Some results of these calculations (for $r=A=14$) are given in Table I. The high energy mesons must also be produced in groups. If $E_P \sim 10^{17}$ ev, we find multiplicities $\sim 10^5$ mesons, and meson energies $\sim 10^{12}$ ev sufficient to explain the penetration of mesons at great depths.[11]

[1] Symposium on Cosmic Rays, Acad. Bras. Ciencias 129 (1941); G. Wataghin, Phys. Rev. **70**, 787 (1946); Comptes Rendus **207**, 358 (1938).
[2] In accord with Heisenberg's general idea of explosion showers.
[3] G. Wataghin, Phys. Rev. **71**, 453 (1947); E. P. George and A. C. Jason, Nature **161**, 248 (1948); J. Tinlot, Phys. Rev. **73**, 1476 (1948).
[4] L. Janossy, Proc. Roy. Soc. **A179**, 361 (1941); L. Janossy and Rochester, Proc. Roy. Soc. **A183**, 181 (1944); V. H. Regener, Phys. Rev. **64**, 252 (1943).
[5] More data about these showers can be found in our paper (see reference 1).
[6] G. F. Chew, Phys. Rev. **73**, 1128 (1948).
[7] P. S. Gill, M. Schein, and V. Yngve, Phys. Rev. **72**, 733 (1948).
[8] M. Schein and J. Steinberger, Phys. Rev. **72**, 734 (1948).
[9] H. W. Lewis, J. R. Oppenheimer, and S. A. Wouthuysen, Phys. Rev. **73**, 140 (1948).
[10] P. S. Gill and G. H. Vaze, Phys. Rev. **73**, 1395 (1948).
[11] See Professor A. H. Compton's remarks at the Symposium (reference 1).

Non-Rectifying Germanium

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RECENTLY germanium of rather unique properties has been prepared in this laboratory. Most unique of the properties observed is an almost complete absence of surface rectification at the germanium-metal contact. Several ingots of this type were prepared by melting germanium powder at a pressure of less than 10^{-4} mm Hg. The powder was prepared by reduction of germanium dioxide in a hydrogen furnace. Ten-point, plane-welded contact rectifiers were made from one ingot. Their average rectification ratio for 20 volts and at room temperature was 3.54. At −196°C the average ratio was 1.22. These units were weakly *N*-type at room temperature, *P*-type at −196°C. Hall effect measurements on larger samples showed that the material was *P*-type at low temperatures, reversing to *N*-type at 70°C. Potential distribution studies indicated a uniform resistivity of 17.8 ohm cm. The mobility averaged 2890 cm²/volt sec. and the Hall coefficient 514,000 e.m.u.

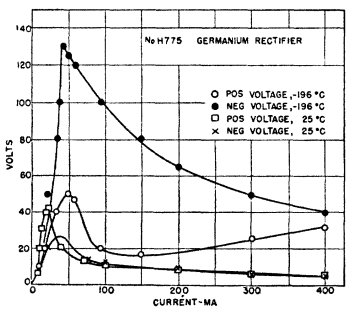

FIG. 1. Residual rectification characteristics for a welded contact rectifier made from "non-rectifying" germanium. At voltages below 10 the rectification ratio is less than 1.5, both at 25°C and −196°C, but at voltages of the order 50 there is a slight rectification with ratio ~2 at both temperatures. "Breakdown" occurs at 25 volts for 25°C, at 125 for −196°C. It is the result of heating at the point of contact.

The room temperature resistivity was increased by 22 percent by application of a magnetic field of 13,750 gauss. The Hall coefficient decreased by 29 percent on changing the magnetic field from 3600 to 13,750 gauss. Resistance of the point-contact rectifiers increased by about 18 percent in a field of 13,750 gauss, for both directions of current. Since this result is almost as large as the magnetoresistance of the bulk, one is compelled to conclude that practically all the resistance at the contact was "spreading resistance," with little contribution from contact barriers. The contact resistance averaged 2900 ohms. This is roughly ten times the forward resistance of *N*-type units made from material of comparable resistivity. Thus the "electric field-sensitive" conductivity studied by Bray, Lark-Horovitz, and Smith,[1] and by Brattain and Bardeen[2] may not appear in *P*-type germanium.

