fission fragments, the density redistribution due to compressibility can be thought as due to (a) a transfer of matter from one region to the other and (b) the remaining density adjustment. Now (a) will contribute only if the fragments are unequal; and therefore, the associated energy decrease will be greatest for some asymmetric configuration.

We can separate ΔE into ΔE_{scale} and ΔE_{red}, associated with a uniform change of scale and a redistribution of density inside the nucleus, respectively. The former is easily shown to be:

$$\Delta E_{\text{scale}} = -(1/2E_v'')[(2-3\dot{\gamma})E_s - E_c]^2, \tag{1}$$

where E_c, E_s are the coulomb and surface energies calculated in the absence of compressibility, E_v'' is the nuclear compressibility coefficient,[2] and $\dot{\gamma}=(n/\gamma)d\gamma/dn$ is a dimensionless parameter giving the dependence of the specific surface energy γ on the bulk density n.

A general method of calculating the density redistribution and ΔE_{red} for a nucleus of *any shape* was developed along the lines of reference 2. If $f(\mathbf{r})$ and $g(\mathbf{r})$ denote the deviations of the local proton and neutron densities from their average values, it is found that (using the notation and assumptions of reference 2)

$$g(\mathbf{r})/f(\mathbf{r}) = \text{constant} = (S-Q)/(S+Q), \tag{2}$$

$$f(\mathbf{r}) = e(S^{-1}+Q^{-1})[\bar{v}-v(\mathbf{r})], \tag{3}$$

$$\Delta E_{\text{red}} = -\tfrac{1}{2}e^2(S^{-1}+Q^{-1})\int[\bar{v}-v(\mathbf{r})]^2, \tag{4}$$

where $v(\mathbf{r})$ is the electrostatic potential of a *uniform* proton distribution, $\bar{v}$ is the average of $v(\mathbf{r})$ over the nucleus, e is the proton charge, S and Q are coefficients related to separability and compressibility[2] [e.g., $Q=(4/9n)(E_v''/A)$], and the integration in Eq. (4) extends over the nucleus.

To find the correction to the threshold energy and the "barrier" against asymmetric fission[3,4] one should repeat the calculations of reference (3) with ΔE included in the deformation energy. As an estimate of these effects we have calculated $\Delta E(\lambda)$ for the configuration of tangent spheres as a function of λ, the ratio of the radii. Figure 1 gives ΔE_{scale} and ΔE_{red} for $A=235$, $E_s^0=587$ Mev, $E_c^0=827$ Mev (undistorted surface and coulomb energies), $E_v''=60.62A$ Mev (see reference 2; an upper limit $E_v''\lesssim 96A$ Mev has since been obtained under certain assumptions). In Eq. (4) S^{-1} can then be neglected in comparison with Q^{-1}, so that ΔE is just proportional to $(E_v'')^{-1}$.

With $\dot{\gamma}=0.3$ (estimated by using results of reference 5) $\Delta E(\lambda)$ falls away rapidly from $\lambda=1$, thus decreasing the energies of asymmetric with respect to symmetric configurations. In fact it can be shown[3] that the increase in energy of an incompressible nucleus, when a small asymmetric $\alpha_1 P_1(\cos\theta)$ term is added to the expansion of the saddle-point shape in Legendre polynomials, is $+0.113\alpha_1^2$ (in units of E_s^0), whereas the addition of our ΔE changes this to $-0.043\alpha_1^2$, so that *the asymmetric configuration now has lower energy.* [Note that for tangent spheres $\lambda=(1-\frac{1}{2}\alpha_1)/(1+\frac{1}{2}\alpha_1)$.]

The effect of compressibility affords, therefore, a possible explanation of the asymmetry of fission. The present estimates are crude, but they have brought to light a large effect which does not appear to be sensitive to the approximations made.

We are not in a position to deduce the size of the asymmetry. The minimum in ΔE occurs at a fragment mass ratio of 8:1, but this neglects the dependence on λ of the energy of the incompressible configurations. A tentative estimate of this dependence gives a mass ratio $\sim$2:1.

The calculations also indicate that the compressibility may have a considerable effect on the threshold energy. Actually, the order of magnitude, as given by $\Delta E(1)-\Delta E(0)=5.7$ Mev, is comparable with the empirical threshold energy. This problem and the allied question of the effect of compressibility on nuclear stability are being studied further.

The effect on ΔE of changes in γ due to changes in the curvature of the nuclear surface (like ΔE_{scale} of order $A^{1/3}$) was found to be small.

