the polarization of the surrounding medium given by[2]

$$\varphi=\frac{e}{R}\left(1-\frac{1}{\kappa_0}\right). \quad (1)$$

(c) Thus, in removing an electron from the center of the vacancy to a point in the crystal far removed from the vacancy and at the bottom of the conduction band the work done is

$$W=eV_m-\chi-e\varphi. \quad (2)$$

The criticism of this reasoning is that including in V_0 the full potential which would exist at the vacancy center in the absence of the electron is tantamount to assuming that the optical polarization of the medium cannot follow the motion of the F-center electron. If this assumption is correct then the usual choice of V_0 is justified. If, on the other hand, the optical polarization follows the electron motion adiabatically, then the medium will not be polarized at all (to a first approximation) when the electron replaces the negative ion right at the vacancy center. Since the characteristic frequencies for fundamental optical absorption are much higher than those of the electron in the F center, it is probable that the polarization can in fact follow the

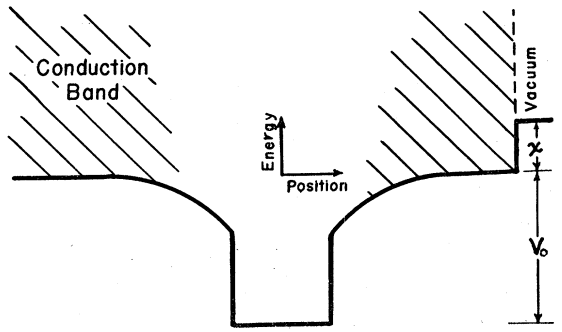

FIG. 1. Potential energy for electron in F center.

electron motion adiabatically. In this case, using the same argument usually applied to calculations of energies of formation of defects in ionic crystals,[3] one must use the average polarization so that instead of (2) one gets

$$W=eV_m-\chi-\tfrac{1}{2}e\varphi. \quad (3)$$

In typical calculations in the alkali halides the polarization potential φ is of the order of 3 electron volts, and the factor of $\frac{1}{2}$ in (3) then makes the well deeper than the conventional estimate by about 1.5 ev. This has a strong effect on the $1s$ level but does not lower the $2s$ and $2p$ so much. The result is to increase the energy separation between the $1s$ and $2p$ levels.

Some further remarks are in order. In the first place the simple potential model used is already an idealization made necessary for simplifying calculations. For this reason the quantitative significance of the present criticism is not very great (at least in so far as the results on the alkali halides are concerned). On the other hand, in the alkaline earth oxides where φ is larger the difference may be significant. In the second place, the use of (3) leads to a higher thermal activation energy than estimates based on (2). This may give greater disagreement between theory and experiment; for instance, see Dutton, Heller, and Maurer,[4] concerning experiments on V_1 centers where very small thermal activation energies are observed compared with what one might expect.

Professor H. Brooks has brought to the authors' attention the similarity between this problem and that of estimating the image potential for Schottky corrections to thermionic emission. Here also it is assumed that the conduction electrons in the metal can follow the motion of an external electron adiabatically. The analogous competing arguments are: (a) If an electron is at a distance x from the metal the electrostatic potential produced by its image is $e/2x=\varphi$ at the electron. If the electron is removed to infinity the work done would be $W=e\varphi$, if it is assumed that the metal electrons (image charge) cannot follow adiabatically. But, (b) if one assumes that the metallic electrons do follow adiabatically, the work done is only $\frac{1}{2}e\varphi=e^2/4x$, in agreement with the usual choice.[5]

We have included these considerations in a calculation of F center levels in representative alkali halides. The levels for NaCl and KCl are tabulated below. The energies are given in ev, and the zero of energy has been taken at the bottom of the conduction band. These results were obtained using (3), and the contribution to the potential energy that depends upon the wave function of the trapped electron was introduced as a perturbation. The perturbation calculation shows that the effect of the latter on the ground state is small, thus accounting for the agreement between the results obtained by Pincherle and those found by Simpson. The effect on the excited state is greater, as expected. Agreement with experiment is as good or better than that obtained by previous calculations.