Figure 1 illustrates the residual rectification of a typical non-rectifying unit, No. H775. For small voltages the rectification was negligible, at both 25°C and −196°C, but the rectification factor increased to a value of the order 2 at 20–100 volts. It seems probable that the observed rectification was due to heating and consequent inhomogeneity in the germanium rather than to a true rectification between the germanium and the Pt-10 percent Ru whisker. Pressure contacts utilizing brass, stainless steel, and dural were found to yield negligible rectification. A study is now being made of the relation of the above results to the theory of the contact properties of a *P*-type semi-conductor.

A second point of interest is that, in spite of the apparently high degree of homogeneity in this *P*-type germanium, the magnetoresistance was large, as was the variation of Hall coefficient with magnetic field. Since the magnetoresistance of the ten test units was determined largely by a very small region of germanium around the point of contact, it seems that either the magnetoresistance (and probably also the variation of Hall coefficient with field) is intrinsic (not a result of inhomogeneity) or else the inhomogeneity is on a scale small compared to the dimensions of the point contact (~0.0002 in.). Although we cannot decide definitely as yet between these possibilities, a plausible picture retaining the second hypothesis is that the inhomogeneity consists of a rather uniform distribution of sub-microscopic lattice defects, which may also be responsible for the *P*-type conduction. Work is continuing to test these ideas.

[1] R. Bray, K. Lark-Horovitz, and R. N. Smith, Phys. Rev. **72**, 530 (1947).
[2] W. H. Brattain and J. Bardeen, Phys. Rev. **74**, 231 (1948).

γ-Radiation from Be^8

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THE cross section for the capture of a proton by the Li^7 nucleus, resulting in a state of Be^8 having an excitation energy of 17 Mev, shows a strong resonance

maximum at a proton energy, E_r, of 439 kev; and the form of the maximum agrees, at least approximately, with that to be expected from the Breit-Wigner dispersion formula ($\Gamma_r = 12$ kev).[1] For proton energies very different from E_r, the cross section does not fall away as rapidly as would be expected from the dispersion formula; in fact, there appears superposed on the resonance peak a much smaller cross section which varies only slowly for proton energies up to 1.0 Mev.[2] The energy of the γ-radiation following proton capture has been measured by several investigators, the general indication of the results being that at the resonance the γ-radiation is predominantly of quantum energy 17.0 Mev[1,3] (i.e., a transition to the ground state of Be^8). But for proton energies substantially different from E_r, the γ-energy is somewhat smaller[4] (probably mostly 14.0 Mev, i.e., transition to the well-known excited state of Be^8 at 3 Mev).[5] These facts are usually explained by assuming that the resonance corresponds to a state of Be^8 with odd total angular momentum, J, or odd parity (or both), and that the slowly varying cross section corresponds to one or more broad levels of Be^8 with even parity and J. Be^8 nuclei formed in the former states cannot break up into two α-particles; those formed in the latter states can—hence the marked difference in the widths of the two states. The approximate isotropy[6] of the γ-radiation at resonance (i.e., formation by S-protons) and the large radiation width (10 ev) together suggest that the resonance corresponds to a state of Be^8 with odd parity and $J=1$ (assuming Li^7 to have odd parity). The "non-resonant" radiation arises from states of Be^8 with even parity and $J=2, 4, \cdots$. This latter radiation should therefore show marked anisotropy. Furthermore, if the γ-transitions from the two states are not *always* of different energies and, if in addition both narrow and broad states can be formed by the same arrangement of Li^7 and proton spins (i.e., Li^7 and proton spins antiparallel, if $J=1$ is the correct assignment for the resonance level), then interference between the radiation from the two states can occur. A difference in parity in the two states will then be revealed as an asymmetry in the intensity of the γ-radiation with respect to the plane perpendicular to the incident proton beam.

We have made careful investigations, in particular of the angular distribution, of the γ-radiation from this process for proton energies of 300–800 kev, and have been able to verify most of the features of the above interpretation. The main results of our investigation are:

(1) With a "thick" Li target and protons of 500-kev energy, the γ-radiation is not exactly isotropic but is of the form:

$$1+0.05\cos\theta.$$

(θ is the angle between proton beam and direction of γ-radiation. Allowance is made for center of gravity motion.)