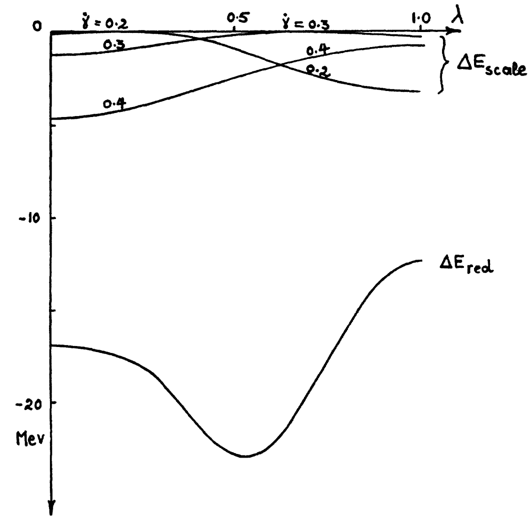

FIG. 1. Corrections ΔE_{scale}, ΔE_{red} due to compressibility for the configuration of tangent spheres as functions of λ, the ratio of the radii.

Quantitative results may be obtained in the future by repeating the calculations of reference 3 with ΔE included in the energy. The asymmetry of the saddle-point shape may provide a possible method of estimating E_v'' empirically.

A fuller account of these investigations will be published in the *Communications* of the Copenhagen Academy of Science.

I wish to thank Professor N. Bohr for his interest in this work, my colleagues at the Institute for many valuable discussions, and the Department of Scientific and Industrial Research (London) for an award.

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Low Excited States in Li^6 and Be^9

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VARIOUS investigators[1] have reported an energy level in Li^6 at about 2.5 Mev. Pollard and Margenau[1] find a resonance in the yield of alpha-particles scattered by deuterons indicating a level at 2.4 Mev, and Hushley[1] has observed 3-Mev gamma-radiation when beryllium is bombarded with protons. There is also some indication of a resonance in the yield of deuterons scattered from helium in the early data of Heydenberg and Roberts.[1] Unpublished work of Boyer[1] on the $Li^7(d,t)Li^6$ reaction indicates a level at approximately 2.3 Mev in Li^6.

In the present experiment alpha-particles from the reaction $Be^9(p,\alpha)Li^{6*}$ have been observed with a spherical electrostatic analyzer.[2] Protons of well-defined energy from the Wisconsin cylindrical analyzer were allowed to strike targets of thin beryllium foils or thin layers of beryllium evaporated onto nickel foils of 1×10^{-5} cm thickness. The energy of particles emitted at 135° from the incoming beam are measured with the spherical analyzer. A scintillation counter is used for detection. Figure 1 is a plot of number of emitted particles *vs* energy for an incident beam energy of 2.35 Mev. Peaks corresponding to singly, doubly, and triply charged Li^6 particles and doubly charged alpha-particles from the ground-state reaction are found. In addition, peaks attributed to singly and doubly charged alpha-particles from the excited state are seen. Elastically scattered protons from beryllium and the singly charged ground state alphas have energies beyond the range of this plot.

To identify these peaks, their position was observed for three different bombarding energies from 2.35 to 3.29 Mev. At each energy both the singly and doubly charged particles were found at the expected positions. The use of both foil and evaporated targets verified that the alphas came from a reaction in beryllium. Reactions with possible contaminants and elastically scattered protons from contaminants do not give rise to peaks which could be confused with this reaction.

Sufficient counts to fix accurately the alpha-particle edge were taken only at 2.555 Mev bombarding energy. In order to calculate the energy of the alphas, the center of this edge was compared with the center of an edge of protons of known energy scattered from thick platinum. Incident proton energies were obtained by calibrating the cylindrical analyzer against the $Li^7(p, n)Be^7$ threshold.[3]

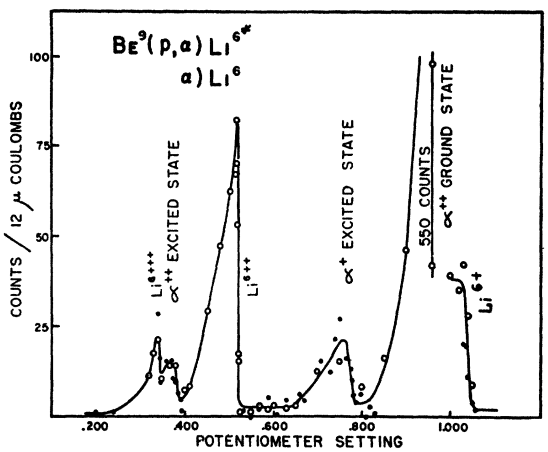

FIG. 1. Alpha and Li^6 counts *vs* potentiometer setting from 10-microinch beryllium bombarded with 2.35-Mev protons. Potentiometer setting is approximately energy/charge in Mev. Closed and open circles represent data taken with different amplifier gain settings normalized to equalize background counts. Other data at 2.55-Mev bombarding energy from an evaporated beryllium target were used to determine the position of the alpha-edge.