	$-E_{1s}$	$-E_{2p}$	$(E_{2p}-E_{1s})$ Calc.	Obs.
NaCl	3.85	1.23	2.62	2.7
KCl	3.18	0.82	2.36	2.3

* This work was assisted by the U. S. Office of Naval Research.

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Uranium Photofission Yields*

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MANY investigations of high energy fission, both with particles and x-rays, have been reported.[1–8] One striking feature of these studies is the decrease in the peak-to-trough yield ratio of the yield-mass curve as the energy of the bombarding particle increases, resulting in the one hump yield-mass curve as the energy of the particle enters the hundred Mev range. This paper reports the results of the radiochemical study of the photofission of natural uranium at the University of Chicago Betatron.[9] The study was made, in the main, at 48 Mev maximum energy, with a beam intensity of 300 roentgens per minute, 1 meter from the target. Measurements were made on the yields of 28 fission-product nuclides. Some experiments at 22 and 100 Mev were performed on the yields of selected peak and trough nuclides. Experiments were performed on the contribution of neutrons to the observed fission rate; it was found that this effect could not have appreciably affected the results.

In the betatron experiments, about 10 g of uranyl nitrate was irradiated within the half-angle of the x-ray beam about 32 cm from the tungsten target for periods of 10 min to 2 days. Radiochemical analyses[10] were employed to isolate the desired nuclides which were counted with a Geiger-Mueller β-counter. Most of the separated samples had counting rates of about 2000 counts per minute. In addition, neutron irradiations were performed in which about 2 g of uranyl nitrate was irradiated in the thermal column of the Argonne heavy-water pile, and the same nuclides were studied as in the betatron irradiations. Some neutron irradiations were also made at the 37-inch cyclotron of the University of Chicago. The photoyield curve was obtained by the comparison method, previously described by Spence[4] and Turkevich and Niday.[11]

The photoyields given in Fig. 1 were calculated from a thermal-neutron fission-yield curve for U^{235} which is a combination of that given by Glendenin *et al.*[12] for yields greater than 2 percent, and of the familiar double-humped curve[13] for yields less than 2 percent. The photocurve of Fig. 1 was constructed by the "folding" process with the fragment mass sum of 234 for masses in the mass range 90 to 103 and 131 to 141. In the mass range 111 to

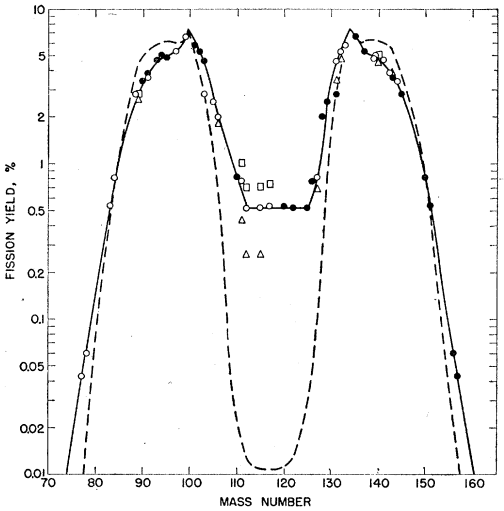

FIG. 1. Photofission yields of uranium at 22 Mev, 48 Mev, and 100 Mev. Dashed curve is that of thermal-neutron fission of U^{235}, solid curve for 48-Mev x-rays. △, 22 Mev; ○, 48 Mev; ●, 48 Mev reflected yields; □, 100 Mev. The yield of Mo^{99} at 22 Mev and 100 Mev is normalized to 6.6 percent.

127 it was noted that more concordant agreement was obtained with a mass sum[14] of 237. The curve is normalized to 200 percent total fission yield.

The peak-to-trough ratio, as determined from the yields at masses 97 and 115, was observed to be dependent upon the maximum energy of the x-ray beam, varying from 7 at 100-Mev maximum energy to 20 at 22-Mev maximum energy. These results, as well as those of other reported experiments, are summarized in Table I. The fact that the peak-to-trough ratio was

TABLE I. Peak-to-trough ratios at various x-ray energies.

