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NEAR BARRIER FUSION OF NEUTRON RICH PROJECTILES WITH HEAVY TARGET NUCLEI

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[Invited Talk at the Notre Dame Workshop on Giant Resonances and Related Phenomena, October 21–23, 1991, Notre-Dame, Indiana, USA.]

Abstract: The cross-sections for the fusion of ^{11}Li with ^{208}Pb and ^{238}U are calculated at near-barrier energies. The coupling of the entrance channel to the soft giant dipole resonance in ^{11}Li is taken into account together with the coupling to the break-up channel ^{9}Li + 2n. The deformation of ^{238}U is also considered. The cross-section is found to exhibit important structure around the barrier.

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November/1991

Introduction

Recently, the low energy fusion of radioactive beams, such as ^{11}Li, with heavy target nuclei has been discusssed[1–4]. The principal motivation is twofold: i) the enhancement of the fusion cross-section σ_f that arises from the existence of the halo neutrons can be used to further understand these exotic nuclei, ii) the potential production of superheavy cold compound nuclei, with a reasonably measurable cross-sections.

In the calculations made so far, two features of the halo are taken into account: the lowering of the static Coulomb barrier and the coupling of the entrance channel to the low lying soft giant resonance (the pygmy resonance). Both of these effects lead to an enhanced fusion cross-section.

The existence of the pygmy resonance at about 1.2 MeV has recently been firmly established though the study of the double charge exchange reaction ^{11}B(π^-,π^+)^{11}Li [5]. One anticipates, on general ground, that this state has a large width due to the very low binding energy of the dineutron (~ 0.2 MeV). Thus it is of great importance in any fusion calculation to consider the finite lifetime of the pygmy resonance. This leads to an enhancement of σ_f reduced with respect to that already reported. The purpose of this talk is to consider the above effect by coupling the pygmy resonance to the break-up channel in the calculation of the fusion cross-section.

In what follows are copies of the transparencies that I used in my talk at the Notre Dame Workshop on Giant Resonances and Related Phenomena that was held in Notre Dame, Indiana, October 21–23. My talk is based on several publicatons by my colleagues in Rio and São Paulo, and I. Ref. 6 above concerns the ^{11}Li fusion.

References

1. A.S. Ilginov, M.V. Mebel and E.A. Cherespanov, Proceedings of the Berkeley Conference on Radioactive Beams (World Scientific) pg. 289.
2. M.S. Hussein, *Phys. Rev.* C44 (1991) 446.
3. M.S. Hussein, *Nucl Phys.* A531 (1991) 192.
4. N. Takigawa and H. Sagawa, *Phys. Lett.* B265 (1991) 23.
5. T. Kobayashi et al. contributions to the Symposium on Structure and Reactions of Unstable Nuclei, June 17–19, 1991, Niigata, Japan, pg. 28.
6. M.S. Hussein, M.P. Pato, L.F. Canto and R. Donangelo, IFUSP/P–942 and submitted for publication.
7. L.F. Canto, R. Donangelo and M.S. Hussein, *Nucl. Phys.* A529 (1991) 243.
8. L.F. Canto, R. Donangelo, M.S. Hussein and M.P. Pato, submitted to *Nucl. Phys.* A.

Sub Barrier Fusion Induced by Neutron Rich Nuclei

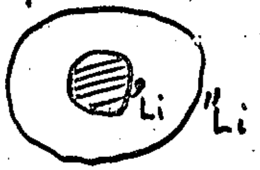
Canto, Donangelo, Pato, M.S.H.

- Short summary of general features of the structure of neutron-rich nuclei : The pygmy resonance
- Important reactions : break-up
- Coupled channels effects on sub barrier fusion of HI systems
- Effect of pygmy resonance on fusion of exotic (neutron-rich) nuclei with spherical and deformed heavy targets.
- Future directions and general conclusions.

