is related to a fundamental process lifetime τ_d by

$$\tau=\tau_d \exp(-\varphi/kT),$$

where τ_d may or may not be temperature dependent.

Kulin and Kurtz[1] have proposed a model of the band edges in the neighborhood of the dislocation which traps both holes and electrons. Approaching the compression side of the slip plane, the energy gap becomes larger due to the pressure of the edge of the extra plane of atoms. On the expansion side the energy gap is reduced, the band edges coming closer together. As a result the carriers have a greater density in the neighborhood of this lower-energy gap region. To a first approximation, a constant deformation potential φ will be assumed here to approximate the bands depicted by Kulin and Kurtz. Thus,

$$p_d=p \exp(\varphi/kT) \quad (1)$$

at temperatures for which Boltzmann statistics are applicable. Here p is the density of holes in the valence band, and p_d is that in the neighborhood of the expansion side of the dislocation edge. This relationship holds as long as the recombination rate is small compared to transition rates within the band. Since the transition rate will be greatest for a continuum of levels as compared to isolated lower-energy levels, the former is preferred for this picture.

Carrier lifetime is defined in terms of the recombination rate of excess carriers in the conduction and valence band by the equation:

$$\text{recombination rate}=(p-p_0)/\tau.$$

The subscript 0 refers to the equilibrium values of parameters. τ is the lifetime of minority carriers. If recombination takes place almost entirely at edge-type dislocations, it is clear that a more fundamental lifetime, that related to the actual transition process, is given by $(p_d-p_{d0})/\tau_d$. The assumption that all recombination takes place at dislocations then leads to

$$(p-p_0)/\tau=(p_d-p_{d0})/\tau_d. \quad (2)$$

Equation (2) can be solved for τ in terms of τ_d by using Eq. (1):

$$\tau=\tau_d \exp(-\varphi/kT). \quad (3)$$

The model of Kulin and Kurtz for germanium gives a value of about 0.2 ev for φ (averaging the "classical" gap change over one atomic lattice). Measurements of the temperature dependence of τ can therefore be used to find the approximate dependence of τ_d on temperature.

Experiments on temperature dependence of lifetime have been done in these laboratories and by others.[3] In our measurements, made by an interpretation of the temperature dependence of saturation current of a p-n junction, the hole lifetime gave a value of 0.2 ev to the activation energy down to 235°K, below which the simple exponential relationship did not hold. The measurements of Fan *et al.*[3] give a value for φ of 0.26 ev, also deviating from the exponential below 235°K. These two values are very close to the value of φ expected from the model of Kulin and Kurtz.

If the model is assumed, the lifetime τ_d of the fundamental recombination process must be explained by a mechanism which has only weak temperature dependence.

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Properties of Fm^{252}†

A. M. Friedman, J. E. Gindler, R. F. Barnes, R. Sjoblom, and P. R. Fields

Argonne National Laboratory, Lemont, Illinois

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THE alpha-decay energies of Cf^{248}, Cf^{250}, and Cf^{252} show an anomaly at mass 250. This has been ascribed to a nuclear subshell filling at 152 neutrons.[1] A sample of californium was bombarded with an alpha beam in the Argonne 60-inch cyclotron in order to prepare Fm^{252} to determine whether this effect also occurs in the fermium isotopes.

The target material was pure californium having the estimated isotopic composition: 30% Cf^{250}, 10% Cf^{251}, 60% Cf^{252}. Four bombardments were performed; two at 34-Mev and two at 42-Mev alpha beam energy. The targets were prepared by the deposition of (2–5) $\times 10^{-10}$ g of californium onto a copper probe target which was water-cooled during irradiation. A beam intensity of approximately 3000 microamperes per cm^2 was used for each bombardment.

After the bombardment the californium and resulting products were dissolved with hydrochloric acid. The actinide elements were separated from impurities by coprecipitating with lanthanum hydroxide, dissolving the precipitate in hydrochloric acid, and passing the solution through a Dowex-1 anion resin column. The eluate containing the actinide fraction was then separated into the individual elements by elution from a Dowex-50 column at 87°C with 0.3M α-hydroxyisobutyric acid at pH=4.2.[2]

Figure 1 represents a typical pulse analysis of the fermium fraction ninety-eight hours after bombardment. The 7.20-Mev alpha activity of Fm^{254} (3.3 hr) formed in the bombardment has decayed to a negligible amount, and an alpha peak at 7.04±0.02 Mev can be seen. The energy of the 7.04-Mev alpha was determined by comparing it simultaneously with a Fm^{255} (7.08-Mev alpha emitter) energy standard. The 7.04-Mev alpha activity was observed to decay with a half-life of 22.7±0.7 hours.