Energy of x-rays, Mev	Nuclide irradiated	Peak-to-trough ratio	Reference
2.6, fission neutrons	U^{238}	100	Engelkemeir, Seiler, Steinberg, and Winsberg. See reference 10, Paper 218.
10	U^{238}	126	See reference 6.
16	U^{238}	121	See reference 6.
~20	U^{235}	20	See reference 4.
22	U^{238}	20	This paper.
48	U^{238}	10	This paper.
69	Th^{232}	10	D. M. Hiller and D. S. Martin, Jr., presented before the 122nd Natl. Meeting of the American Chemical Society, Sept. 14–18, 1952.
100	U^{238}	7	This paper.

observed to change from 48 to 100 Mev indicates that absorption of photons is occurring in this energy interval and that the average fission process is of a more symmetric type than that occurring at lower energies. The fission activation curve for uranium given by Baldwin and Klaiber[15]—their cross-section curve has a maximum at 16 Mev with a half-width of about 4 Mev, and approaches zero at about 33 Mev—must then have a high energy tail. If it is assumed that the trough yield at high energy is due to symmetric fission,[11] then the contribution to the total fission rate from photons of 48 to 100 Mev energy amounts to about 3 percent.

Further work on the (γ,f) reaction of uranium is planned at the 330-Mev University of Illinois Betatron. Work is also in progress on independent yields of some shielded nuclides and other selected fission products.

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Assignment of Y^{92} and Y^{94}*

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A SHORT-LIVED isotope of yttrium assigned to Y^{94} has been reported as a fission product from uranium[1] and plutonium[2] and as the result of an (n,p) reaction on zirconium.[3] A recent investigation of the isotope indicates that the half-life is 16.5±1 minute,[4] but the mass assignment of this activity is still listed[5,6] as "probable but not certain." In addition, the assignment of the 3.5-hour yttrium activity to Y^{92} has recently been reclassified[5] as "probable but not certain."

We have checked the mass assignment of these activities by comparing relative bombardment yields of Y^{90}, Y^{92}, and Y^{94} prepared by the (d,α) reaction. Zirconium metal (high purity foil except for two percent hafnium content) was bombarded in the 7.8-Mev deuteron beam of the University of Michigan cyclotron and the yttrium produced was separated chemically. The foil was dissolved in dilute hydrofluoric acid, carriers of niobium and yttrium added, and the yttrium precipitated as the fluoride. This precipitate was metathesized to the hydroxide and then dissolved. The resulting solution was scavenged with zirconium phosphate and niobic acid precipitates to complete the separation. A final precipitate of yttrium fluoride was slurried onto copper plates for counting. The total separation required about 25 minutes. It gave a decontamination from zirconium and niobium of at least 10^4 and a yield of yttrium of about 50 percent.

Decay of the samples was followed for several weeks to determine the relative yields of the yttrium isotopes formed. The gross decay of the yttrium samples was resolved into a 65-hour, a 3.5-hour, and an 18-minute line. No 2.0-hour Y^{88m} was detected in the decay. A small amount of 105-day Y^{88} was undoubtedly formed in the bombardment, but its yield was so low as to be scarcely detectable above background. The energy of the bombardment was low enough that no products of a $(d,\alpha n)$ reaction were observed. The lutecium isotopes arising from a (d,α) reaction on the small amount of hafnium impurity present in the target material were not separated by the chemical procedure but were formed in such low abundance that their effect on the decay curve was negligible.

Absorption curves taken at different times on the above samples indicated that the 18-minute isotope emitted a beta-particle of energy greater than 5 Mev; the 3.5-hour isotope emitted a beta-particle of about 3.5-Mev energy and a gamma-ray of about 0.5 Mev; while the 65-hour activity emitted a beta-particle of 2.35 Mev. These energy data are consistent with the values reported in the literature.[5]

The experimental yields for these three isotopes normalized to