Hauser Feshbach Calculations in Deformed Nuclei

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Hauser Feshbach Calculations in Deformed Nuclei

- Bohr Hypothesis:

  Compound reaction has relative decay probabilities independent of entrance channel.

- Weisskopf Ewing (1940):

  $\sigma(E) \propto \sigma_{inv}(E)\ E\ \rho(E^{*}\text{-}B\text{-}E)$

  No *J* or π dependence

  Often unreliable for smaller decay channels

- Hauser Feshbach (1952)

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- Wolfenstein (1952):

$$\frac{\pi \; x^2}{(2I_1+1)(2I_2+1)}\left(\sum \frac{(2J+1)T_{in}T_{out}}{\sum T_{out}}\right)$$

Assume $T_{in}=1 \quad \ell \leq \ell_{max}$

$T_{in}=0 \quad \ell > \ell_{max}$

Target and projectile spins are zero

Hauser Feshbach --Wolfenstein (continued):

$$\sigma_\ell \propto c(2\ell+1) \qquad \ell \le \ell_{\max}$$
$$= 0 \qquad \ell > \ell_{\max}$$
$$J_{ave} = \tfrac{2}{3}\,\ell_{\max}$$

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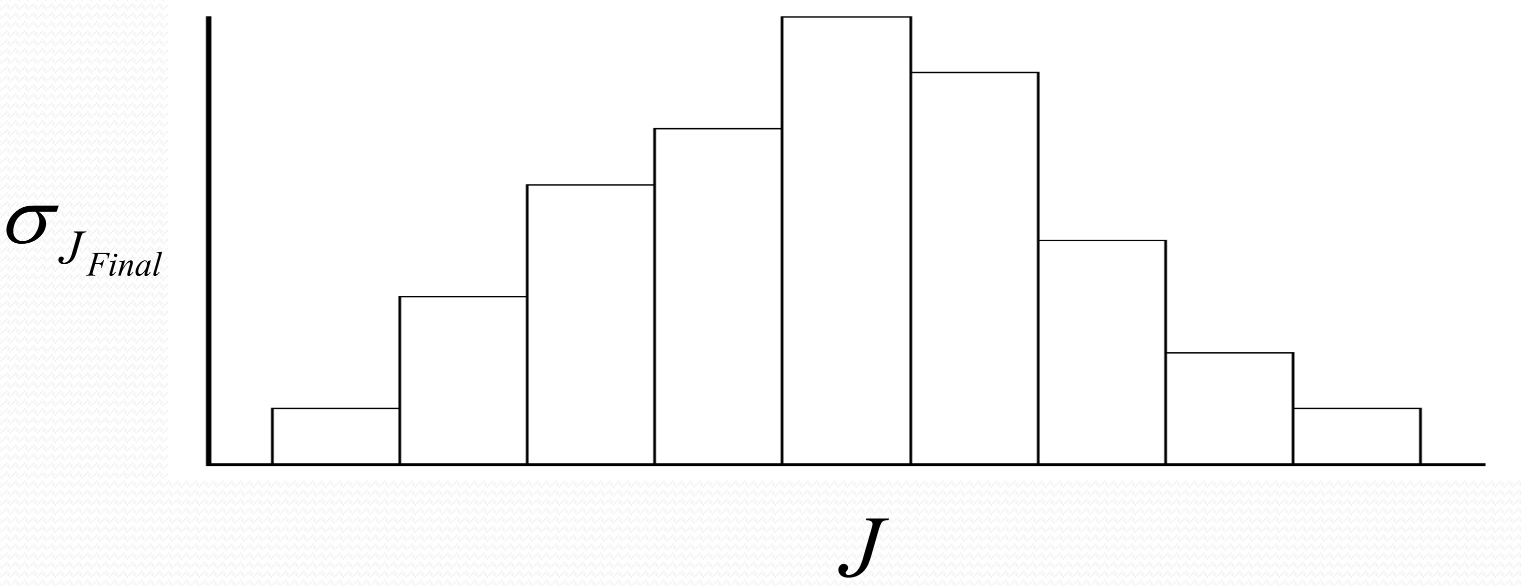
Decay: If $J_{final} < \ell_{\max}$ and $J_{final} < J_{comp}$

then σ to that level is proportional to J_{final}



Maximum σ for $J_{Final} \approx \ell_{\max}$

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Spherical symmetry:

Level	States
J	$m_Z = -J$ … $m_Z = J$

$$\sum = 2J + 1 \text{ states}$$

Deformed nuclei:

$5/2$ →

$\pm 5/2 = K \quad 5/2 = J$

$\pm 3/2 = K \quad 5/2 = J$

$\pm 1/2 = K \quad 5/2 = J$

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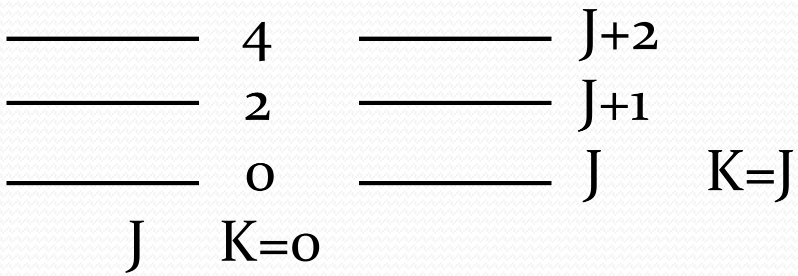
Also build bands



