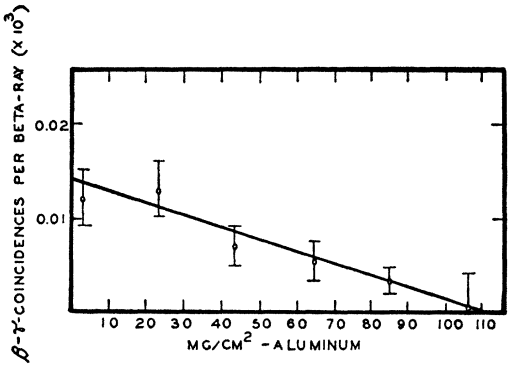

FIG. 1. Beta-gamma-coincidence rate of the 43-day cadmium as a function of the surface density of aluminum placed before the beta-ray counter.

radioactive contaminants. The beta-rays of the 43-day Cd^{115} were absorbed in aluminum. The absorption limit occurred at 600 mg/cm^2, corresponding to an energy of 1.41 Mev as calculated from Feather's equation.[2] An absorption curve in lead revealed the presence of two gamma-rays, having approximate energies of 0.10 and 2.0 Mev, the latter being of low intensity. A coincidence absorption curve gave a maximum gamma-ray energy of 1.10 Mev. It was also noted that the gamma-ray intensity was considerably less than one gamma-ray per beta-ray.

The results relating to gamma-rays were so markedly different from those of the earlier report that additional chemical purification was carried out for removal of any residual silver and indium. After completion of this chemical purification, the various absorption measurements on the beta-rays and gamma-rays were repeated. Two months had now elapsed since removal of the target material from the pile. The results were identical with those taken prior to the last chemical separation and one month previously.

A source of the highly purified Cd^{115} was placed in a beta-gamma-coincidence counting arrangement, and the beta-gamma-coincidence rate was observed as a function of the surface density of aluminum placed before the beta-ray counter. These data are shown in Fig. 1, where the beta-gamma-coincidence rate is observed to decrease from 0.014×10^{-3} coincidence per beta-ray at zero absorber thickness to zero at 110 mg/cm^2, indicating the presence of an inner beta-ray spectrum having a maximum energy of 0.38 Mev which is coincident with gamma-radiation. The harder beta-spectrum of 1.41-Mev maximum energy apparently leads to the ground state of the residual nucleus.

Assuming that on the average each beta-ray of the inner spectrum is followed by 1.10 Mev of gamma-ray energy, the calibration of the gamma-ray counter indicated that only one percent of the total beta-radiation is contained in the group of maximum energy 0.38 Mev.

A gamma-gamma-coincidence rate of 0.07×10^{-3} coincidence per gamma-ray was observed in Cd^{115}, showing that gamma-rays are present in cascade.

Bell, Cassidy, and Hughes of the Oak Ridge National Laboratory have independently reached conclusions similar to ours. Using a coincidence spectrometer employing scintillation counters, they find gamma-rays at 1.29, 0.93, 0.72, 0.50, 0.198, and 0.074 Mev and that 0.7 percent of the beta-rays are coupled with gamma-rays. They have also demonstrated that the gamma-ray at 2 Mev is associated with an impurity. Assuming that each beta-ray of the inner spectrum is followed by 1.29 Mev of gamma-ray energy, the beta-gamma-coincidence rate observed by the writers indicates that 0.85 percent of the total beta-radiation is contained in the low energy spectrum.

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† Assisted by the joint program of the ONR and AEC.

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Energy Barrier for Asymmetric Fission in the Static Liquid Drop Model

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WE have attempted to calculate the fission barrier for U^{236} by two approximate methods. As a first approximation a model was chosen which consisted of two tangent spheres of arbitrary radii joined by a frustrum of a cone which was tangent to each sphere. This configuration gives the sum of Coulomb and surface energies as 7.32 Mev greater than the parent nucleus if equal radii are chosen for the spheres. When the ratio of the radii is seven to eight (approximately a splitting in mass of two to three as is observed), the above energy is increased by 0.2_6 Mev. These results utilize 532.0 Mev for the surface energy and 799.8 Mev for the Coulomb energy of the U^{236} nucleus in agreement with Frankel and Metropolis.[1] Since the symmetric shape is quite similar to that given by the above authors, we feel that the barrier against asymmetric fission at the true saddle point should be of the above order of magnitude.

