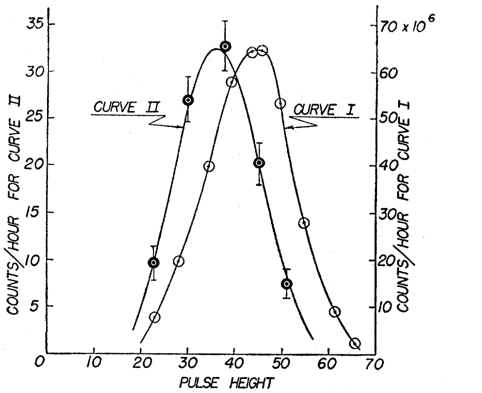

FIG. 1. Scintillation pulse-height distributions for Po-α-particles. Curve II is the distribution produced by α-particles in coincidence with γ-rays.

The number of coincidences was also studied as a function of artificial delays introduced in the coincidences selector. The result indicated that the half-life of the γ-emitting state of Pb^{206} is less than 10^{-9} sec.

In the second part of the experiment a stronger Po source was used. The α-particles were collimated by means of an aperture defining the direction of their emission within $\pm 10°$, and detected by a stilbene crystal after having traveled 1 cm in air. The γ-detector defined the angle of emission of the γ-rays within $\approx \pm 15°$, and the coincidences were counted as a function of the angle between α- and γ-rays. From the raw data was subtracted the background due to random coincidences (measured by interposing a sufficiently long delay) and that caused by spurious immediate coincidences (measured as a function of angle, with the α-detector covered by a thin absorber).

The results are plotted in Fig. 2 together with the curve $\sin^2 2\vartheta$. The total background amounted to about 30 percent of the net counting rate on the maxima.

If one assumes that both Po^{210} and Pb^{206} have 0 spins in their ground states, they must have the same parity (probably even) since they are connected by α-decay. Thus the γ-rays cannot be of magnetic polarity, having to carry the same angular momentum and parity as the short range α-particle. The agreement of the experimental curve with the $\sin^2 2\vartheta$ distribution indicates that the γ-rays are electric quadrupole ($E2$) and that the short-range α-particles have angular momentum 2. The fact that the 0.8-Mev excited state of Pb^{206} has spin 2 and the same parity as the ground state is in agreement with the behavior of most other even-even nuclei.[4] The $E2$ assignment is also consistent with the short half-life of the γ-emitting state.

However, this assignment seems difficult to reconcile with measurements of conversion coefficients of the γ-rays from Pb^{206}.[1,2] One might look for an explanation of this disagreement in the incompleteness in the theory of K/L ratios for high Z, and in the experimental difficulties of an absolute measurement of K conversion coefficients.

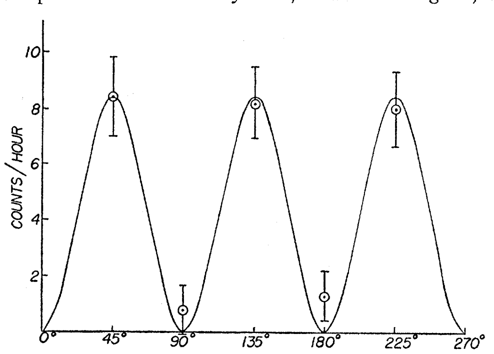

FIG. 2. Angular distribution of γ-rays from Po. The background has been subtracted. The curve is a plot of $\sin^2 2\vartheta$.

* Supported in part by the AEC.

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Zinc as an Acceptor in Germanium

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(Received January 8, 1952)

IT has long been known that some third and fifth column elements can act as donor (electron) or acceptor (hole) impurities for germanium and silicon. In particular, arsenic, antimony, and phosphorus are donors; indium, aluminum, gallium, and boron are acceptors. Numerous other elements (notably tin) have been taken to be effective as impurities.[1] In most, if not all, such cases, it has not been established that traces of impurity in the added element were not responsible for the observed effects.

In the present note, I wish to report what seems to be convincing evidence that zinc can act as an acceptor element in germanium. The evidence is based upon two sorts of experiments.

In the first experiments, several samples of single crystal germanium were prepared by adding small amounts of highest purity zinc (Johnson-Mathey 99.99 percent material) to the melt. In all such melts, the germanium crystals were p-type. The resistivity of the single crystals was measured in the temperature range of liquid hydrogen to room temperature. A curve of log conductivity *versus* $1/T$ for a single crystal of zinc-doped germanium is shown in Fig. 1. The activation energy for excitation of carriers from the impurity state can be obtained from the slope of the $\log\sigma$ *versus* $1/T$ curve. This value for the zinc single crystals is 0.031 ev. The significant point for this discussion is that this value is greater by a factor of five or ten than values obtained for such acceptors as indium. A high activation energy might be expected for zinc in a substitutional site because of its position in the second column of the periodic table.

