ON THE EXISTENCE OF GIANT NUCLEAR SYSTEMS

W. T. Pinkston
Vanderbilt University, Nashville, TN 37235

Time delays, long compared to collision times, seem to be required in order to explain the GSI positron data. Greiner first suggested a strong dependence on mutual orientation for the HI potentials of deformed nuclei, so that nuclei with favorable orientations (colinear symmetry axes) can make surface contact and stick together even at nominally sub-Coulomb energies. In this model the sticking together is provided by minima or "pockets" in the potentials[1] at separation distances corresponding to surface contact (see Figure 1). Direct observation of such pockets, in nuclear rather atomic processes, would be a major advance. In this paper some of the consequences of this model for nuclear processes will be discussed.

Resonances can result from such potentials with lifetimes which are identified with the sticking times. Resonances with widths of order 100 keV or less can exist in pockets only a few MeV deep. The trapped nuclei perform quantized hindered rotations[2] of the kinds illustrated in Figure 2. Because of the large moments of inertia of such giant nuclear systems, the pockets persist in the effective potentials up to large ℓ so that rotational bands of resonances should exist, with angular momenta up to ℓ = 200 or more, built on the vibrational states pictured in Figure 2. Their widths grow slowly with ℓ.

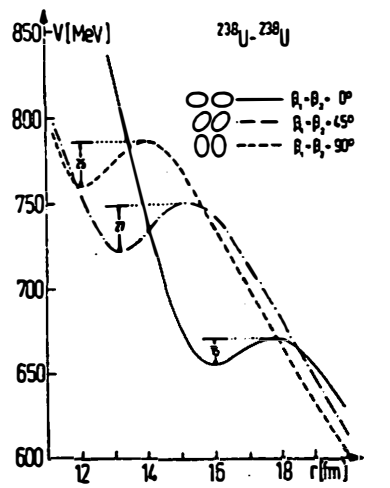


Figure 1. Heavy-ion potentials with pockets.

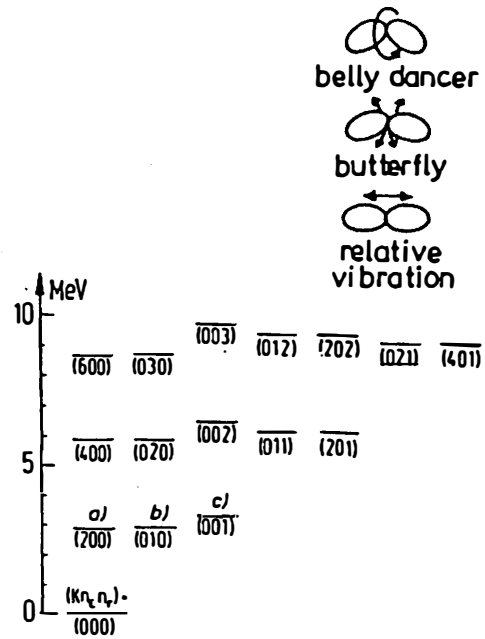
The wave function of the system can be written,

$$\psi = \sum_{\ell\alpha J} \frac{u_{\ell\alpha J}(r)}{r} [Y_\ell \phi_\alpha]_J \qquad (1)$$

The channel states ϕ_α are products of bound state wave functions for the two nuclei (energy = e_α). The relevant bound states are rotational states. The multichannel aspect of the resonances is very important. In order for the nuclei to "see" the pocket, their wave function must be an angular wave packet, centered at the most favorable orientation. Such a packet in angles corresponds to a linear combination of products of rotational wave functions.

