UNIFIED SEMICLASSICAL DESCRIPTION OF REACTIONS WITH POLARIZED HEAVY IONS

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Observations of nuclear reactions induced by beams of polarized heavy ions have supplied various informations on interactions and reaction mechanisms of colliding nuclei. Analyzing powers are observables reflecting the relative change of cross sections when the spin orientation of the incoming projectiles is varied. Thus, one probes into the physics of nuclear spin and spin-dependent forces between heavy ions.

Semiclassical methods constitude a well-established tool in the theoretical discussion of heavy ion scattering. The extension of the semiclassical considerations to cover polarization phenomena again has contributed to a better understanding of the observed effects. The approach starts from the classical picture of trajectories determined by the real central interactions between projectile and target nucleus. The fate of the reaction partners while moving along the orbit, e.g. reorientation of spin, excitation, nucleon transfer and fusion is calculated in a semiquantal manner. This line of thought obviously corresponds to the well-known theory of Coulomb excitation. For energies above Coulomb barrier the considerations must be amended by taking care of diffraction into the geometrical shadow region.

The aim of semiclassical considerations is not to get a perfect fit of the data but rather a reproduction of the characteristic features. Yet it is gratifying that in several cases, e.g. in calculations of analyzing powers for fusion around barrier[1], the results fit just as well as those of extensive quantum-mechanical coupled-channels calculations.

To start with, the physical picture emerging for elastic scattering of aligned deformed heavy ions is as follows[2]. The orientation of the nucleus at closest approach determines the second rank analyzing powers T_{2q} up to one common factor. The so-called shape-effect relations state that T_{2q} is proportional to $Y_{2q}(\hat{q})$ with $\hat{q}$ a unit vector in recoil direction. Taking $\hat{q}$ as spin quantization axis, the tensor interaction Hamiltonian then reads $(m^2-I(I+1)/3)\ V_T(r)$ for states with spin quantum number m. The radial potential $V_T(r)$ comprises contributions from electric and nuclear forces connected with the quadrupole deformation. Integrating this interaction along the trajectories, one derives tensor phase shifts which in turn lead to cross sections dependent on m^2. Second rank analyzing powers calculated within this simple picture are in accordance with experiment for elastic scattering of aligned ^{7}Li on ^{58}Ni at 21 MeV and on ^{120}Sn at 44 MeV.

The tensor interaction indicated in the above also enters the discussion of fusion of polarized deformed heavy ions[1]. At closest approach projectiles with different values of $|m|$ are confronted with different barriers. The tunneling probabilities thus depend on the orientation of the nucleus at the turning point of the classical orbit. The inclusion of excitation degrees of freedom is straightforward by extending standard semiclassical techniques to the case of projectiles with non zero spin. Analyzing powers for fusion constitute an additional probe into the physical role of various degrees of freedom. While the fusion cross section for umpolarized projectiles is enhanced in any case, the m -dependence of the landscape of the multidimensional barriers shows up in the analyzing powers. Fusion of aligned ^{23}Na with ^{48}Ti and with ^{206}Pb are successfully analyzed within this framework.

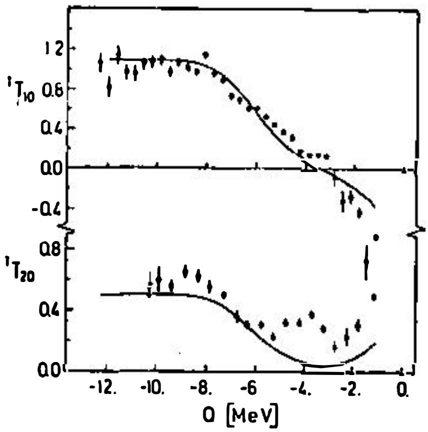

Fig.1. Analyzing powers for ^{120}Sn($^7\vec{\mathrm{Li}}$,^{6}Li) reaction at 44 MeV as functions of Q-value.

Neutron transfer can be understood as hopping of a neutron from an internal orbit in the projectile into an orbit around the target nucleus (or vice versa) during the relative motion of the reaction partners. Supposing that no dependence on spins of the neutron or of the residual projectile core is relevant, the transfer amplitude depends on the internal neutron orbital angular momenta before and after hopping. Denoting by quantum numbers m_i and m_f their respective orientations with respect to the normal to the scattering plane as quantization axis, the transfer amplitude A behaves essentially as

$$\begin{aligned} &A(m_i,m_f) \propto \exp\,[-c(m_i-m_f+x)^2], \\ &x=M_n v_o R_o/2\hbar + QR_o/\hbar v_o, \end{aligned} \qquad (1)$$

where Q is the Q-value of the reaction and R_o, v_o are distance and velocity at closest approach respectively.

The matching or mismatch of the orbital angular momenta, quantitatively given by the value of m_i-m_f+x, determines out of which m_i-states and consequently out of which states of orientation of projectile nuclear spin the neutron transfer occurs. In fig.1 the dependence of two analyzing powers on Q-value is displayed.

Some of the discrepancies between data and theoretical curve for $^TT_{20}$ can be remedied by taking into account neutron spin dependent effects. E.g. introducing a small spin-orbit transfer potential, the quantity $^TT_{20}$ at large negative Q-values attains to a level larger than 0.5. At low Q-values the fine structure splitting of neutron levels in ^{121}Sn must produce some irregular behaviour deviating from the smooth curve.

1. D.Mukhopadhyay et al., Phys.Rev.C35(1987) 1324.
2. G.Grawert and D.Mukhopadhyay, Nucl.Phys.A415(1984)304.

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