

EVIDENCE FOR ENERGY DEPENDENT INTERACTION IN ONE-PARTICLE TRANSFER REACTIONS BETWEEN HEAVY IONS

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The recently measured proton stripping cross sections in the collision $^{16}\text{O} + ^{208}\text{Pb}$ at 793 MeV [M.C. Mermaz et al., *Z. Phys. A* 326 (1987) 353] is analyzed in the semiclassical approximation. Taking into account an energy dependence in the interaction, consistent with the proton scattering data, an accurate description of the absolute cross sections is obtained.

The semiclassical approximation for transfer reactions [1] between heavy ions is useful at high bombarding energies where, due to the short wavelength and large orbital angular momenta, the usual DWBA treatment becomes cumbersome. The total cross section for a given transfer reaction is

$$\sigma = 2\pi \int_0^\infty b db |a(b)|^2 P_0(b), \quad (1)$$

where b is the impact parameter. The transfer amplitude $a(b)$ can be calculated in first-order perturbation theory as

$$\begin{aligned} a(b) = & \frac{1}{i\hbar} \int_{-\infty}^{+\infty} dt \langle \psi_\beta | (V_{1A} - \langle V_{1A} \rangle) \\ & \times \exp[i\sigma_{\beta\alpha}(\mathbf{k})] | \psi_\alpha \rangle \\ & \times \exp\left(\frac{i}{\hbar} [(E_\beta - E_\alpha)t + \gamma_{\beta\alpha}(t)]\right), \end{aligned} \quad (2)$$

where the integral is taken along the classical trajectory. The quantities ψ_α and ψ_β are the single particle wavefunctions of the initial and final states in projectile and target, respectively, while V_{1A} is the nuclear plus Coulomb interaction of the target on the transferred proton. With E_α and E_β we have indicated the total energies of the entrance and exit channels respectively, being $E_\beta - E_\alpha$ the Q -value of the reaction. The phase $\gamma_{\beta\alpha}$ depends on the charge and mass trans-

fer while $\sigma_{\beta\alpha}$ describes the momentum transfer $\mathbf{k}$ in the reaction (for more detail cf. ref. [1]). The quantity $P_0(b)$ is the probability to remain in the elastic channel. It is given by

$$P_0 = \exp\left(\frac{2}{\hbar} \int_{-\infty}^{+\infty} dt W(r(t))\right), \quad (3)$$

where $W(r)$ is the absorptive potential for elastic scattering and where the time integral is performed along the classical trajectory.

For high bombarding energies the matrix element in (2) depends not only on the distance $\mathbf{r}$ between the colliding ions but also on the momentum $\mathbf{k}$ of relative motion carried by the transferred nucleon, i.e.

$$\begin{aligned} & \langle \psi_\beta | (V_{1A} - \langle V_{1A} \rangle) | \psi_\alpha \rangle \\ & \sim f(r(t), k_{\parallel}(t), k_{\perp}(t)), \end{aligned} \quad (4)$$

where both the longitudinal and transverse components of $\mathbf{k}$ contribute. At low bombarding energies the interaction V_{1A} coincides with the shell model potential which binds the proton to the target in the state $|\psi_\beta\rangle$. At higher energies it is expected [2] that this interaction is reduced in the same way as the real part of the optical potential for proton-nucleus scattering. Proton scattering data are analyzed by using a nuclear interaction of Woods-Saxon shape with an energy dependent depth parametrized as

$$V_0(E) = \left(1 - \beta \frac{E}{V_0}\right) V_0, \quad (5)$$

where E is the energy of the impinging proton. Values of β in the range $\beta=0.3-0.5$ are quoted in the literature [3].

