In addition to an enhanced yield resulting from some preferential mode of fission, delayed neutron and neutron boil-off effects from the fragments after fission could affect the yields in the 133–136 region further. Evidence supported the latter effects is provided by the abnormally low yield of Xe^{136} (and of I^{136} determined radiochemically[6]). However, the existence of a short-lived isomeric state could account for the observed result in the case of I^{136} and perhaps faulty normalization in the case of Xe^{136}.

A treatment of beta-decay systematics by Suess[7] indicates that the observed energies of Zr^{93} and Zr^{95} are much lower than expected. This may be an indication of a shell at 40 protons. Recent mass measurements by Duckworth and Preston[8] also indicate extra stability for a 40-proton configuration. If this is true, the high yields near mass 100 may also be the result of a preference in fission for a 40-proton configuration. In any event, it appears that the only reasonable explanation for the anomalous yield at Mo^{100} is a nuclear structure preference in the fission act.

The data also indicate a dip in the curve at mass 92 which is unexplained at present. Since low binding of closed shell plus 3 and 5 neutrons seems probable from published data on neutron binding energies,[9] boil-off of the 55th neutron (at Rb^{92}) is perhaps prominent here.

Further investigations are in progress with a view toward establishing as complete a fission yield-mass curve as possible by mass spectrometric measurements of the isotopic abundances of fission produced elements as well as accurate radiochemical determinations. Similar studies on U^{233} and Pu^{239} fission products are planned to observe the effects of change in mass and nuclear charge of the fissile nucleus on the observations reported here.

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Evidence for Production of Hole Traps in Germanium by Fast Neutron Bombardment

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In Si^1 both acceptors or electron traps and donors or hole traps, presumably associated with lattice vacancies and interstitials, respectively, are introduced near the middle of the forbidden band by nucleon bombardment. Consequently, the Fermi level ζ of N-type Si is depressed and that of P-type Si is elevated by bombardment toward a limiting or saturation value ζ_{limit} causing a corresponding decrease in the conductivity of both N- and P-type Si. Heretofore, experiments on both N- and P-type Ge^2 indicate that bombardment causes an increase in P-type character with an accompanying depression of ζ toward the top of the filled band. This behavior may be interpreted as being the result of the introduction of acceptors only. However, in view of the close similarity of the electronic and crystal structure of Ge and Si, one would expect donors to be introduced into Ge as well.

James and Lehman[3] have investigated the situation in which both acceptors and hole traps (donors) are introduced in equal numbers below the middle of the filled band and find that ζ_{limit} lies half way between the two introduced levels. Thus the ζ of originally N-type or high to moderate resistivity P-type Ge will be depressed toward ζ_{limit} by bombardment while low resistivity P-type Ge with a ζ value below ζ_{limit} will show an elevation of ζ corresponding to a decrease in conductivity.

TABLE I. Bombardment data for low resistivity P-type Ge.

Sample	$n_h{}^0$	$dn_h/d(nvt)_{\text{fast}}$	T_e
1	7.0×10^{17} cm^{-3}	−5.0	32°C
2	1.01×10^{19}	−5.0	37
3	1.3×10^{19}	−2.2	48
4	1.5×10^{19}	−2.9	48

The conductivity of 5 low resistivity P-type Ge single crystals[4] ($n_h > 7 \times 10^{17}$ cm^{-3}) was followed during fast neutron bombardment in the Oak Ridge pile. The initial rate of change in carrier concentration per incident neutron $dn_h/d(nvt)_{\text{fast}}$, the original hole concentration $n_h{}^0$, and the exposure temperature for these samples sre listed in Table I. All samples showed a decrease in conductivity with bombardment and a gradual approach to a limiting value as predicted by the model.