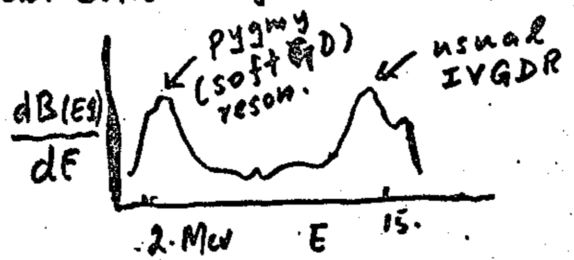
Phys. Rev. C (July) Phys. Rev. Lett.
Nuclear Physics A (near future)

^{11}Li : A reasonably well studied system

- Large Coulomb dissociation cross section
- Evidence for halo neutrons (from break-up study of $^{11}Li \to {}^{9}Li + 2n$)



- Very small 2n separation energy (0.2 MeV) and about 1.0 MeV one neutron separation energy
- Spin of ^{11}Li is 3/2 (the ang. mom. of the $p_{3/2}$ proton in ^{9}Li)
- great collectivity at low exc. energy



- Within a cluster model ($^{11}Li = {}^{9}Li + 2n$) one has

$$\longrightarrow \frac{dB(E1)}{dE^*} = \frac{3\hbar^2 e^2}{\pi^2} \frac{Z^2 \Delta N}{A A_c} \sqrt{\varepsilon} \frac{(E^* - \varepsilon)^{3/2}}{E^{*4}}$$

sep. energy

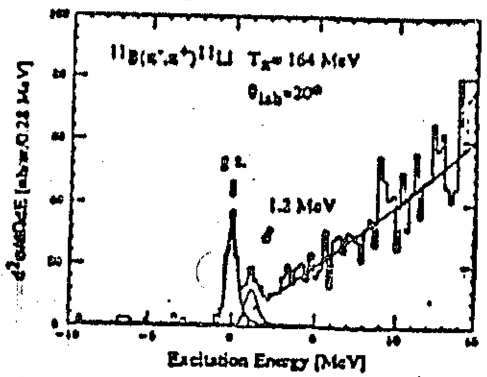
excess neutrons

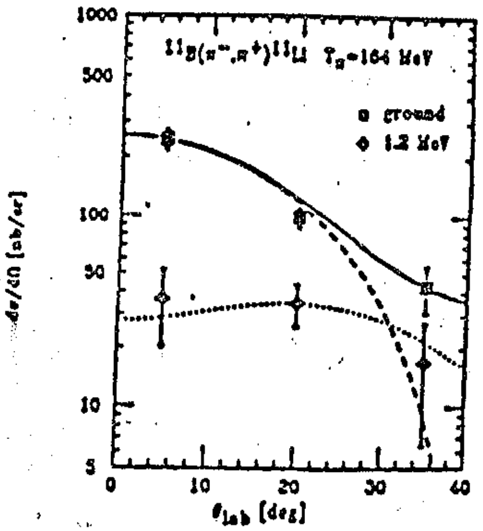
important

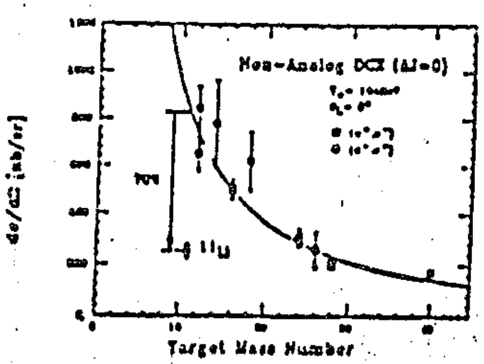
$$\longrightarrow B(E1) = \frac{3\hbar^2 e^2}{16\pi} \frac{Z^2 \Delta N}{A A_c} \frac{1}{\varepsilon}$$