The second model used an arbitrary ellipsoid of revolution which was subjected to a deformation. We took the deformation to be:

$$r=a(\beta^2-\mu^2)^{\frac{1}{2}}\Sigma_l c_l\mu^l. \tag{1}$$

Here r is measured along the radius of the ellipsoid, R, in units of its major axis, a, μ is the cosine of the angle between R and a, and

$$\beta^2=a^2/(a^2-b^2), \tag{2}$$

where b is the minor axis of the ellipsoid. The C_l's are constants to be determined so that the deformation energy is a minimum. An expansion in powers of r/R permitted calculation of the surface energy, the mutual Coulomb energy between the deformation and the ellipsoid, and finally the self-Coulomb energy of the deformation to the order $(r/R)^2$. In this manner we obtained a quadratic expression for the deformation energy, ΔE, in terms of the C_l's for a given β. The energies were calculated as far as $l=4$, and in principle could be extended to higher l values without fundamental difficulty.

The equations

$$\partial\Delta E/\partial C_l=0,\quad l\text{ even} \tag{3}$$

together with the constant major axis condition

$$\Sigma_{l\text{ even}}\, C_l=0 \tag{4}$$

and the demand of zero volume change

$$\int_{-1}^{+1}(R^2r+Rr^2)d\mu=0 \tag{5}$$

determine the extremal values of the C_l's. This procedure does not determine the extremal values for odd l, since the corresponding C_l's enter only in second order in ΔE or condition (5).

For the choice $\beta^2=1.27$, $a/b=2.17$, the following minimal values of the C_l's were obtained: $c_0=-0.04558$, $c_2=+0.23567$, $c_4=-0.19009$; and these give $\Delta E=-1.0_2$ Mev. The difference in energy between this ellipsoid and the parent nucleus of the same

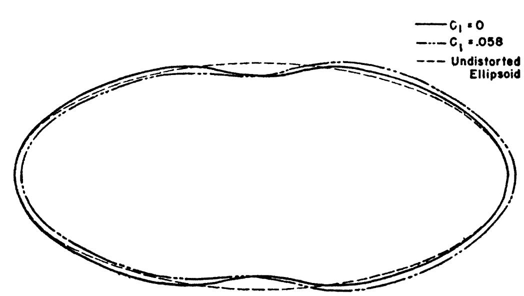

FIG. 1. Minimum energy configurations on the ellipsoid model for $\beta^2=1.27$.

volume is 8.64 Mev, so that the fission barrier is 7.6_2 Mev. If this calculation is repeated for several values of β, the maximum barrier found should be an approximate saddle-point value. Unfortunately, this procedure gives barriers that are much too high. When a plot is made of the shape of the nucleus produced by the above deformation, it shows a rather marked curvature in the equatorial region and is very close to the ellipsoid elsewhere. This can be seen in Fig. 1. The saddle-point curves of Frankel and Metropolis show a much smoother variation of nuclear surface. We believe this to be the root of our difficulty in obtaining a reasonable saddle point. An increase in the maximum value of l taken should ultimately remove this trouble. However, it probably would be better to start with $(\beta^2-\mu^2)^{1/2}$ or $(\beta^2-\mu^2)^{3/2}$ in the denominator of the expression for r so that the deformation would be accentuated in the region near the poles. The integrals for the deformation energy appear to be just as readily done for these choices of r.

The ellipsoid and tangent sphere models are complementary in that the former has marked curvature in the equatorial region whereas the latter has none. It is therefore interesting to compare the respective asymmetry barriers. In the introduction of asymmetry into the ellipsoid model again a somewhat arbitrary choice has to be made as to how the elongated drop will ultimately divide. On the assumption that the split will occur at the minimum of the constriction, the choice $c_l=0.05800$ will give roughly a two to three splitting of the above ellipsoid.

For minimum ΔE the other C_l's now become: $c_l=-0.04479$, $c_2=+0.22049$, $c_4=-0.17570$. This configuration is shown also in Fig. 1. The corresponding $\Delta E=-0.8_2$ Mev so that the barrier against this asymmetry is 0.2_0 Mev, in fair agreement with the tangent cone model. If the division of fragment masses is one to two, the asymmetry barrier becomes 0.61 and 0.75 Mev for the tangent cone and the above ellipsoid, respectively. The fact that the energy barrier disfavors asymmetric fission is in agreement with previous results.[1,2]

Since the barrier is not very great, the effects of non-uniformity of nuclear charge may be important. The model of two spheres in contact and the results of Feenberg[3] on increased nuclear binding due to non-uniform charge distribution give a crude estimate of 0.1 and 0.6 Mev in favor of asymmetric fission for two to three and one to two splittings, respectively. Thus the effect of non-uniformity appears to be of the same order of magnitude and opposite in sign to the barriers calculated above. The true influence of non-uniform charge would be obtained by including it systematically in the calculations of the Coulomb energy of a saddle-point configuration.

The author would like to thank Professor H. A. Bethe for many helpful discussions and for suggesting the models used.