The limiting value of the hole concentration, above which a decrease in hole concentration with bombardment is expected, is given by

$$(n_h)_{\text{limit}} = 2(2\pi m_h{}^* kT/h^2)^{\frac{3}{2}} \exp(-\zeta_{\text{limit}}/kT], \qquad (1)$$

where ζ_{limit} is measured from the top of the filled band. Consequently, it should be possible to choose Ge samples with appropriate hole concentrations which on bombardment would show a decrease in carrier concentration at low temperatures and an increase at high temperatures within a convenient temperature range. Several samples with hole concentrations of $\sim 10^{16}$ cm^{-3} were bombarded at −78°C, and the conductivity was followed at that and at ambient temperature (55°C) after the dry ice was sublimed. A typical conductivity *vs* integrated fast neutron flux $(nvt)_{\text{fast}}$ curve is shown in Fig. 1. The values of $dn_h/d(nvt)_{\text{fast}}$ for both temperatures and the original hole concentrations for these samples are listed in Table II. In every case the slope is negative at

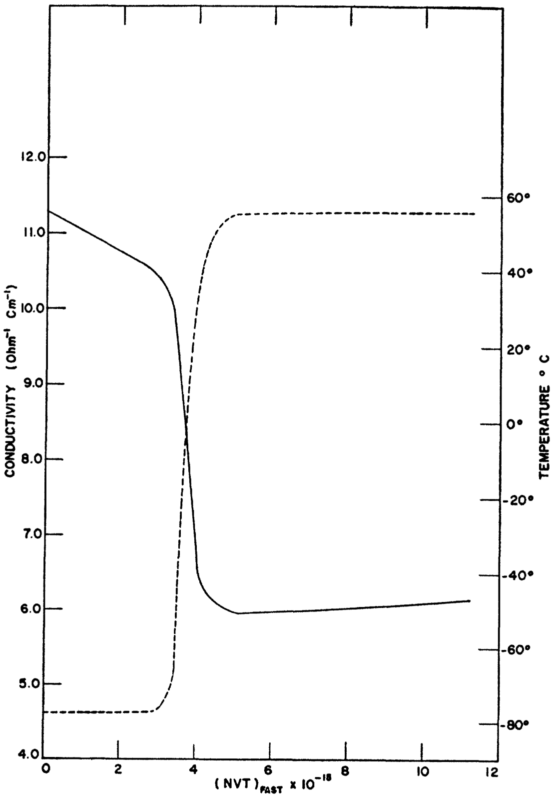

FIG. 1. Conductivity *vs* integrated fast neutron flux for P-type Ge ($n_h{}^0 \sim 4 \times 10^{16}$) exposed successively at −78°C and 55°C. The dashed curve is temperature.

TABLE II. Bombardment data for *P*-type samples bombarded successively at −78°C and 55°C.

Sample	$n_h^0(-78°\mathrm{C})$	$dn_h/d(nvt)_{\mathrm{fast}}$ at −78°C	$dn_h/d(nvt)_{\mathrm{fast}}$ at 55°C
1	4.01×10^{16}	−0.99	0.20
2	4.69×10^{16}	−1.12	0.396
3	4.86×10^{16}	−1.03	+
4	7.23×10^{16}	−1.10	+

−78°C and positive at 55°C in agreement with theory. Thus the James-Lehman model is qualitatively verified by these experiments.

An idea of the magnitude of ζ_{limit} for Ge may be obtained from Eq. (1) and the experimental data. The values of n_h^0 for sample 1 of Table I and sample 4 of Table II may be used to bracket $(n_h)_{\mathrm{limit}}$. At 55°C $7.23\times10^{16}\ \mathrm{cm}^{-3}<(n_h)_{\mathrm{limit}}<7.02\times10^{17}\ \mathrm{cm}^{-3}$, and from Eq. (1) it can be shown that $0.168\ \mathrm{ev}>\zeta_{\mathrm{limit}}>0.105\ \mathrm{ev}$. Further experiments designed to determine ζ_{limit} more exactly and to test the model more rigorously are underway.

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Measurement of the Cross Section for the Reaction $T+T\rightarrow He^4+2n+11.4$ Mev*

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A MEASUREMENT of the cross section for the reaction

$$T+T\rightarrow He^4+2n+11.4\ \mathrm{Mev}$$

has been made using the 2.5-Mev Los Alamos electrostatic generator. An analyzed beam of tritons was passed through a 1/20-mil Ni foil into a thin gaseous tritium target.[1] The triton energy was varied from 40 kev to 2.22 Mev. The average triton energy in the center of the target was calculated by taking into account the energy loss in the Ni foil and the target gas. At triton energies below 100 kev the straggling is quite large, and the results at this low energy are presented only to show the general shape of the cross section. The neutrons produced from the reaction were detected with a "long counter."[2]

The neutron spectrum from the reaction has been examined in some detail,[3,4] and except for the presence of two rather broad peaks at 8.1 and 10.4 Mev, there seem to be equal numbers of neutrons per energy interval up to 11 Mev, with few neutrons having an energy greater than 11.5 Mev. The neutron detector had a response which was essentially flat up to 5 Mev and had an efficiency at 14 Mev which was 67 percent of that at 5 Mev. However, since the neutron spectrum from the T+T reaction is similar to that obtained from the Ra−Be source which was used to calibrate the detector, no counter efficiency correction has been applied in computing the cross section.