Thus coupling ($\propto B(E1)$) goes with with B(E1) and smaller ε

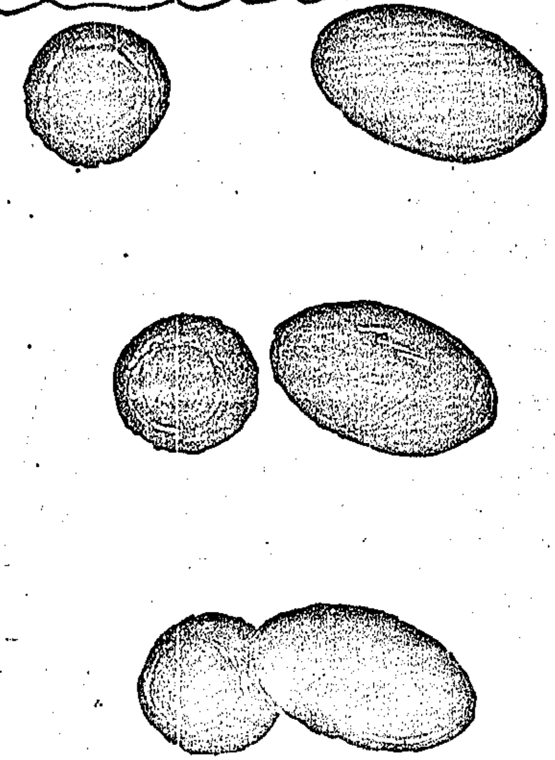
{Smaller / Weaker} restoring force







Fusion of Neutron-Rich Nuclei



The system feels stronger nuclear attraction

Result: Larger fusion probability at low energies (even with spherical targets)

Coupling of entrance channel to low-lying pygmy resonance and to the deformed target (rotor)!

Coupled-Channels Effects on Sub Barrier Fusion of HI Systems

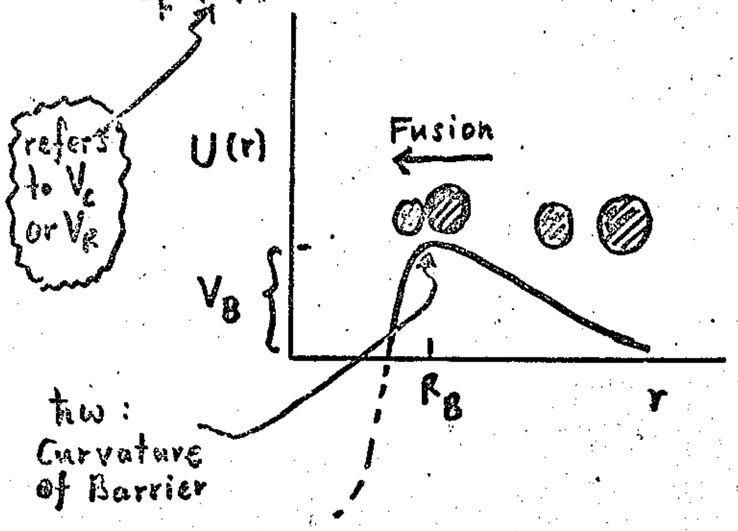
Vibrational coupling : V_v

Rotational coupling : V_R

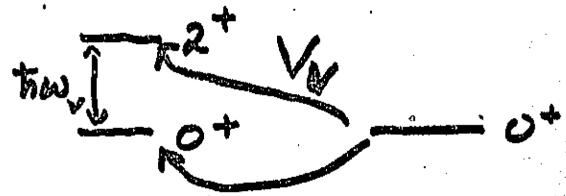
Purely spherical case ($V_v = V_R = 0$)

$$\overset{\circ}{\sigma}_F = \frac{\hbar\omega R_B^2}{2E} \ln\left[1 + \exp\left[\frac{E - V_B}{\hbar\omega/2\pi}\right]\right]$$

$= \sigma_F(\cdot)$



Vibrational case



For the fusion cross-section in the sudden limit, $\hbar\omega_v \simeq 0$, one has :

$$\sigma_F = \frac{1}{2}\left[\overset{\circ}{\sigma}_F(V_v) + \overset{\circ}{\sigma}_F(-V_v)\right]$$

