Lawrence Livermore National Laboratory

Neutron Scattering on Excited States

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Channel Couplings in Neutron-nucleus Collisions

Neutrons incident on Deformed Nuclei

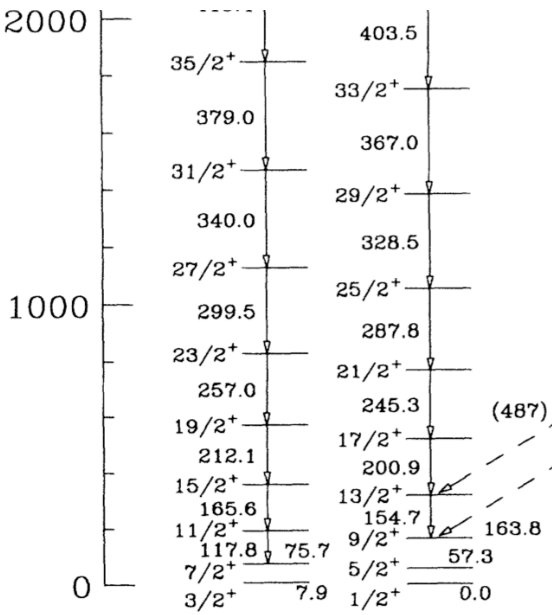
Method:

- Rotational excitation of ground-state band
- Calculate compound-nucleus production
  = fusion = absorption
- Compare for ground & excited states I,I’
- Compare K=0 and K>0 rotational bands
- Compare realistic rotational excitations E* with adiabatic limit of E*=0.

Neutrons incident on Deformed Nuclei

Look at ^{239}Pu:

- Even-odd nucleus
- K=½ ground state band
- Dominant E2 transitions couple every second band member
- J=$^{3}/_{2}^{+}$ excited state at 7.9 keV.



^{239}Pu

Deformed coupled-channels calculations

Standard method to model neutron-actinide scattering:

Use

- Flap 2.2 optical potential (Frank Dietrich)
- Deformations $\beta_2 = 0.205$ and $\beta_4 = 0.075$
  - Legendre-expand potential up to 6 or 8.
- Standard practice:
  - Couple 3 states: $0^+ - 2^+ - 4^+$ for even nuclei
  - Couple 5 states $1/2^+ - 3/2^+ - 5/2^+ - 7/2^+ - 9/2^+$ for odd
  - (because of E2 jumping alternate levels).

Calculate $\sigma_{CN} = \sigma_R - \sigma_{out}$:

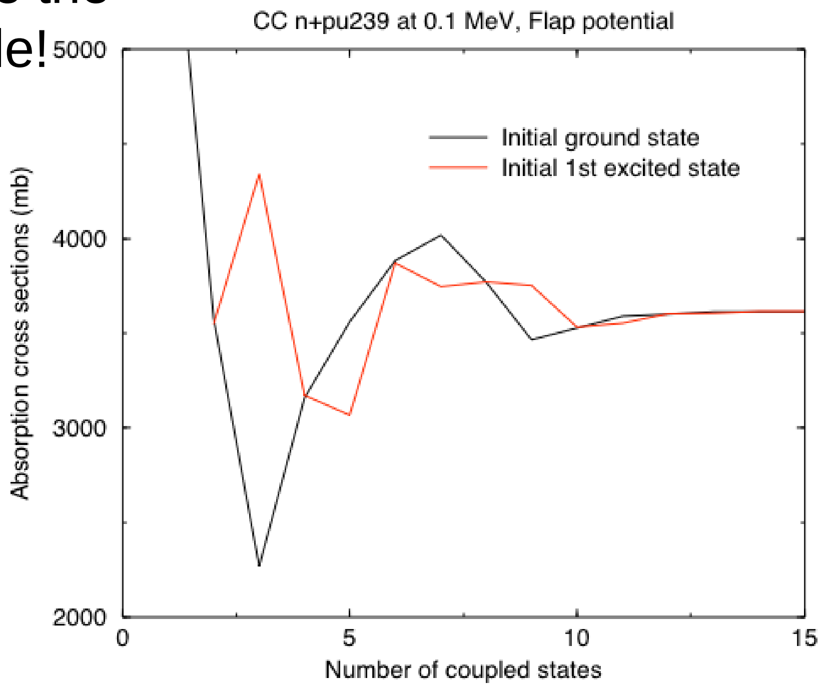
CN production = reaction cross section - outgoing channels