For the nuclear part of V_{1A} in (2) we shall also use a Woods-Saxon parametrization which for $E=0$ coincides with the nuclear shell model potential that binds the proton to the target. With the parametrization (5) of the strength of V_{1A} we notice that the real part of the ion-ion optical potential, which is the folding of this interaction with the particle density of the projectile, is reduced by the same law where the energy E is the kinetic energy per nucleon above the Coulomb barrier. This expectation seems to be born out from the experimental data. In fig. 1 we have plotted, as a function of the bombarding energy and for two center-of-mass distances close to the distance of closest approach for grazing collision, the real part of the ion-ion potentials that fit the elastic scattering data for $^{16}\text{O} + ^{208}\text{Pb}$. The energy dependence of these potentials is seen to be consistent with values of β in the range $\beta=0.5-0.7$.

With the simple scaling (5) also the form factor (4) achieves an approximate scaling although the Coulomb component of V_{1A} does not scale with energy. With this energy dependent proton-nucleus interaction we have calculated, as a function of the bombarding energy, the total cross sections (1) for all the proton stripping reactions which have been

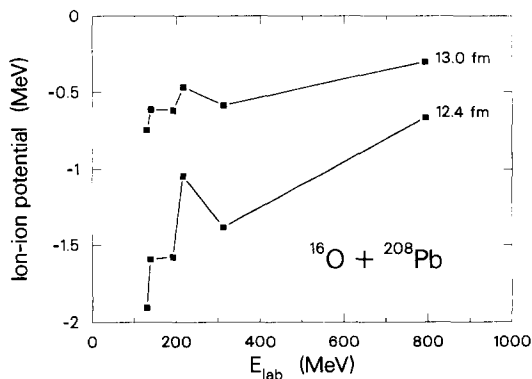


Fig. 1. Real part of the optical potential from refs. [4-6] plotted as a function of the bombarding energy for the indicated r -values.

measured. In fig. 2 we show the results for the $(1p_{1/2}^{-1}) \rightarrow (1h_{9/2})$ transition for different values of β in comparison with the experimental data of refs. [4-6] (the theoretical curves have been plotted here with spectroscopic factor unity). The result for $\beta=0$ agrees quite well with the DWBA calculation of ref. [4]. It is seen that a value of $\beta=0.5$ gives a rather good fit to the data at high energy so we will use this value to calculate the cross sections for the other transitions. The discrepancies we observe at low energies is a well known problem that may be ascribed to higher order processes [7].

In fig. 3 the results for all one-proton stripping transitions from the $^{16}\text{O}(1p_{1/2}^{-1})$ to the ground state and first excited states of ^{209}Bi are given in comparison with the experimental data. Using a spectroscopic factor of 0.95 for the ground state transition, of 1 for the transition to the $2f_{5/2-}$, of 0.65 for the transition to the $2f_{7/2-}$ and of 0.28 for the transition to the $1i_{13/2}$ -state a good description of the absolute cross section is obtained.

It is the conclusion of this investigation that the

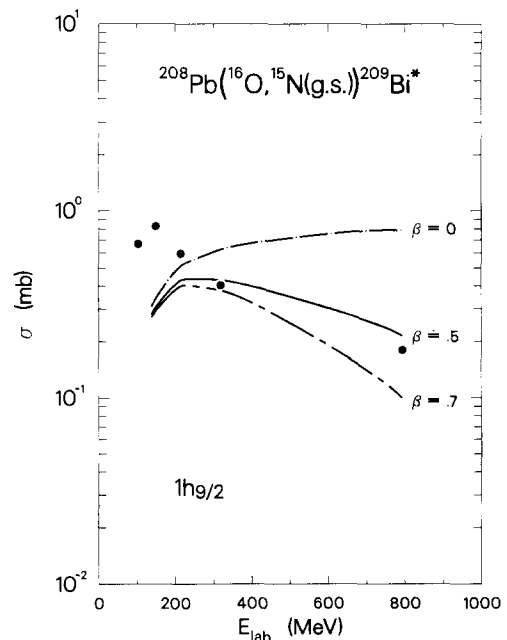


Fig. 2. Total transfer cross section for the ground state transition for different values of β [cf. eq. (5)] in comparison with the experimental data [4-6]. The curves have been plotted with unity spectroscopic factor. The curve labelled with $\beta=0$ agree well with the DWBA calculation of ref. [4].