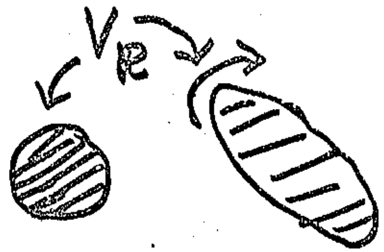
$$\overset{\circ}{\sigma}_F(V_v) = \frac{\hbar\omega R_B^2}{2E} \ln\left[1 + \exp\left[\frac{E - V_B - V_v}{\frac{\hbar\omega}{2\pi}}\right]\right]$$

At very low energies :

$$\sigma_F(V_v) \longrightarrow \frac{\hbar\omega R_B^2}{4E} \exp\left[\frac{2\pi}{\hbar\omega}(E - V_B + V_v)\right]$$

Enhancement : $\mathcal{E} = \frac{\sigma_F}{\overset{\circ}{\sigma}_F} = \frac{1}{2}\exp\left[\frac{2\pi}{\hbar\omega} V_v\right]$

Rotational case



take only 0^+ and 2^+ states of the rotor (deformed target)

$$\sigma_F = 0.652\, \overset{\circ}{\sigma}_F(0.73 V_R) + 0.348\, \overset{\circ}{\sigma}_F(-1.37 V_R)$$

At very low energies,

$$\sigma_F \sim 0.348 \frac{\hbar\omega R_B^2}{2E} \exp\left[\frac{2\pi}{\hbar\omega}(E - V_B + 1.37 V_R)\right]$$

Enhancement

$$\mathcal{E} = 0.348 \cdot \exp\left[\frac{2\pi}{\hbar\omega}(1.37) V_R\right]$$

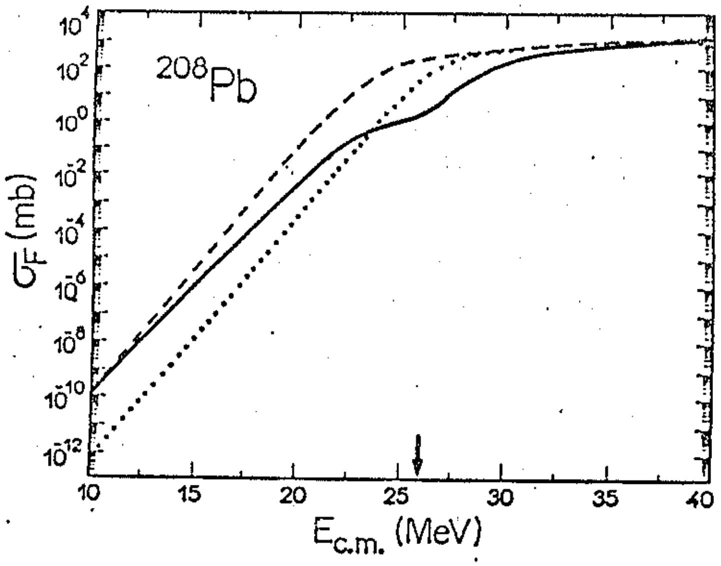
Need more detailed calculation that includes the possibility of the projectile breaking-up. Namely how to couple a resonating state to the entrance channel in a sub-barrier fusion calculation.