The main difficulties encountered in this experiment were caused by the presence of background neutrons produced by the interaction of tritons with various materials present on defining slits, etc. It was found that at energies above 1 Mev a large number of neutrons were produced from the action of tritons on aluminum. For this reason 1/20-mil Ni foils instead of aluminum foils were used as windows between the acceleration tube and the target chamber. Backgrounds were taken with He^4 replacing the tritium in the target. Above 1.2 Mev the background neutron yield increased more rapidly than did the (T+T) reaction, and as a consequence the errors of the measurement increased markedly. Since the arc gas contained a high percentage of H_2, the triton beam of highest energy whose composition was known (there was no deuterium in the system) was the HT^+ beam. However, in order to reach higher energies it was necessary to use a mass 3 beam. The mass 3 beam, however, was composed of singly ionized triatomic hydrogen molecules as well as monatomic tritium ions. To correct the beam current measurement for the presence of the triatomic hydrogen molecules the ratio of the yield between singly ionized mass 4 and mass 3 beams was obtained for several energies between 1150 and 1350 kev, and the factor was applied to the data taken with the singly ionized mass 3 beam above 1.35 Mev. The ratio which was obtained was checked at the end of each run, and the beam composition was found to remain quite constant.

Figure 1 gives the differential cross section in millibarns per steradian at 0° for the reaction $T+T\rightarrow He^4+2n+11.4$ Mev as determined by detecting the neutrons. If one wishes to obtain the number of neutrons produced, since there are two neutrons pro-

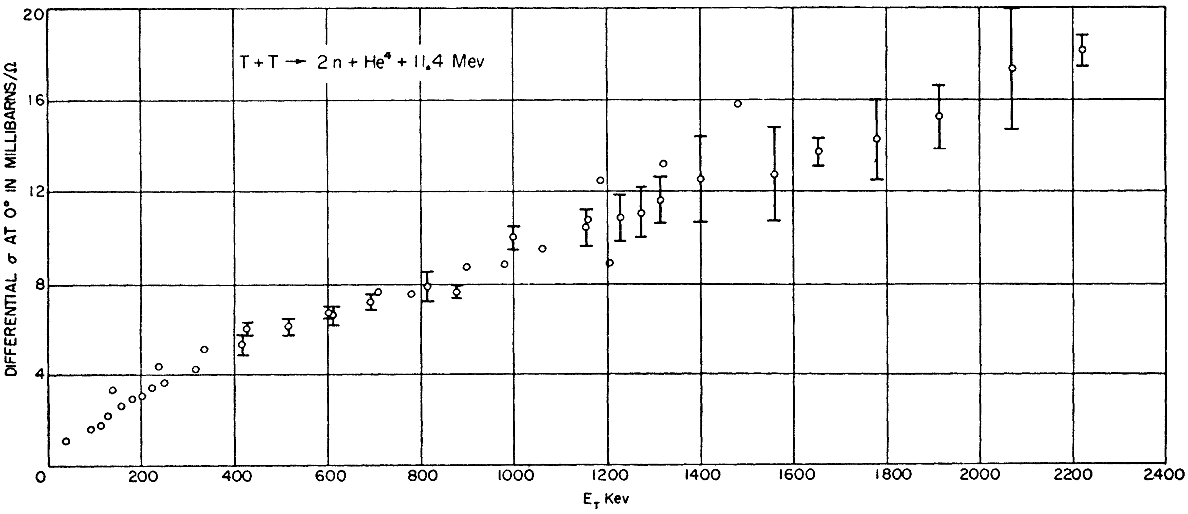

FIG. 1. Differential cross section in millibarns per steradian as determined with the neutron detector at 0° for the reaction $T+T\rightarrow He^4+2n+11.4$ Mev.