(2) With a "thin" target and varying proton energy the angular distribution near resonance is of the form $1+\alpha\cos\theta$, where α is positive for proton energies greater than about 435 kev and negative for smaller proton energies.

(3) The forward-backward asymmetry is a maximum ($|\alpha| \sim 0.3$) for proton energies of about 350 kev and 620 kev.

The experimental results are not sufficiently precise to exclude the possibility of small higher terms of the type $\cos 2\theta$, etc. The measured variation of $I(30°)/I(150°)$ is shown in Fig. 1. These results are consistent with the interpretation of the radiation as a superposition of electric-dipole radiation (from the 439-kev level) and electric-quadrupole radiation (from the broad level). The change in sign of α on passing through resonance is just that to be expected from the change in phase of the resonant state on passing through the resonance energy. The occurrence of maxima in α at energies so far from the resonance energy is at first sight surprising, but is in accordance with slow variation in the *amplitude* of the resonance state predicted by the dispersion formula (namely, as $(E-E_r+\frac{1}{2}i\Gamma_r)^{-1}$). With some simplifying assumptions the value of $R=I(0°)/I(180°)$ is given by:

$$R=\frac{a^2+\sin^2\gamma+2\sqrt{2}a\cos(\chi-\gamma)\sin\gamma}{a^2+\sin^2\gamma},$$

where $a^2(\ll 1)$ represents the relative intensities of resonant and "non-resonant" γ-radiation, $\tan\gamma=2\Gamma_r/(E-E_r)$ and χ is an angle related to phase difference of the two nuclear states at a particular energy. The asymmetry will clearly be a maximum when $\gamma\sim a\sim 2\Gamma_r/(E-E_r)$, or, physically, the interference term causing asymmetry will have maximum *relative* magnitude when the amplitudes of the radiation from the two states of Be^8 are of comparable magnitude. From the experimental results $2\Gamma/(E-E_r)$ is about 0.2 for E corresponding to maximum asymmetry; hence $a^2\sim 0.04$, a result consistent with the observed ratio of γ-intensities from the narrow and broad levels, as deduced from observations at angle of 90° to the proton beam where the interference term vanishes.

The above results require, *inter alia*, that the γ-radiation from the broad and narrow levels contain components of the same energy. We have made some qualitative measurements of the variation of γ-energy in the neighborhood of the resonance, and find that the component of energy

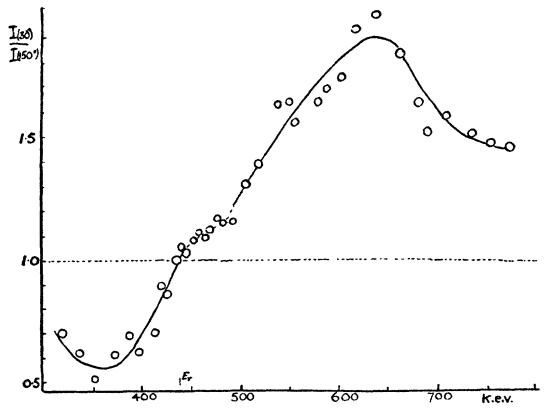

FIG. 1. Variation of asymmetry with proton energy. This curve is strongly distorted in the region near E_r owing to the finite target thickness (~30 kev).

17-Mev is present at all energies although its intensity relative to the total γ-intensity does vary by a factor of about two. Measurements of the γ-radiation asymmetry near resonance, as a function of γ-energy, indicate that the 17-Mev γ-component is responsible for most of the asymmetry, which confirms the conclusion that γ-radiation from the broad level contains an appreciable 17-Mev component. This result would be expected from the known properties of the ground state and 3-Mev level of Be^8.