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Gamma-Rays from Ag^{110}

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EARLY measurements on radioactive silver revealed a long-lived activity whose half-life has been variously reported[1] as being from 90 days to 300 days. From a previous investigation here on silver activated in the pile a half-life of 282 days was reported.[2] Pool[3] has found 270 days as best fitting the observations taken over several years. This value is in accord with our continued observation.

Many electron lines were noted in our first study indicating four gamma-rays as reported. In a subsequent study Siegbahn observed[4] these four, together with six additional gamma-rays.

TABLE I. Electron energies from radioactive Ag^{110}.

Electron energy (kev)	Interpretation	Gamma-energy (kev)	Electron energy (kev)	Interpretation	Gamma-energy (kev)
90.6	$K^1(47)$	116.1	630.5	K^9	657.2
112.4	$L_{1,2}{}^1(47)$	116.1	632.4	$Ph-K^{12}$	720.0
115.3	$M^1(47)$	116.0	639.5	$Ph-L^9$	655.3
347.6	Ph(Pb)K^2	435.2	650.3	K^{10}	677.0
358.8	$Ph-K^3$	446.4	652.9	L^9	656.7
382.2	$Ph-K^4$	469.8	673.2	L^{10}	677.0
410.8	K^2	437.5	673.3	$Ph-K^{13}$	760.9
410.8	$Ph-K^5$	498.4	678.6	K^{11}	705.3
419.3	K^3	446.0	696.0	K^{12}	722.7
441.0	L^3	444.8	700.8	L^{11}	704.6
444.3	K^4	471.0	717.3	L^{12}	721.1
451.5	$Ph-K^6$	539.1	727.8	$Ph-K^{14}$	815.4
467.3	L^4	471.1	737.2	K^{13}	763.9
472.3	K^5	499.0	758.4	L^{13}	762.2
484.4	$Ph-K^7$	572.0	763.0	M^{13}	763.8
494.9	L^5	498.7	790.7	K^{14}	817.4
514.7	K^6	541.4	793.7	$Ph-K^{15}$	881.3
530.2	$Ph-K^8$	617.8	847.4	$Ph-K^{16}$	935.0
537.8	L^6	541.6	857.4	K^{15}	884.1
548.4	K^7	575.1	880.2	L^{15}	884.0
567.7	$Ph-K^9$	655.3	910.4	K^{16}	937.1
571.8	L^7	575.6	932.0	L^{16}	935.8
588.6	$Ph-K^{10}$	676.2	1293	$Ph-K^{17}$	1381
592.3	K^8	619.0	1357	K^{17}	1384
616.1	$Ph-K^{11}$	703.7	1377	K^{18}	1504

Continued investigation using photographic spectrometers and observing electrons due both to internal conversion and to photoemission from lead reveals a large number of previously unobserved electron lines. In order to have a source with greater specific activity, one irradiation was carried out in the Chalk River pile with its greater neutron flux. From measurements of the electron energies 18 gamma-rays can be identified and evaluated as associated with the radioactive decay. There is very good evidence that in the region from 400 to 600 kev additional gamma-rays exist but that their electron lines are too weak to be measured with sufficient accuracy, and hence they are not included in this report.

A summary of the electron energies together with their interpretation is presented in Table I. It is noted that the $K-L-M$ differences for the first three electron lines are characteristic of silver and thus represent a gamma-ray emitted in a transition between isomeric states of silver. For all other conversion electron energies the $K-L-M$ differences which fit best are those for cadmium. This indicates that competing decay processes occur, in one of which gamma-emission to a metsatable state is followed by beta-decay, whereas in the other decay mode beta-emission occurs

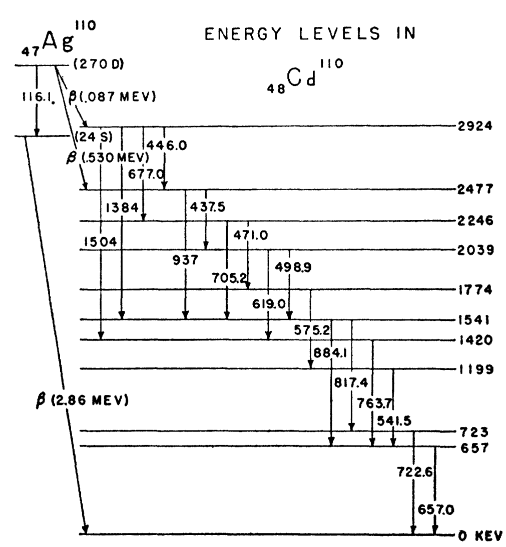

FIG. 1. Energy levels associated with the decay of radioactive Ag^{110}.