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Spin-Orbit Interaction and Fission Anisotropy*

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ABSTRACT

Previous calculations of fission fragment anisotropies assumed an optical potential with no spin orbit interaction. It is shown that a similar analysis including such interaction can be carried out and that the earlier results are essentially unchanged. In particular, the discrepancy between theory and experiment with regard to the effect of target spin on fragment anisotropy is not resolved by including a spin-orbit interaction.

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In a previous discussion⁽¹⁾, the exact power series description of fission fragment anisotropies was developed for the case where the projectile spin (S, σ) and the target spin (I_0, μ) couple to a channel spin (j, m) . Such treatment is appropriate when the projectile's penetration probability is a function only of its orbital angular momentum $(L, 0)$ and not at all dependent upon its total angular momentum, (J, σ) .

In the present note, the alternative situation, which prevails when there exists a significant spin-orbit effect on the projectile penetrabilities, is formulated for spin $1/2$ projectiles. The procedure is very similar to that of reference 1 so that only the points of difference will be detailed here. One wishes to calculate

$$W(\vartheta) = 2\pi \sum_{JL} \sum_{IM} \bar{P}(I, J; IM) W(I, M; \vartheta) \quad (1)$$

where

$$W(I, M; \vartheta) = \sum_{K=-I}^I \left[\exp - \beta K^2 \right] \left[|\vartheta_{MK}^I(\vartheta)|^2 \right] \left\{ \sum_{K=-I}^I \exp - \beta K^2 \right\}^{-1} \quad (2)$$

gives the angular distribution of the fragments emitted from a compound state of angular momentum (I, M) , and where

$$\bar{P}(L,J;IM) = \left\{ \sum_{\sigma\mu} (2L+1) T_L^J(E) \left| C_{O\sigma\sigma}^{L S J} \right|^2 \left| C_{\sigma\mu M}^{J I_O I} \right|^2 \right\} \\ \times \left\{ 2(2I_O+1) \sum_{JL\sigma} (2L+1) T_L^J(E) \left| C_{O\sigma\sigma}^{L S J} \right|^2 \right\}^{-1} \quad (3)$$

is the probability that a compound state (I,M) is formed by absorption of an incoming projectile with orbital angular momentum $(L,0)$ and total angular momentum $(J, \pm \sigma)$.

For projectiles with spin, $S = 1/2$, one notes that

$$(2L+1) \left| C_{O\sigma\sigma}^{L S J} \right|^2 = (2J+1) \cdot 1/2 \left[\delta_{L,J-1/2} + \delta_{L,J+1/2} \right] \quad (4)$$

is independent of σ . Then, by defining

$$\bar{T}_J = \frac{1}{2} \left[T_{L=J-1/2}^J + T_{L=J+1/2}^J \right] \quad (5)$$

the function $\bar{P}$ can be simplified to

$$\bar{P}(L,J;IM) = \left\{ (2J+1) \bar{T}_J \sum_{\mu\sigma} \left| C_{\sigma\mu M}^{J I_O I} \right|^2 \right\} \left\{ 2(2I_O+1) \sum_J (2J+1) \bar{T}_J \right\}^{-1} \quad (6)$$

One has then only to insert $W(I,M;\vartheta)$ from reference 1, and to use Clebsch-Gordan identities similar to those derived there to evaluate the angular distribution (1) to any desired order in β . Here we present only the result for the anisotropy:

$$W(0^\circ)/W(90^\circ) = \left[\sum_J (2J + 1) \bar{T}^J(E) \left\{ 1 + \frac{1}{3} \beta \mathcal{L} + \beta^2 \left[\frac{1}{90} \mathcal{L}^2 - \frac{1}{30} \mathcal{L} - \frac{2}{27} I_0(I_0 + 1) \mathcal{L} \right] \right\} \right] \quad (7)$$

$$\times \left[\sum_J (2J + 1) \bar{T}^J(E) \left\{ 1 - \frac{1}{6} \beta \mathcal{L} + \beta^2 \left[\frac{23}{720} \mathcal{L}^2 - \frac{23}{240} \mathcal{L} + \frac{1}{27} I_0(I_0 + 1) \mathcal{L} \right] \right\} \right]^{-1}$$

where

$$\mathcal{L} = \{J(J + 1) - 3/4\} \quad (7a)$$

has been substituted to condense the expression and to exhibit directly the fact that the leading terms in each order of β of this result are identical with those obtained from equation (7b) of reference 1 by the following replacements:

$$L(L + 1) \rightarrow \mathcal{L} = \{J(J + 1) - 3/4\} \quad (8)$$

and

$$\sum_L (2L + 1) T_L \rightarrow \sum_J (2J + 1) \bar{T}^J \quad (8a)$$

In particular, the terms proportional to the target spin, $I_0(I_0 + 1)$, in (7) occur with coefficients identical with those obtained previously.

Inclusion of a fission probability dependent on angular momentum⁽¹⁾ in the present calculation leads to a similar result: the coefficients of terms involving $I_0(I_0 + 1)$, as well as those of the leading terms in $\mathcal{L}$

are identical with those obtained by making the substitutions (8) in the earlier formula.

It follows that the earlier theoretical result that the anisotropy should decrease with increasing target spin is not modified by considering the effect of the spin-orbit interaction on the penetrabilities. The disagreement between theory⁽¹⁾⁽²⁾⁽³⁾ and experiment⁽⁴⁾⁽⁵⁾ in this regard therefore remains without a satisfactory explanation. This discrepancy is especially noteworthy because of the circumstance that the analogous theoretical treatment of (d,pf) anisotropies seems adequate to explain the data in that case⁽⁶⁾.

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