$_{45}Rh_{58}{}^{103}$ has a $1/2^-$ ground state and levels at 40 kev and 95 kev to which 702^+ and $9/2^+$ have been assigned.[22] The necessary experiments here would be very difficult. Four other nuclei $_{34}Se_{43}{}^{77}$, $_{34}Se_{47}{}^{81}$, $_{47}Ag_{60}{}^{107}$, $_{47}Ag_{62}{}^{109}$) have $1/2^-$ ground states and $7/2^+$ levels between 87 and 160 kev but in these cases the $9/2^+$ level has not been seen.

Five nuclei ($_{32}Ge_{45}{}^{77}$, $_{34}Se_{45}{}^{79}$, $_{36}Kr_{43}{}^{79}$, $_{36}Kr_{45}{}^{81}$, $_{45}Rh_{60}{}^{105}$) have $7/2^+$ ground states and a $1/2^-$ level between 80 and 400 kev. But in none of these cases is the $9/2^+$ level known.

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Evaluation of the Imaginary Part of the Nuclear Complex Potential

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NEUTRON scattering data for several incident energies in between 0 and 30 Mev have now been analyzed fairly successfully with a simple complex potential model.[1] Figure 1 shows the various experimental values of V_i, the imaginary part of the potential, plotted against incident energy.[2] We have estimated V_i theoretically, using a method proposed by Goldberger for high incident energies.[3] Although application of the method to lower energies is not clearly justifiable,[4] we feel that the agreement obtained with experiment is noteworthy.

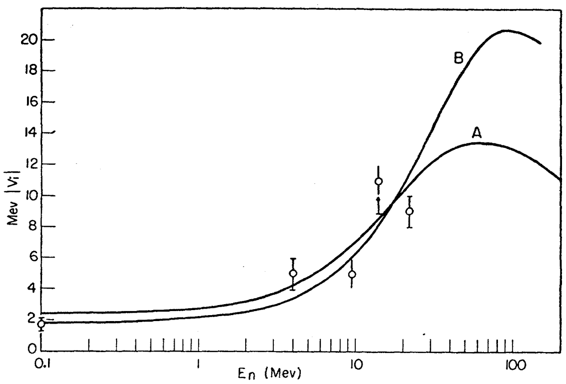

FIG. 1. The imaginary part of the complex potential V_i, plotted against incident neutron energy E_n (both in Mev). Curves A and B are computed according to the theory outlined in the text assuming nuclear radii of $1.48A^{1/3}\times10^{-13}$ and $1.20A^{1/3}\times10^{-13}$ cm respectively. The experimental points are taken from analyses of data by the following: $E_n=0$ Mev—Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954) (these authors fit cross sections up to $E_n=3$ Mev with the same V_i). $E_n=4.1$ Mev—M. Walt and J. R. Beyster (private communication from Los Alamos). $E_n=9.5$ Mev—D. J. Prowse and A. Hossain (private communication to Prof. V. F. Weisskopf from Bristol, England) (these authors do not state the uncertainties in their values of V_i). $E_n=14$ Mev—Lower point: Gittings, Barschall, and Everhart, Phys. Rev. **75**, 610 (1949) (lower limit on V_i). Upper point: Culler, Fernbach, and Sherman, University of California, Livermore Laboratory Report, UCRL-4436, 1955 (unpublished) (these authors do not state the uncertainties in their values of V_i). $E_n=22$ Mev—D. S. Saxon and R. D. Wood, Phys. Rev. **95**, 587 (1954) (these authors analyze proton scattering data).

A typical target nucleus is regarded as a sphere of nuclear matter composed of four degenerate Fermi gases, one for each nucleon spin state, filled up to an energy E_F. The assumption that an incident neutron is absorbed when it collides with a target nucleon leads to an expression for V_i:

$$V_i=\tfrac{1}{2}\hbar v_1(\rho_n\bar{\sigma}_{nn}+\rho_p\bar{\sigma}_{np}),$$

where v_1 is the velocity of the incident neutron inside nuclear matter, ρ_n, ρ_p are the neutron and proton densities and $\bar{\sigma}_{nn}, \bar{\sigma}_{np}$ are certain average neutron-neutron and neutron-proton cross sections. The averages in $\bar{\sigma}_{nn}$ and $\bar{\sigma}_{np}$ are taken in an appropriate fashion over all possible relative collision velocities $\mathbf{v}_r$. Writing $\mathbf{v}_2$ for the velocity of a struck nucleon in the Fermi gas (so $\mathbf{v}_r=\mathbf{v}_1-\mathbf{v}_2$), the precise formula is [see Goldberger,[3] Eq. (4)]:

$$\bar{\sigma}=\int\sigma(E_r)\frac{v_r}{v_1}d\mathbf{v}_2\Big/\int d\mathbf{v}_2,$$

where the integrals are taken over the range of velocities in the Fermi gas.