A striking fact is that the activation energy for zinc-doped samples is the same, within experimental error, as the activation energy previously found for heat-treated germanium.[2] This may

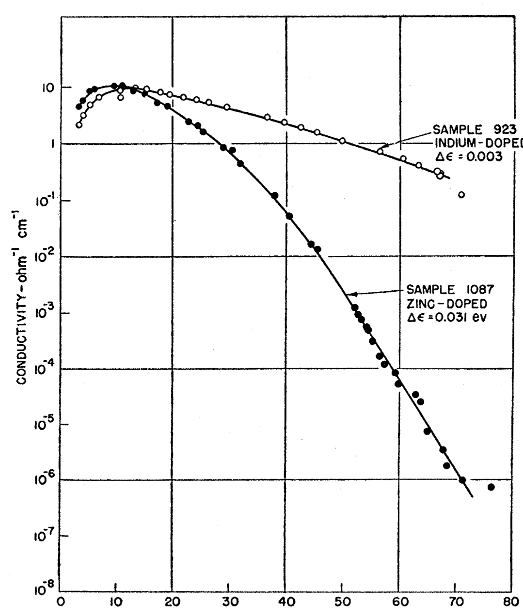

FIG. 1. Conductivity *vs* $1/T$ plots for indium-doped and zinc-doped single crystals of germanium in the temperature range 12–300°K.

point to a similarity between the acceptor centers in zinc-doped germanium and the lattice defects found in heat-treated material.

In the second set of experiments, zinc has been deposited on single crystals of n-type germanium by heating the germanium with a small amount of radioactive zinc (of the order 1–3 micrograms). The diffusion rate has been measured from the location of the $p-n$ junction formed by the penetration of the zinc.[3] These results show that zinc diffuses much more rapidly than indium, gallium, or aluminum. The diffusion coefficient at 900°C is about 1×10^{-11} cm²/sec, the activation energy for diffusion about 2.5 ev.

Additional evidence for the electrical activity of zinc can be obtained by determining the amount of diffusing impurity required to effect the formation of the $p-n$ junction at the depths observed. This amount is orders of magnitude greater than the impurity present and is roughly equal to the amount of zinc actually used.

I wish to thank F. C. Kelley and R. N. Hall for furnishing samples of zinc-doped germanium, and W. DeSorbo for help in the low temperature measurements.

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[3] The diffusion experiments referred to are being reported in detail elsewhere.

Proton Bombardment of Lithium

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(Received January 16, 1952)

LITHIUM of normal isotopic ratio has been bombarded with monoenergetic protons of energies between 1.8 and 5.3 Mev. The yield of neutrons in the forward direction was measured using a conventional "long" counter at a distance of one meter from the rotating target. Gamma-rays of energy greater than roughly 10 Mev were detected using a large sodium iodide crystal as a scintillation detector.

Protons beams, of from one to three microamperes, from the electrostatic generator were obtained after 105° deflection in the analyzer magnet. The beam energy was controlled by varying the corona current in accord with the error signal obtained from slits placed at the 105° beam exit port. The energy calibration was made by correlating magnet current with beam energy by observing the known[1] gamma-ray resonances of fluorine below 1.5 Mev with mass-one, mass-two, and mass-three beams. With careful magnet recycling, repeated runs indicate that the energy determination is accurate to ±0.2 percent relative to the 1.882 $Li^7(p,n)Be^7$ threshold. The fluorine measurements indicate a spread in beam energy of 0.1 percent or less.[2]

The curve of Fig. 1 shows a typical neutron yield in the forward direction for proton energies between 1.8 and 5.3 Mev. Background was negligible. Target thickness was approximately 18 kev at the threshold. In addition to the geometrical peak and the well-known[3] peak at 2.30 Mev, another maximum in the yield occurs at a bombarding energy of about 4.89 Mev corresponding to an excited state in Be^8 in the vicinity of 21.5 Mev. Full width at half-maximum of the resonance at 4.89 Mev is approximately 0.4 Mev.

The lower curve of Fig. 1 shows a typical yield of gamma-rays with energy greater than about 10 Mev. Operation of the counter was checked by observing the 440-kev resonance with the mass-three beam. Target thickness was 15 kev. Background was negligible. The intensity is essentially constant over the region studied. A level with 3 percent of the intensity of the 440-kev resonance would have been easily observed.

The high radiative capture cross section of iodine together with the copious yield of neutrons gave sufficient "background" count in the NaI crystal to effectively prevent the obtaining of a low energy gamma-ray yield curve with the techniques immediately available.

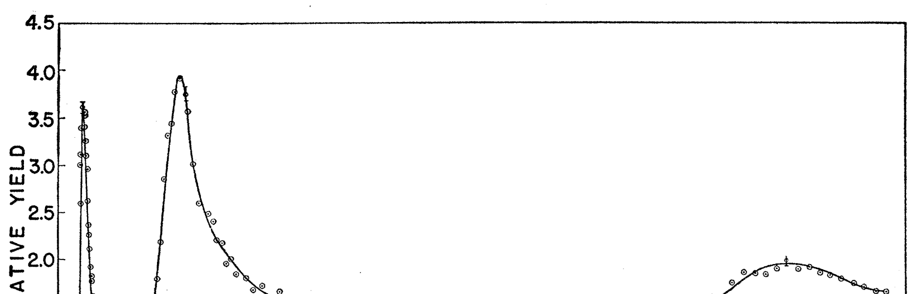

FIG. 1. Yields from the proton bombardment of lithium. Upper curve: neutrons in the forward direction. Lower curve: gamma-rays of energy greater than approximately 10 Mev.

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