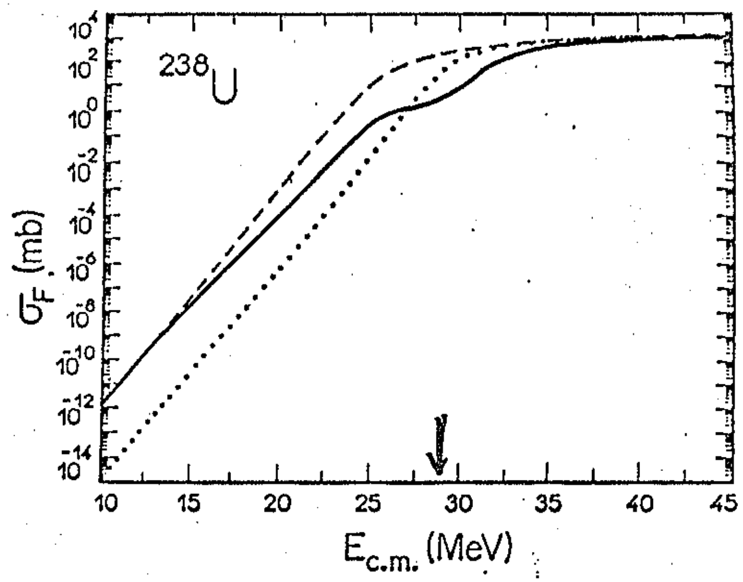
Do $\sigma_F = \sum_\ell P_{b-up}^{(\ell)} \sigma_\ell$

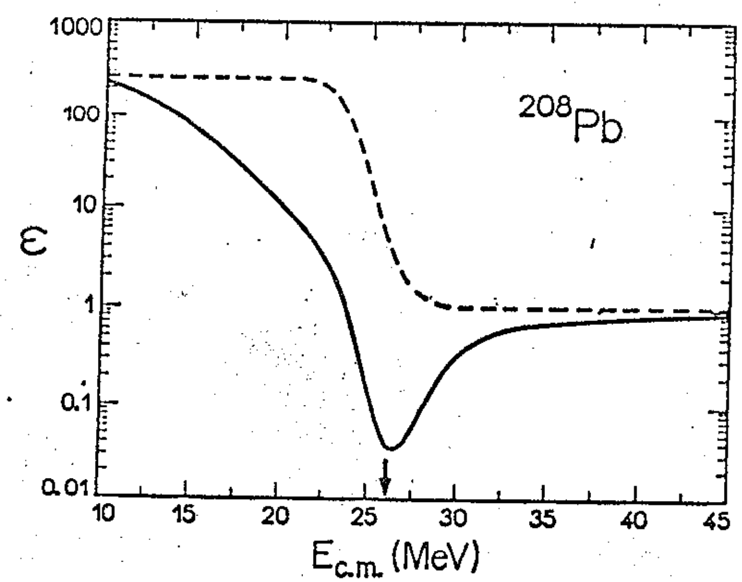
where $\Gamma \propto P_{b-up}^{(\ell)}$

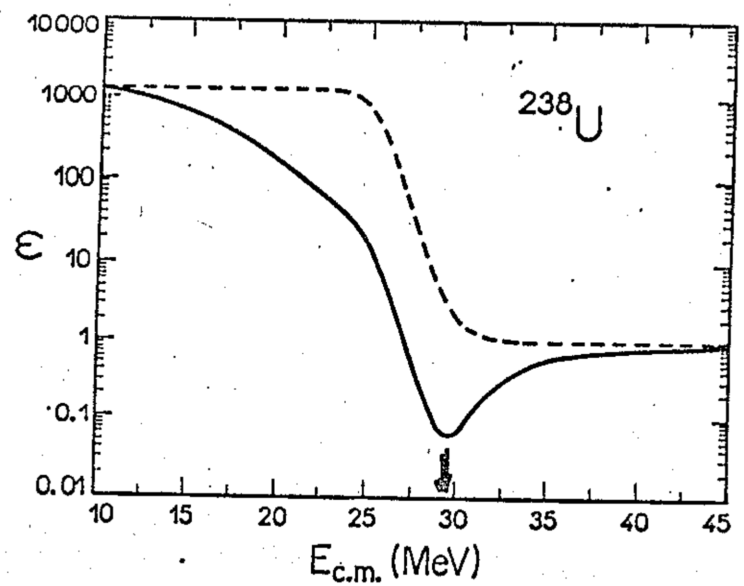
↑ width of the pygmy resonance.