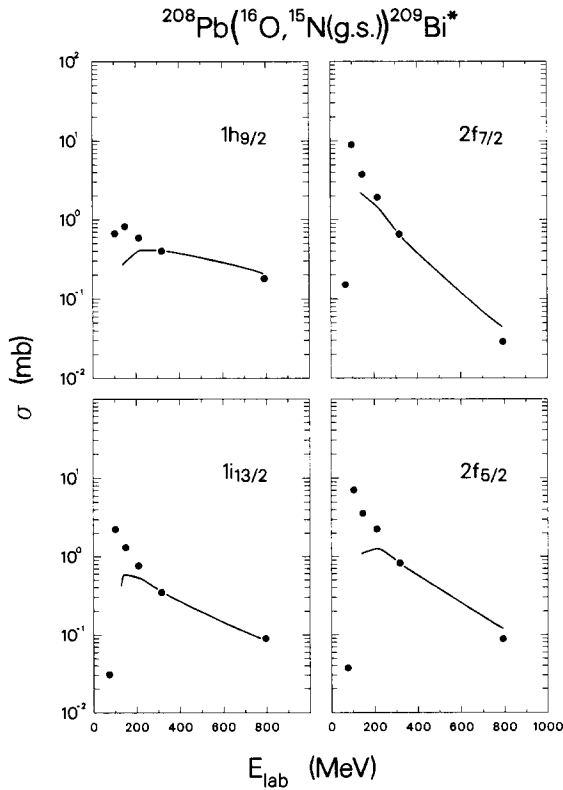


Fig. 3. Total transfer cross sections for all the measured proton stripping reactions from the $(1p_{1/2})$ state in comparison with the experimental data [4–6]. The calculations have been performed using the optical model parameters of refs. [4,6].

semiclassical theory gives a convenient and accurate description of transfer reactions at high energy including the energy dependence of the spin-flip and no spin-flip transition. It seems that heavy ion transfer reactions may be used to give rather direct and accurate information about the energy dependence of the nucleon–nucleus interaction.

References

- [1] R.A. Broglia and A. Winther, Phys. Rep. 4 (1972) 153; R.A. Broglia, G. Pollaro and A. Winther, Nucl. Phys. A 361 (1981) 307; J.H. Sørensen, thesis (1988), unpublished.
- [2] C.H. Dasso, S. Landowne and H.H. Wolter, Nuovo Cimento 92A (1986) 50.
- [3] C. Mahaux, P.F. Bortignon, R.A. Broglia and C.H. Dasso, Phys. Rep. 120 (1985) 1, and references therein.
- [4] M.C. Mermaz, B. Berthier, J. Barrette, J. Gastebois, A. Gillibert, R. Lucas, J. Matuszek, A. Miczaika, E. Van Renterghem, T. Suomijärvi, A. Boucenna, D. Disdier, P. Gorodetzky, L. Kraus, I. Linck, B. Lott, V. Rauch, R. Rebmeister, F. Scheibling, N. Schulz, J.C. Sens, C. Grunberg and W. Mittig, Z. Phys. A 326 (1987) 353.
- [5] S.C. Pieper, M.H. Macfarlane, D.H. Gloeckner, D.G. Kovar, F.D. Becchetti, B.G. Harvey, D.L. Hendrie, H. Homeyer, J. Mahoney, F. Pühlhofer, W. von Oertzen and M.S. Zisman, Phys. Rev. C 18 (1978) 180.
- [6] C. Olmer, M.C. Mermaz, M. Buenerd, C.K. Gelbke, D.L. Hendrie, J. Mahoney, D.K. Scott, M.H. Macfarlane and S.C. Pieper, Phys. Rev. C 18 (1978) 205.
- [7] C.H. Dasso, S. Landowne, G. Pollaro and A. Winther, Nucl. Phys. A 459 (1986) 134.