In making measurements of the angular distribution, particularly near resonance where the asymmetry is small, due regard must be paid not only to the effect of the recoil of the Be^8 nucleus on the angular distribution, but also to the effect of the Doppler frequency shift on the efficiency of detection of the γ-radiation. By deliberately increasing dependence of γ-detection on γ-energy, we have observed a change in apparent angular distribution agreeing with that to be expected for a Be^8 nucleus recoiling with full energy. This is consistent with a short lifetime ($<10^{-14}$ sec.) for the compound Be^8 nucleus.

Details of the above measurements, and their interpretation, and of investigations of other (p, γ) reactions will be published elsewhere.

[1] Fowler, Lauritsen, Lauritsen, Rev. Mod. Phys. **20**, 236 (1948); T. W. Bonner and J. E. Evans, Phys. Rev. **73**, 666 (1948).
[2] Hudson, Herb, and Plain, Phys. Rev. **57**, 587 (1940).
[3] McDaniel, von Dardel, and Walker, Phys. Rev. **72**, 985 (1947).
[4] Tangen, quoted in reference (1).
[5] J. A. Wheeler, Phys. Rev. **59**, 16 (1940).
[6] Ageno, Amaldi, Bocciarelli, and Trabacchi, Ricerca Scient. **12**, 139 (1941).

Nitrous Oxide in the Earth's Atmosphere

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A SERIES of solar spectra in the wave-length range from 2.5μ to 5.0μ have been obtained at the Solar Physics Observatory, Cambridge, England (30 m above M.S.L.) during the last week of July, 1948, using a spectrometer with a lithium fluoride prism and a Hilger-Schwarz thermocouple as detector. They show convincing evidence of the existence of nitrous oxide (N_2O) in the atmosphere above the observatory.

This region of the solar spectrum contains numerous bands, many of which are intense absorptions due to carbon dioxide and water vapor, but bands at 3.90μ, 4.06μ, and 4.50μ agree in wave-length with known absorptions of nitrous oxide[1] and give satisfactory agreement in position, relative intensity, and contour with bands delineated in the laboratory with the same spectrometer, using a Nernst filament as source and an absorption cell filled with N_2O. Nitrous oxide also has other weaker bands at 3.57μ, 2.97μ, and 2.87μ; these are concealed, in the solar spectrum, by the water vapor bands in this region.

In the region around 4.0μ in the solar spectrum, one remarks immediately a doublet of moderate intensity centered at 3.9μ (Fig. 1a). Spectra taken at different solar altitudes show a marked intensification of this band at low solar elevations and, if the beam of sunlight is passed through an absorption tube containing N_2O, the band is intensified but unchanged in position and general appearance (Fig. 1b). A comparison with this band, as obtained from a laboratory source and known amounts of nitrous oxide, indicates that the amount of N_2O present in the atmosphere above Cambridge is of the order of 1.0 atmos./cm, which is in good agreement with the value estimated by Sutherland and Callendar[2] from Adel's[3] work at Flagstaff.

FIG. 1. (a) The solar spectrum from 3.7μ to 4.2μ. Complete absorption beyond about 4.2μ is due to CO_2. (b) Spectrum of sunlight, in the same region, after passage through an absorption tube containing 7 atmos./cm of N_2O. (c) Spectrum of the radiation from a Nernst filament, in the same region, after passage through 25 atmos./cm of N_2O and about 4 meters of air. Absorption bands due to N_2O at 3.90μ and 4.06μ and due to CO_2 at 4.26μ.

The 4.5μ N_2O doublet is a very intense band, but in the solar spectrum it is partially masked by the CO_2 band at 4.3μ which gives complete absorption over a wide region of the spectrum. The central hump and longer wave-length half of the N_2O band are, however, clearly present and confirm the evidence of the 3.9μ-band (Fig. 2). The band at 4.06μ is a much weaker absorption, but its presence too can be observed in the solar spectrum when the sun's altitude is low.

Bands at 7.8μ and 8.6μ, on which Adel[3] based his first suggestion of nitrous oxide in the earth's atmosphere, had previously been sought by us, using a rocksalt prism, but their presence in the solar spectrum could not be definitely established. The region around 7.8μ is largely masked, when observing from such a low altitude station, by the edge of the great 6.3μ-water-vapor band. The 8.6μ-band is a weak one, and even in this region the solar spectrum shows a