New approach to Hauser Feshbach

$$T_{in} \rightarrow \langle \ell m_\ell J_+ K_+ | J_c K_c \rangle^2 T_{in}$$

$$T_{out} \rightarrow \left\langle \ell_{out} m_{\ell_{out}} J_f K_f \middle| J_c K_c \right\rangle^2 T_{out}$$

$$J_+ = J_{in}$$

$$K_+ = K_{in}$$

Population distribution is similar
Compound J distribution is similar
K degeneracy is broken

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Decay ratios differ

0, 2, 4, 6 sequence in spherical nucleus

has $1:5:9:13$ for population ratio

Deformed nucleus has $K = 0$ band so each level

is non-degenerate

Ratio: $1:1:1:1$

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^{182}W

1.2	8+
0.7	6+
0.33	4+
0.1	2+
0.0	0+

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Fraction of Reaction Cross Section					
Neutron Energy (MeV)		G.S.	2+	4+	6+
0.3	Spherical Deformed	0.84 0.87	0.16 0.13		
0.6	Spherical Deformed	0.52 0.61	0.48 0.39		
0.9	Spherical Deformed	0.38 0.47	0.39 0.37	0.24 0.16	
1.2	Spherical Deformed	0.18 0.34	0.37 0.31	0.29 0.22	0.16 0.13
5	Spherical Deformed	0.00002 0.000075	0.00009 0.00008	0.00014 0.00009	0.00021 0.00012

K Conservation

- If $\ell_{\max}$ is not 0, will get multiple K values.
- Distribution of K values is Gaussian
- Difficult to identify consequence of mixing
- Evaluate theoretical expectations
- Mixing takes place between K and $K \pm 1$ for given J
- Mixing most obvious if level density for K is very different than that for K+1 or K-1

K Conservation (cont)

- This condition is only met for K large, where there are few levels
- K mixing matrix elements are expected to be about 5 to 10 keV
- At low energies ($E < 4$ MeV) level spacing inhibits mixing
- At high energies, compound width is > 25 keV and inhibits mixing
- Expect mixing for $5 < E < 25$ MeV

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Calculations show only few percent effect

for complete mixing.

Find deformed code:

- Enhances cross section for small J levels
- Reduces cross sections for large J levels
- Affects cross sections to resolved levels
- Could affect (n,2n) and (n,n'f)
- Ratios slightly larger for (n,α) than (n,n')

Isospin Mixing:

Also involves addition of Clebsh-Gordon coefficients

Proton incident on target with N > Z

Target isospin $T_0 = T_Z = \frac{N-Z}{Z}$

Proton has $T = 1/2, T_Z = -1/2$

Coupling: $\frac{1}{2T_0+1}$ to $T = T_o + 1/2$, $T_Z = T_0 - 1/2$

$\frac{2T_0}{2T_0+1}$ to $T = T_0 - 1/2$, $T_Z = T_0 - 1/2$

Decay of $T = T_0 + 1/2$ is mostly protons

Decay of $T = T_0 - 1/2$ is mostly neutrons

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Ratio of level densities is large

Energy shift

$$\Delta E = a_a\left[-\frac{(N-Z)^2}{A}+\frac{(N-Z+2)^2}{A}\right] \cong \frac{24}{A}\left[\frac{2(N-Z)+4}{A}\right]$$

for $A \approx 40 \quad \Delta E \approx 6\,\mathrm{MeV}$

$A \approx 100 \quad \Delta E \approx 9\,\mathrm{MeV}$

$A \approx 200 \quad \Delta E \approx 19\,\mathrm{MeV}$

Level density ratio

$A \approx 40 \quad R = 60$

$A \approx 100 \quad R = 2.2\times 10^4$

$A \approx 200 \quad R > 10^{10}$

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All mixing is down

$$\frac{\dfrac{\sigma(p,p')}{\sigma(p,\alpha)}}{\dfrac{\sigma(\alpha,p)}{\sigma(\alpha,\alpha')}} > 1$$

for proton and alpha induced reactions through the same compound nucleus

Angular Momentum Effects

- Without isospin $R \approx 1.15$
- With isospin conserved $(A \approx 60)$ $R \approx 1.7$
- Experiment $R \approx 1.45$
- Result: Mixing ~ 50% before decay
- Measurements for E ~ 18-22 MeV
- Show mixing is 40-60% for A ~ 60-70

K mixing differs

- Only two values of T – many values of K
- Big difference in branching ratios for two T values
- Smaller difference for K
- Mixing in both directions for K – only one direction for T
- These factors explain why mixing can be seen for T but not for K
- K mixing likely occurs but has no obvious signature

SUMMARY

- New approach proposed for Hauser Feshbach calculations in deformed nuclei
- Can accommodate both spherical and deformed nuclei in same calculation
- Code is slower (~8x) than conventional HF
- Cross sections for low J enhanced and for large J are reduced
- Effects on (n,2n), (n,f), (n,n'f) still to be examined

The End