Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985
J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 786-787

2.13

Semiclassical Models for Fusion of Polarized Heavy Ions

G.Grawert[a], K.Heck[a] and P.Fröbrich[b]

a) Fachbereich Physik der Universität, D-3550 Marburg, West-Germany
b) Hahn-Meitner-Institut für Kernforschung, Berlin-West, and Fachbereich Physik (WE3) der Freien Universität, Berlin-West, Germany

Analysis of data for elastic scattering of polarized Li-projectiles on spin-zero target nuclei has yielded valuable information on spin-dependent interactions between heavy ions [1]. Firstly, for deformed nuclei second rank tensor interaction is most important. Secondly, coupling to excited states is necessary in order to explain the observed analysing powers. Recently, cross sections and analysing powers for fusion reactions with polarized Na-projectiles have been measured [2]. Theoretical models for these processes should take into account the above-mentioned features.

For energies near barrier the following semiclassical model works nicely. Starting with the assumption that the relative motion of nuclei can be described by classical trajectories up to the point of closest approach, fusion is understood as penetration at that point through the 'barrier' which contains the reorientation and transition terms for both nuclei. Thus deformation and coupling to excited states of the projectile lead to the following terms in the interaction Hamiltonian

$$\begin{aligned} \langle \mu,m|H_{int}|\mu',m'\rangle &= \delta_{\mu\mu'}\cdot\delta_{mm'}\cdot V_C(r) \\ &+ \sum_q \langle s,m|s',m';2,q\rangle \cdot Y^*_{2q}(\hat{R}_o)\cdot\sqrt{4\pi}\cdot\gamma_{\mu\mu'}\cdot V_T(r) \end{aligned} \tag{1}$$

μ,μ' numbering energy states with spin s,s' and spin direction quantum numbers m,m', respectively. Corresponding terms which refer to the target nucleus are added. Identical central potentials $V_C(r)$ in all channels, consisting of a repulsive Coulomb and an attractive real nuclear potential $V_N(r)$, are assumed. Correspondingly, the radial form factor $V_T(r)$ is supposed to be the same for all tensor reorientation and quadrupole transition terms, containing besides the electric r^{-3}-interaction again a nuclear force term $\beta R dV_N/dr$ being proportional to the spectroscopic deformation parameter β and the projectile radius. In the present model, the spherical harmonics in eq.(1) depend on the unit vector $\hat{R}_0$ along the line connecting the two centres of mass at closest approach. The strength constants $\gamma_{\mu\mu}$ in eq.(1) are determined by the quadrupole moments and the nondiagonal $\gamma_{\mu\mu'}$ by the B(E2)-values.

By diagonalizing the complete potential the one-channel central potential barrier is found to split into a set of barriers, some of which being lower than the original one. The calculated cross section for unpolarized projectiles shows sub-barrier enhancement as expected. The analysing power T_{20} decreases steeply with energy from 0.6...0.5 down to a few percent above barrier in agreement with $^{23}Na + ^{48}Ti$ data.

Obviously, the model sketched above can be expected to give satisfactory results only for energies around barrier. For that reason, the surface friction model [3] which successfully describes heavy ion fusion above the barrier, has been extended to cover fusion processes of polarized nuclei over a larger range of energies. In this classical model, coupling to excited states is handled by introducing frictional forces. Polarized projectiles in spin state m with respect to beam direction are now described as deformed rigid bodies with deformation parameter $\beta(m)$ derived from the quantal quadrupole moment $Q(m)$. Initially the symmetry axis is parallel to the beam. The equations of motion are derived from a conservative Hamiltonian H and a Rayleigh dissipation function R, both of which depend on the variables of the

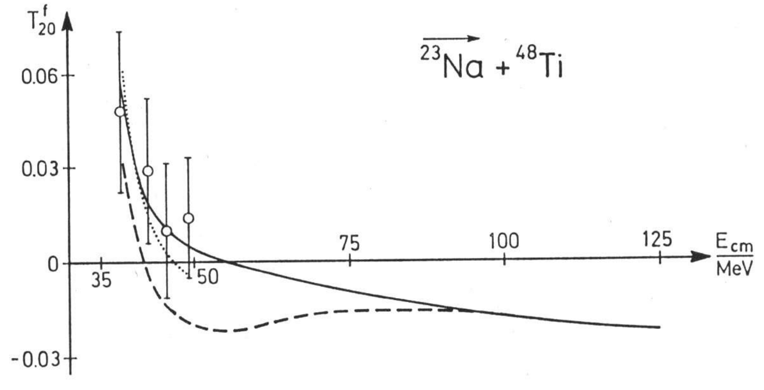

Fig.1 Second rank analysing power for fusion of polarized ^{23}Na with ^{48}Ti. The dotted curve is derived from the barrier penetration model taking into account the first excited states of both projectile and target. The solid and the dashed curve are calculated using the extended surface friction model with and without non-diagonal frictional forces, respectively. Data are from ref.2.

trajectory r,ϕ, the angle κ describing the orientation of the projectile symmetry axis in the plane of motion, and on the conjugate momenta. Besides kinetic energies, H contains Coulomb and electric monopole-quadrupole interactions and corresponding nuclear force terms. Besides the usual ansatz of tangential friction, the most significant frictional forces are derived by assuming that the 'radial' term R_r in the dissipation function is

$$R_r = K_r \cdot \dot{d}^2/2, \quad K_r = K_r^\circ \cdot (dV_N/dr)^2$$
$$d = r - \{R_T + R_P \cdot [1+\beta(m)\; Y_{20}(\phi-\kappa,0)]\} \qquad (2)$$

where d is (approximately) the closest distance between the nuclear surfaces. K_r° is the universal radial friction constant [3]. The formfactor K_r is strongly peaked at touching surfaces. It is obvious from (2) and fig.1 that non-diagonal frictional coupling between the radial motion and angular velocities is important.

Classical trajectory calculations show that below a critical angular momentum the trajectories are captured. This is interpreted as usual. Within the extended version of the surface friction model sketched here, the critical angular momentum for fusion is m-dependent because of m-dependent input in the equations of motion solved. Thus, calculations give different cross sections $\sigma(m)$ for the various m-states from which unpolarized beam cross section and second rank analysing power are computed by standard formulae.

References:

1) D.Fick, Comments Nucl.Part.Phys. 12 (1983)29
2) R.Butsch et al. and K.Blatt et al., contributions to this conference
3) P.Fröbrich, Phys.Rep. 116 (1984)337