The peak at 6.3±0.05 Mev was found to increase with time in the fermium fraction. The amount (of the order of 0.01 count per minute) was too small to

observe the growth rate; but in each bombardment the number of disintegrations observed could be accounted for by the alpha decay of Fm^{252} (7.04-Mev peak) to Cf^{248} (6.26 Mev).[3] The observed increase in the yield of the 7.04-Mev alpha emitter relative to Fm^{254} with increased cyclotron energy further agrees with the assignment of the 7.04-Mev alpha energy to Fm^{252}.

A small amount of a 6.85-Mev alpha emitter with a half-life greater than 10 days was also observed in each bombardment. This was tentatively assigned to Fm^{253}. However, results on this are preliminary and further work is being done.

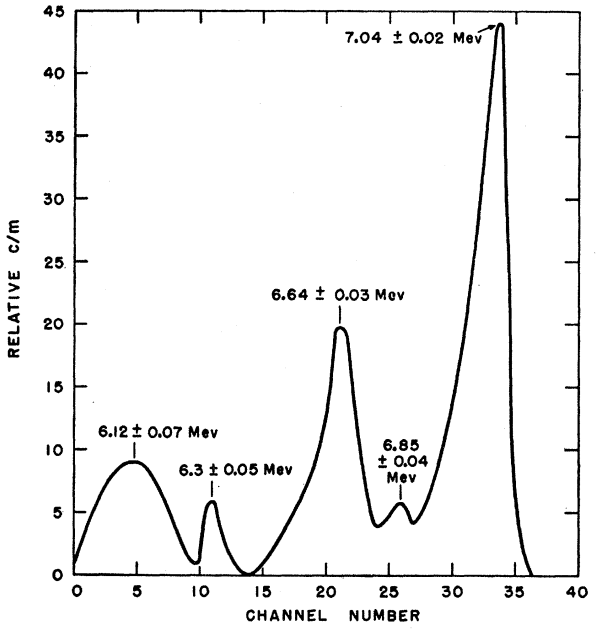

FIG. 1. Pulse analysis of fermium fraction 98 hours after bombardment.

A lower limit of 3000 days was set for the spontaneous fission half-life of Fm^{252}.

Assigning the 7.04-Mev alpha energy to the decay of Fm^{252}, indicates a more marked anomaly at 152 neutrons in the alpha-decay energies of the fermium isotopes than occurs in the case of the californium isotopes.[1]

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Liquid Xenon Bubble Chamber*

J. L. BROWN, D. A. GLASER, AND M. L. PERL
Harrison M. Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan
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A PARTICLE detector capable of detecting gamma rays with high efficiency in addition to giving accurate information concerning the paths, velocities, and energies of charged particles should be of great value in studies of elementary particles and high-energy nuclear phenomena. It was pointed out by one of us[1] that a bubble chamber filled with a liquid of high density and large atomic number would have these properties. Of a number of possible liquids, xenon seemed the most promising because it is nontoxic, noncorrosive, chemically stable, and was expected to require convenient pressures and temperatures for bubble chamber operation.

The investigation of xenon as a filling liquid for bubble chambers was carried out in an aluminum chamber with a sensitive volume one inch in diameter and one-half inch deep along the camera axis. The expansion mechanism, photographic apparatus, and chamber construction were closely similar to those of bubble chambers already described,[2] except that the temperature of the circulating air was maintained by dry ice cooling. The measurements of the temperature of the liquid inside the chamber were indirect and may be in error by as much as two degrees C.

As a preliminary test of the operation of the entire system, the chamber was filled with ethylene which has a vapor pressure curve almost identical with that of xenon in the range of temperatures of interest here. Figure 1 shows the tracks of electrons produced in ethylene by gamma rays from a 100-mC radium beryllium source held 8 inches from the center of the chamber, when the chamber was at $-18°$C.

When the chamber was filled with liquid xenon and run under closely similar conditions immediately after the ethylene experiments, no tracks were obtained. The chamber was then altered in an attempt to produce tracks in xenon by enlarging the expansion channel to expand the chamber faster, and by replacing the original Teflon gaskets and diaphragm by butyl rubber to avoid the excessive absorption of xenon exhibited by the Teflon. Still no tracks could be seen.

Shortly after these failures to observe tracks, we learned[3] that gaseous xenon had been found to be an efficient scintillating material, so that some sizeable fraction of the energy lost by an ionizing particle in liquid xenon might escape in optical radiation instead of being deposited locally in the xenon itself. Other experiments recently completed in this laboratory[4] seemed to indicate that the operation of a bubble chamber depends upon the local deposition and thermalization in the liquid of energy from the ionizing particle. To capture locally the energy which was