convenient parameters by letting $c = \mu_e/\mu_h$ and $x = C/n_e$, so that

$$(\Delta\rho/\rho) = x^2(c+1)\Delta E_G/(x^2+c)(x^2+1)kT. \tag{6}$$

The value of c is assumed to be 1.5 and x is determined from resistivity measurements which may be easily extended well into the intrinsic temperature range if the material is reasonably pure. Thus, at any given temperature at which $\Delta\rho/\rho$ is observed the ratio

$$\rho_{\text{pure}}/\rho = (c+x^2)/[x(c+1)] \tag{7}$$

may be used to calculate the corresponding value of x and hence to obtain $(\Delta\rho/\rho)_{\text{pure}}$ from Eqs. (5) and (6). Here, ρ_{pure} refers to the resistivity value obtained by extrapolation from high (intrinsic) temperature measurements to the temperature at which the pressure measurements are made. If the samples are inhomogeneous with regard to distribution of impurity atoms, the correction factor of Eq. (6) is too large. Consequently, observations requiring large correction factors have been weighted lightly in obtaining the average. The values $(\Delta\rho/\rho)_{\text{pure}}$ computed from observations taken at different temperatures have been reduced by an inverse temperature factor to values at 300°K for purposes of intercomparison; this reduction is based on Eq. (4) and the further assumption that $\Delta E_G/\Delta P$ is independent of pressure and temperature.

The experimental observations were taken on germanium samples of high purity enclosed in a steel tube which was submerged in a boiling liquid to keep the temperature constant to about 0.01°C. Pressures up to 4500 lb/in.^{2} were applied to the sample through silicone oil which completely filled the tube; glass wool inside the tube and an auxiliary heater at the top of the tube were used to prevent circulation of the oil. The results of the measurements and calculations are shown in Table I. A weighted

TABLE I. Summary of experimental data and calculation.

Sample	T °K	$(\Delta\rho/\rho)$ $\times 10^5$ (per atmos.)	$\rho_{\text{pure}}/\rho_{\text{obs}}$	Correction factor	$(\Delta\rho/\rho)_{\text{pure}}$ $\times 10^5$ (per atmos.)	$(\Delta\rho/\rho)_{300°K}$ $\times 10^5$ (per atmos.)	Weight used in average
A	475*	2.1	2.5	5.3	11.1	18.0	1
B	297	1.5	3.4	9.6	14.4	14.3	0
	352	5.5	1.25	1.44	7.9	9.3	2
	373	7.0	1.1	1.18	8.2	10.2	3
	413	6.9	1	1.00	6.9	9.5	5
	428	7.0	1	1.00	7.00	10.0	5
C	299	1.7	6.0				
	352	4.1	1.6	2.22	9.1	10.8	2
	413	7.7	1	1.00	7.7	10.6	5
	428	7.3	1	1.00	7.3	10.4	5
D	361*	1.6	2.4	4.8	7.7	9.3	1
	413	5.5	1.15	1.25	6.9	9.5	2
	428	6.2	1.05	1.1	6.8	9.7	3
					Weighted average	10.2	

* Measurements taken at peak of resistivity.

average $(\Delta\rho/\rho)_{\text{pure}}=10.2\pm0.4\times10^{-5}$/atmos. was obtained for the pressure coefficient of resistance of germanium at 300°K. Assuming a compressibility 1.4×10^{-6}/atmos. and a coefficient of linear expansion 8×10^{-6}/°C leads to a value $\Delta E_G/\Delta T=-0.87\times10^{-4}$ ev/°C.

This result is, with one exception, in excellent agreement with calculations from other experiments. Shockley and Bardeen[1] found for this constant the value -0.9×10^{-4} ev/°C using data on the mobilities of holes and electrons; their result is proportional to $m_e^{5/4}$. Johnson and Fan[2] have estimated from data on the temperature dependence of the Hall effect a value -1.1×10^{-4} ev/°C. Correction of this result by subtraction of the contribution of the lattice vibrations computed by Fan[3] leads to the value -1.0×10^{-4} ev/°C for the contribution of the volume effect alone. Only the latter value is comparable to the results of the pressure measurements; the uncorrected result of Johnson and Fan, which depends on $(m_e m_h)^{3/4}$, includes both the volume effect and the change in lattice vibrations which accompany a change in temperature. Fan,[4] using data from optical absorption measurements found the quite different value -4.0×10^{-4} ev/°C.