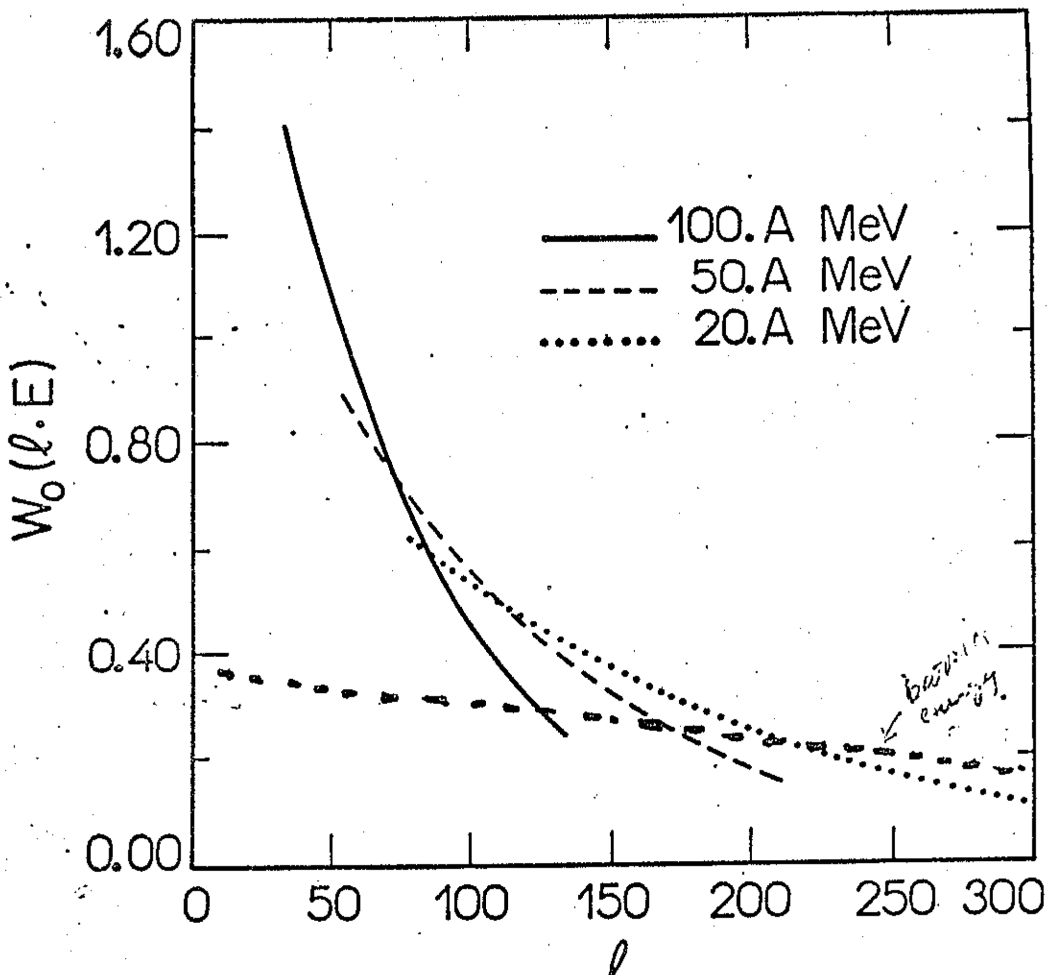
Use dynamic polarization potential for b-up effects. Results:


208Pb
σF (mb)
Ec.m. (MeV)


238U
σF (mb)
Ec.m. (MeV)


208Pb
ε
Ec.m. (MeV)


238U
ε
Ec.m. (MeV)



Dynamic polarization potential in $^{11}Li + Pb$. FIG. 1 May supply the width of the pygmy resonance

$\Gamma \sim 2\, \mathrm{Im}\, V = 2\overline{W}_0$

~ 1.0 MeV.