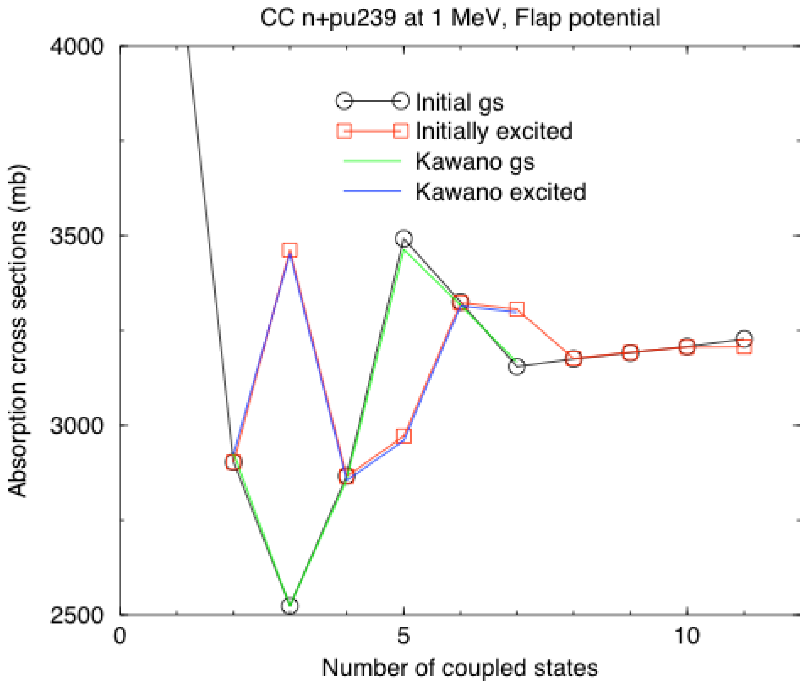
First Results: rather slow convergence!

$E_n = 0.1$ MeV,
4 open channels

$E_n = 1.0$ MeV,
12 open channels

Note the scale!