Relativistic corrections were applied to both analyzers and the relativistic expression used to calculate Q values. The targets were heated during bombardment, and after the data were taken scattered protons from carbon contamination on the target were observed. The amount of carbon present had a negligible effect on the measured Q values. The result obtained is -0.064 ± 0.005 Mev. The 0.1 percent uncertainty in the lithium (p, n) threshold[3] adds an additional uncertainty of 0.06 kev to Q. Table I lists the major errors and their effect on the Q value.

Using our value of 2.123 ± 0.004 Mev[4] for the Q of the ground state reaction, the energy level of Li^6 is 2.187 ± 0.009 Mev. The error of our measurement is 0.007 Mev, while the added error of 0.002 Mev is due to the uncertainty in the $Li(p, n)$ threshold.

The slope of the high energy edge of thick target data is such that an upper limit of 8 kev may be given to the width at half-maximum of the excited level. At 2.34-Mev bombarding energy, the ratio of doubly charged ground-state alphas to the sum of singly and doubly charged excited-state alphas was about 8. The differential cross section at 135° in the laboratory system for the excited state reaction was estimated to be $2.2\pm1\times10^{-27}$ cm²/steradian based on a knowledge of the solid angle and resolution of the spherical analyzer.[2]

Inelastically scattered protons from an energy level in Be^9 (previously reported at 2.422 ± 0.005 Mev from data on $B^{11}(d, \alpha)Be^{9*}$) were observed at a bombarding energy of 3.46 Mev. Our measurement gives the level at 2.433 ± 0.005 Mev. The differential cross section for inelastic scattering at 135° is $1.4\pm0.4\times10^{-27}$ cm²/steradian at 3.46-Mev incident energy. From this data, an upper limit of 3 kev may be given to the level width. Table I lists the estimated errors of both measurements.

TABLE I. Summary of errors.

Quantity	$Be^9(p, \alpha)Li^{6*}$ Error	Effect on Q	$Be^9(p, p')Be^{9*}$ Error	Effect on Q
Bombarding energy	0.7 kev	0.5 kev	1.7 kev	1.5 kev
Emitted energy	2.0 kev	4.0 kev	0.60 kev	0.8 kev
Uncertainty in angle	3 min	0.6 kev	3 min	0.2 kev
Total error of our measurement		5 kev		2.5 kev
Lithium (p, n) threshold uncertainty	0.1%	0.06 kev		2.4 kev

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The Mass-Differences $C^{12}(H^1)_4-O^{16}$, $C^{12}(H^1)_2-N^{14}$, and $C^{12}(H^1)_3-N^{15}$

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THE Bainbridge-Jordan type mass spectrograph which had been installed in the Osaka University was disassembled in the middle of 1943, and its reconstruction and improvement were commenced in 1947 and completed near the end of 1950. Features of its improvement were in the collimating system and in the evacuating system. The collimating system consists of a hole with a diameter of 0.5 mm, and a slit whose width is 0.005–0.008 mm and whose length is 0.2 mm; the distance between them is 45 cm. The energy-selecting slit, which is placed immediately after the energy selector, is 0.08 mm wide. The photographic plate is located nearly along the direction focusing plane through the double-focusing point, because the depth of velocity focusing is deeper than the direction focusing. The evacuating system consists of one 6-in. fractionating oil diffusion pump, two 4.5-in. oil diffusion pumps, and one mercury diffusion pump with liquid air trap, the vacuum being about $7-8\times10^{-6}$ mm Hg at the operating condition. The ions are created by the ordinary gas discharge in a cylindrical glass discharge-tube with a diameter of about 50 mm and a length of about 50 cm; while a stable electric discharge is maintained using a 20-kv transformer with a rectifier and a 2-μf smoothing condenser. The photographic plates used in this experiment are of the Schumann-type prepared in our laboratory.

Under the above-mentioned conditions, the total breadth of a line of medium intensity near the double-focusing point is about 0.01 mm and the dispersion for a one percent mass difference is about 5.82 mm, resulting in an experimental resolving power of about 58,000. The mass-scale calibration is made by using the separation of $Br^{79}-Br^{79}H^1$ and $Br^{81}-Br^{81}H^1$ for each plate, where the masses of Br^{79}, Br^{81}, and H^1 are assumed to be 78.943, 80.941, and 1.0081, respectively; the masses of Br being the mean values of Aston's[1] and ours,[2] while the mass of H^1 is taken from the Mattauch-Flammersfeld table.[3]

With this apparatus, the mass differences of $C^{12}(H^1)_4-O^{16}$, $C^{12}(H^1)_2-N^{14}$, and $C^{12}(H^1)_3-N^{15}$ have been determined. The results are listed in Table I. The table also contains the $(C^{12})_2(H^1)_4-C^{12}O^{16}$ and $(C^{12})_2(H^1)_4-(N^{14})_2$ mass differences, which were measured in order to check whether any discrepancy exists between atomic-molecular doublets and molecular-molecular