Since a full coupled channels (CC) treatment is unfeasible, a simple, schematic model incorporating much of the interesting physics has been devised. The CC equations are greatly simplified by replacing V by a scalar function of r and the internal variables, resulting in

Figure 2. Energy level spectrum of hindered rotations of giant nuclear systems.



$$-\frac{\hbar^2}{2\mu}\left(\frac{d^2}{dr^2}-\frac{\ell(\ell+1)}{r^2}\right)u_{\alpha\ell}+\sum_{\beta}\langle\phi_\alpha|V|\phi_\beta\rangle u_{\beta\ell}+e_\alpha u_{\alpha\ell}=E\,u_{\alpha\ell} \qquad (2)$$

Next the usual CC procedure is reversed: resonances of given properties are assumed, and a potential constructed which produces them. The approach is similar to the eigenchannel theory of Danos and Greiner[3]. In the vicinity of a resonance the S-matrix is assumed to have the Breit-Wigner form,

$$S_{\alpha\beta}=e^{i\sigma_\alpha}e^{i\sigma_\beta}\left(\delta_{\alpha\beta}-i\frac{\gamma_\alpha\gamma_\beta}{E-E_R+i\Gamma/2}\right)\quad,\quad\sum_\alpha\gamma_\alpha^2=\Gamma \qquad (3)$$

If the slowly-varying phases σ are assumed to be independent of channel index α then (3) can be trivially diagonalized:

$$S_k=e^{2i\sigma}\left(1-i\frac{\delta_{kR}\,\Gamma}{E-E_R+i\Gamma/2}\right) \qquad (4)$$

A new basis χ_k of channel states is constructed from the eigenvectors of the S-matrix; the special resonant state, $i=R$, is

$$\chi_R=\frac{1}{\Gamma^{1/2}}\sum\gamma_\alpha\,\phi_\alpha \qquad (5)$$

The new basis is used to define a potential,

$$V = V_o(r) + \Delta V(r)|\chi_R\rangle\langle\chi_R| \quad . \tag{6}$$

The potential V_o is monotonic; $V_o + \Delta V$ contains a pocket. A further approximation consists of neglecting the differences in channel kinetic energy, $E_\alpha = E - e_\alpha \approx E$. With this approximation the CC equations (2) decouple; their solution reduces to the solution of two elasatic scattering problems, with potentials V_o and $V_o + \Delta V$.

In most experiments resolution of individual final states is not possible. For such experiments the results of the model are very simple, depending on a single resonance parameter, $\xi = \Gamma_o/\Gamma$, where Γ_o is the entrance channel width. Two kinds of processes are under study, quasielastic scattering and nucleon transfer. The differential cross section for quasielastic scattering is predicted to be

$$\frac{d\sigma}{d\Omega} = |f_o|^2(1 - \xi) + \xi|f_o + f_R|^2 \quad ,$$

$$f_R = -\frac{\Gamma}{2k}\sum_{\ell}(2\ell + 1)e^{2i\sigma(\ell)}P_\ell/[E-E_R+i\Gamma/2) \quad . \tag{7}$$

One expects $\xi << 1$, so that the pocket has a negligible effect on the cross section. Numerical calculations bear this out. Nuclear sticking should enhance the cross sections for nucleon transfer reactins. This seems intuitively obvious and has been shown[4] to be the case in a simple one-dimensional model. There is some evidence[5] in GSI data on neutron transfer in ^{238}U-^{238}U collisions for deviations from the usual theory of sub-Coulomb transfer. Calculations are underway, based on a weak coupling model, in which the channel states ϕ are products of collective and single particle parts. The transfer is assumed to be independent of the collective degrees of freedom, which influence the scattering, and the scattering of the ions independent of the transfer. Instead of a single radial equation for each ℓ, the model results in a pair of coupled equations, corresponding to two assumed transfer channels. The transfer form factor varies slowly in the pocket region. It is treated as a constant, so that these equations decouple in the interior. They are matched to exterior solutions computed semiclassically. The single-nucleon transfer cross section takes the form,

$$\frac{d\sigma}{d\Omega} = |F_o|^2(1 - \xi) + |F_R|\xi^2 \tag{8}$$

The amplitude F_o corresponds to transfer in the field of V_o, computed with DWBA or an equivalent semiclassical model. F_R is the resonant contribution.

1. M. Seiwert, W. Greiner and W. T. Pinkston, to be published.
2. P. O. Hess, W. Greiner and W. T. Pinkston, Phys. Rev. Letts., in press.
3. R. F. Barrett, et al., Revs. Mod. Phys. 45 (1973) 44.
4. D. W. Russell and W. T. Pinkston, unpublished.
5. G. Wirth, et al., GSI Scientific Report (1982), p. 13.