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† Now at Morgan State University, Baltimore, Maryland.
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Penetrating Showers of Cosmic Rays

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AN experiment has been carried out at sea level in which the relative penetration of local penetrating showers was investigated as a function of their lateral spread. Figure 1 shows the experimental arrangement of the counters and lead absorbers. The figure is drawn to scale except that the upper absorber P_1 was 35 cm thick. The counters M were connected in fivefold coincidence. The analyzer counters A_1, A_2, B_1, B_2, C_1, C_2, each connected in coincidence with the fivefold coincidence M, indicated the lateral spread of the showers of which the range was measured by coincidence with K and L. This arrangement of coincidences reduces the error due to secondaries from a single meson to 6 percent or less. To discharge one of the analyzer counters in coincidence with M, a single meson would have to produce at least three successive knock-on electrons. The group of counters S allowed the discrimination between local showers and Auger showers.

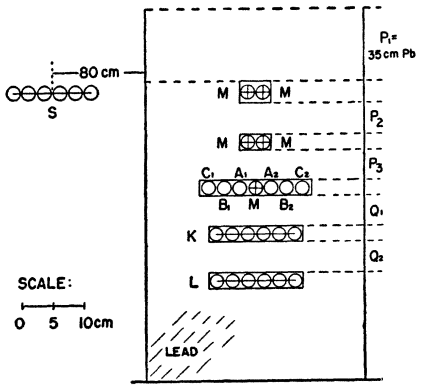

FIG. 1. Arrangement of the counters and lead absorber.

TABLE I. The lateral spread gives the separation in number of counters between the most remote particles of the showers.

Lateral spread	2	3	4	5	6	7
Showers per hour						
stopped in $Q_1=5$ cm Pb	0.022	0.026	0.022	0	0	0
stopped in $Q_2=5$ cm Pb	0.017	0.017	0.013	0.013	0.009	0
penetrating Q_1+Q_2	0.043	0.061	0.077	0.048	0.030	0.069
Total rate (per hour)	0.082 ±0.018	0.104 ±0.021	0.112 ±0.022	0.061 ±0.016	0.039 ±0.013	0.069 ±0.017
$\frac{\text{Stopped in } (Q_1+Q_2)}{\text{Total rate}}\times100$	48%	41%	31%	21%	23%	0

The results indicate that *the most penetrating showers are the most divergent.* It can be seen from Table I that nearly 50 percent of the narrower showers are stopped in the absorber $Q_1+Q_2=10$ cm Pb, whereas most of the larger showers include particles which can penetrate these absorbers. This unexpected result, however, is not inconsistent with the theoretical calculations of Peyrou, d'Espagnat, and Leprince-Ringuet.[1] Figure 2 also shows that the relative range of the showers is increasing with their divergence.

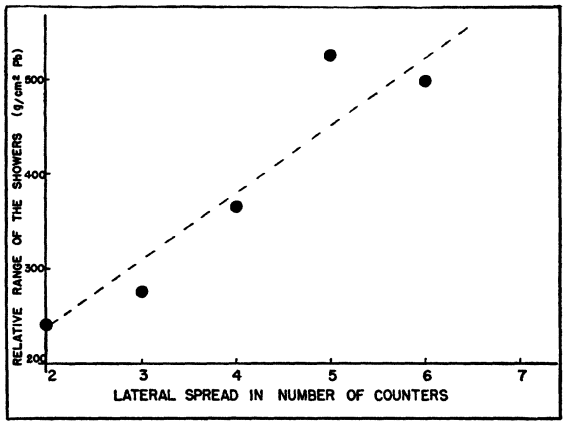

FIG. 2. Relative range of the showers for various lateral spreads.

Though the experiment was not originally designed for the accurate measurement of the angular width of showers, an estimate of this can be made. The point of origin of the shower is not indicated by the counter arrangement, but assuming this to be within 5 cm from the top of the upper absorber, P_1 (this distance corresponds to a cross section of the same order as the geometrical cross section of the nucleus[2]) the measurements indicate that the average angular spread is represented by a cone having a half angle of 15°. Walker[3] has shown that the directional distribution of primary particles producing penetrating showers varies rapidly with zenith angle. It is assumed, therefore, that most of the showers defined by the fivefold coincidence M are produced by primaries in a vertical direction and the angular spread may be referred to the direction of the primary.

The number of analyzer counters A_1, $\cdots$, C_2 discharged per shower gives a lower limit of the multiplicity. It is found that the multiplicity averages at least 3.7 penetrating particles per shower.

A more extensive account of these experiments is being prepared for publication.

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