The effect of the Pauli principle in the present model is to forbid all collisions in which either nucleon ends with an energy $<E_F$. To compute the probability that a given collision will be forbidden on these grounds, some definite angular dependence of nucleon-nucleon scattering must be assumed. In our calculations we have always assumed angular isotropy, and have evaluated the integrals analytically for the following dependences of $\sigma(E_r)$ on relative energy: $\sigma \propto E_r^{-\frac{3}{2}}$, E_r^{-1}, $E_r^{-\frac{1}{2}}$, constant. (The fact that the actual observed n-p scattering has an appreciable dip at 90° for relative energies >30 Mev means that we somewhat overestimate V_i.)

In the numerical evaluation that led to the curves in Fig. 1, we assumed the following constants: Nuclear radius$=1.48A^{\frac{1}{3}}\times 10^{-13}$ cm (curve A); $1.20A^{\frac{1}{3}}\times 10^{-13}$ cm (curve B) (the corresponding values of E_F are 22 Mev and 33 Mev, respectively); energy in nuclear matter $=E_F+8$ Mev+incident energy; σ_{np} (barns)$=8\times(E_r$ in Mev$)^{-1}$; σ_{nn} (barns)$=4\times(E_r$ in Mev$)^{-1}$. (The formula for σ_{np} fits the observed n-p cross section within 15 percent over the energy range from 2 to 280 Mev. The formula for σ_{nn} gives a rough fit to the observed nuclear p-p scattering cross section.)

The most striking feature of the results is the manner in which the experimental fall-off in V_i at lower incident energies is reproduced. In the theoretical curves, this fall-off arises purely from the effect of the Pauli principle which prevents an increasing number of collisions as the incident energy is lowered. We have performed the calculation ignoring the Pauli principle and find that V_i is increased to 30 Mev at zero incident energy in the case of the larger radius. The effect is even larger for the smaller radius. It is to be noted that the two curves, A and B, are not appreciably different below 30-Mev bombarding energy. Above this energy, the experimental values of V_i are not determined to better than factors of the order of 2.

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Thermodynamic Theory of Fission

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An attractive new theory of nuclear fission has recently been proposed by Fong.[1,2] He has used it to calculate for thermal neutron fission of U^{235} a mass yield curve which is in remarkably good agreement with the experimental data.

When we applied Fong's prescriptions to thermal neutron fission of Pu^{239} we found no such agreement: indeed the theory would predict a mass yield curve with four humps, and with much too small a peak-to-trough ratio.

A more detailed analysis shows that the results depend very critically on the exact shape of the line of maximum beta stability in the semiempirical mass formula; i.e., to Fong's correction term[2] ΔZ_A. It does not seem that one could obtain a good fit to observed yield curves over a whole range of fissile isotopes (Th^{232} to Cm^{242}), save perhaps by substantial and ill-authenticated alterations.

Essentially, apart from a slowly varying factor, the relative fission yields are determined by the exponential factor in I, Eq. (2), in which a_1+a_2 is independent of the fission mode. Hence the excitation energy E (calculated for the most probable charge splitting) should behave in much the same way as the mass yield curve itself; i.e., it must exhibit a minimum for symmetrical fission, a maximum for mass ratios ~ 1.5, and must decrease steadily for higher mass ratios.

E is calculated from the fragment masses, by Eq. (1) of I. Well-known semiempirical formulas give

$$M(A,Z)=M_A+B_A(Z_A-Z)^2+\delta_A, \quad (1)$$

but Fong shows that substantial corrections are necessary to the usual analytical expressions[3] for M_A and Z_A, and he writes

$$M(A,Z)=M_A+\Delta Z_A+B_A(Z_A+\Delta Z_A-Z)^2+\delta_A, \quad (2)$$

where ΔM_A, ΔZ_A are given graphically.[2]

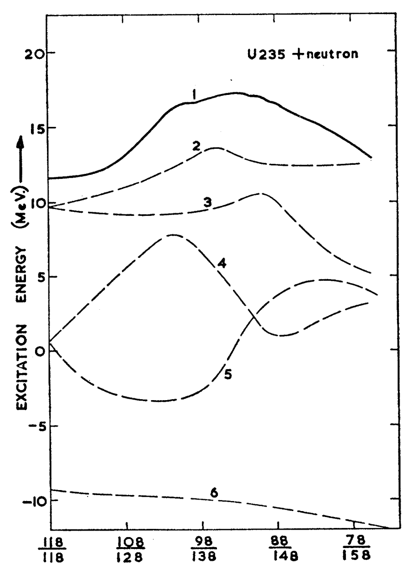

FIG. 1. Excitation energy as a function of mass splitting for thermal fission of U^{235}. Curve 1: Excitation energy E of the fragment pair; it is the sum of the five components 2 to 6. Curves 2,3: Mass corrections ΔM_A for heavy and light fragments respectively. Curves 4,5: Contributions due to the corrections ΔZ_A for heavy and light fragments respectively. Curve 6: Excitation energy E of the fragment pair using uncorrected semiempirical mass formula.