# Reevaluation of experimental estimates of the pairing gap at the fission saddle point*

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New estimates for the height of the fission barriers imply new values for the pairing gap at the deformation corresponding to the second saddle points. Current barriers imply $2\Delta_s = 1.7 \pm 0.3$ MeV and $1.6 \pm 0.3$ MeV for $^{236}$U and $^{240}$Pu, respectively. Uncertainties in the reported values of $2\Delta_s$ for $^{210}$Po and $^{227}$Ra are also discussed.

[NUCLEAR STRUCTURE $^{236}$U, $^{240}$Pu; reevaluate pairing gap at fission saddle point.]

Several years ago it was shown[1-6] that measurements of fission-fragment angular distributions at energies near the fission threshold could be used to estimate the magnitude of the pairing gap for even-even nuclei at the highly deformed fission saddle point. In particular, angular-distribution measurements from $(d, pf)$ and $(t, pf)$ reactions,[2,3] $(n,f)$ reactions,[4,5] and $(\alpha,f)$ reactions[6] showed discontinuities in $K_0^2$ at energies corresponding to the onset of two-quasiparticle excitations at the fission saddle point. The pairing gap at the saddle point, $2\Delta_s$, could then be approximately equated to the difference between the energy for the onset of two-quasiparticle excitations, $E^*_{2\text{qp}}$, and the height of the fission barrier, $E_f$. However, at the time of these experiments it was not realized that the fission barriers for actinide nuclei are double peaked and that fission threshold properties are strongly influenced by shell effects at both the ground-state and saddle-point deformation.

Recent analyses[7,8] of fission results, taking into account the two-peaked nature of the fission barrier and allowing for the effects of shells on $\Gamma_f/\Gamma_n$, have led to new values for the heights of the fission barriers for $^{236}$U and $^{240}$Pu. These new barrier estimates lead to revised values for $2\Delta_s$ for these nuclei as indicated in Table I. Most evidence now suggests[9,10] that the angular distribution of the fragments is determined at the deformation of the second peak for $^{236}$U and $^{240}$Pu and, therefore, the estimate of the pairing gap is assumed to correspond to that deformation for these nuclei.

For $^{236}$U and $^{240}$Pu the new values for $2\Delta_s$ are not significantly different from typical values, $2\Delta_{\text{g.s.}} \approx 1.4$ MeV, for actinide nuclei at their ground-state deformations. Since the relative values of $\Delta$ at the saddle and ground-state deformations are influenced both by the relative pairing strengths $G_s$ and $G_{\text{g.s}}$ and the relative densities of single-particle states near the Fermi surface, it is not possible to conclude from these experimental results alone whether or nor the pairing strength $G$ varies with deformation.

Large values of the pairing gap, $2\Delta_s \approx 4$ MeV for $^{210}$Po and $2\Delta_s \approx 2.7$ MeV for $^{227}$Ra have also been reported.[5,6] For $^{210}$Po the $2\Delta_s \approx 4$ MeV estimate is based on $E_f = 20$ MeV. Reanalysis of this data taking into account shell effects at the ground state, but not at the saddle point, have led to a new estimate[11] of the fission barrier, $E_f = 21 \pm 1$ MeV. More recent attempts[12] to realistically include shell effects at the saddle point have shown that with various assumptions about the saddle-point level densities the data may be consistent with values of the barrier in the range $E_f = 19$ to 22 MeV. Therefore, at present the estimate of $E_f$ for $^{210}$Po must be considered very uncertain and the angular-distribution data consistent with a value $2\Delta_s$ in the range 2–5 MeV. Therefore, these results also do not at present give conclusive evidence that the pairing strength is a

TABLE I. Estimates of saddle-point pairing gaps $2\Delta_s$ from previous measurements of the energies for the onset of two-quasiparticle excitations $E^*_{2\text{qp}}$ and estimates for the height of second peak in the fission barrier $E_B$.

| Nucleus | $E^*_{2\text{qp}}$ (MeV) | $E_B$ (MeV) | $2\Delta_s$ (MeV) |
|---|---|---|---|
| $^{236}$U | $7.4 \pm 0.2$ [a] | $5.7 \pm 0.2$ [b] | $1.7 \pm 0.3$ |
| $^{240}$Pu | $7.0 \pm 0.2$ [c] | $5.4 \pm 0.2$ [d] | $1.6 \pm 0.3$ |

[a] Reference 3.
[b] Reference 8.
[c] Average of values 6.9 MeV from Ref. 3 and 7.1 MeV from Ref. 4.
[d] Average of values 5.35 MeV from Ref. 7 and 5.45 MeV from Ref. 8.

strong function of deformation.

For $^{227}$Ra the data near threshold[5] show a rather sharp structure which is suggestive of a subbarrier resonance. Current theoretical fission-barrier calculations[13] do not predict subbarrier resonance structures near threshold for Ra isotopes but they also fail to predict observed subbarrier resonance structures for Th isotopes.[8] Therefore, in this case we cannot completely rule out the possibility that a subbarrier resonance has led to an underestimate of $E_f$ and a subsequent overestimate of $2\Delta_s$.

In summary, we conclude that because of uncertainties in fission-barrier heights current experimental estimates of $2\Delta_s$ do not provide an unambiguous answer to the question of whether the pairing strength depends on the nuclear surface area.

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