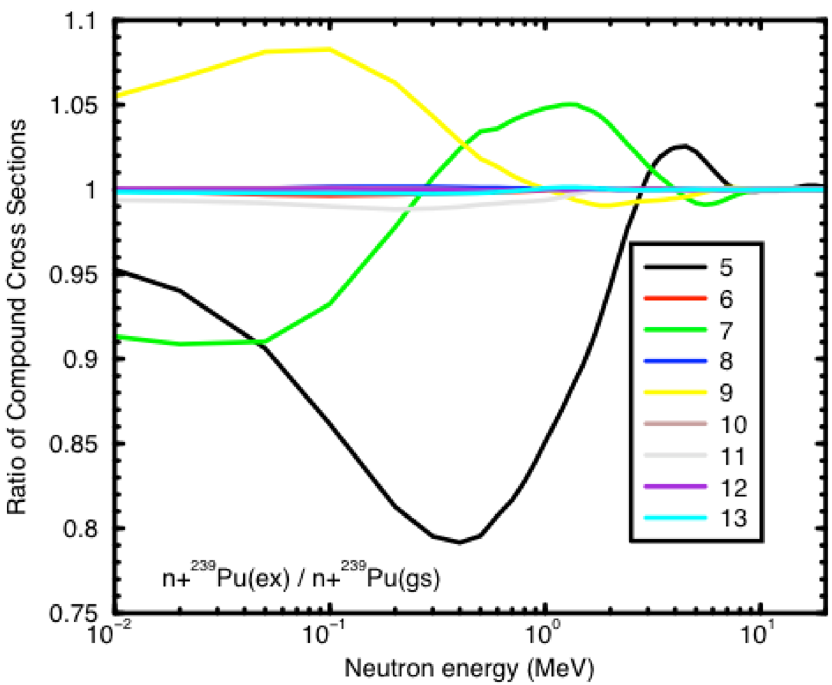




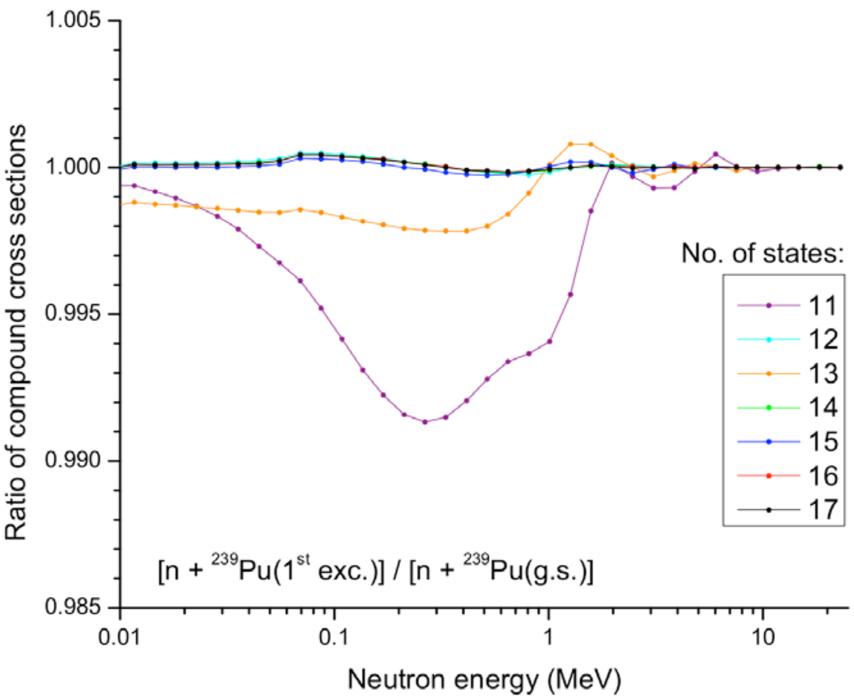
Get essential same results even if set excitation energies E*=0!

Converged Results for σ_{CN} ratio for excited/gs.

Sets of 5 to 13 channels



Sets of 11 to 17 channels



Results same for Dietrich, Kawano & Thompson calculations!

Converges to almost unit ratio.

Note: this unity is for sum over Jπ: not for separate Jπ.

Adiabatic Limit (all excitation energies E*=0 MeV)

Adiabatic limit is:

- Zero excitation energies for the ground state band E*=0
- Equivalent to large (infinite) moment of inertia of target
- Target then does not rotate during the neutron reaction.

Can then prove:

- σ_{CN} = average over all nuclear orientations of the CN production for each orientation.
  - for all nuclei (even or odd; any K)
- This also holds in the PWBA limit (Plane Wave Born Approximation.

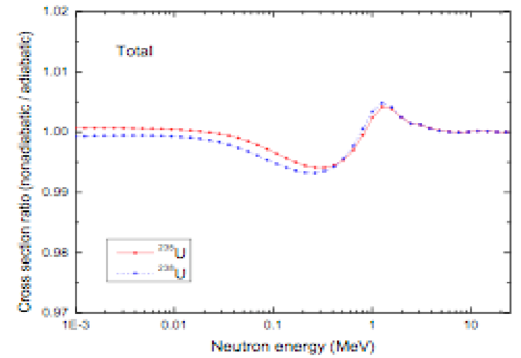
Adiabatic Approximation is Exceptionally Good!

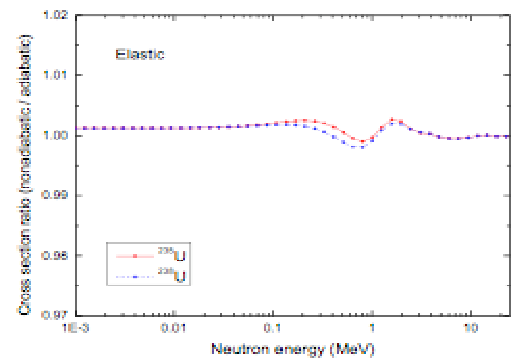
Even at neutron energies much less than E* excitations:

- This implies:
  - Validity of spectator approximation for target spin
  - Correct to average transmission coefficients over target spins (with *m*-state-count weighting)
  - CN production independent of both I,K
  - Can predict any transition IK➔I'K' from knowing all 00➔J0 transitions!

    See Lagrange et al, NSE (1982).

n+^{235,238}U, ratio nonadiabatic/adiabatic





Further research for deformed nuclei

1. Predict spin dependence $\sigma_{CN}(J^{\pi})$
   - since fission and γ-decays depend on spin.
2. Explain small size of deviations from unity for finite E*
   - Are these from resonances even after optical smoothing?
3. Explain (strange) oscillating behavior of convergence
   - Related to E2-stepping matrix elements?
4. Look at convergence on σ_{tot} (the expt results fitted)
   - Need to refit σ_{tot} several actinides with at least 12 – 14 coupled channels sets!
5. Reexamine other deformed nuclei (eg rare earths)
   - Check that calculations are properly converged!