Precompound Reactions: Basic Concepts

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1.The Need to go beyond the Compound-Nucleus Model

Compound-nucleus model is an equilibrium model.

In the GOE, each state interacts with every other state. Realistic only if equilibration time t_{equ} short compared to decay time h/Γ. This condition met at neutron threshold. But Γ grows strongly with excitation energy (ever more channels open up) while t_{equ} roughly independent of excitation energy. Therefore compound-nucleus model fails 10 or 20 MeV above neutron threshold.

More realistic description in terms of hierarchy of states.

If doubly-magic target hit by a nucleon, hierarchy consists of 2p1h states, 3p2h states,…, np(n-1)h states. Populated in a series of two-body collisions. Maximum n given by states with largest statistical weight at energy considered. Equilibrium reached only after n collisions.

Several semiclassical phenomenological approaches not discussed. Focus on quantum-statistical theories.

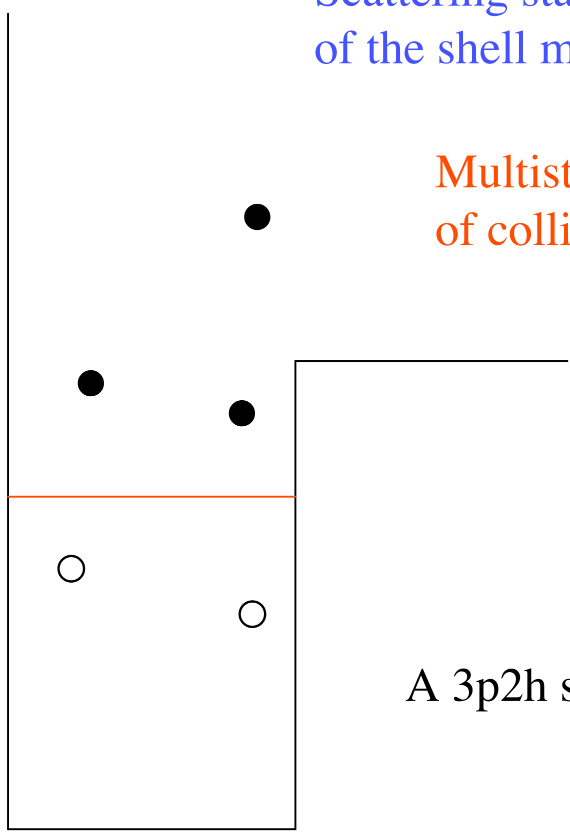
2. Scattering States and Quasibound States

Scattering states: At least one nucleon in shell-model continuum.

Scattering states are coupled with each other by the residual interaction of the shell model. That coupling yields coupled-channels equations.

Multistep-direct reactions: All states populated in course of collision are scattering states. Idea of “leading particle”.

Number of coupled channels grows exponentially with bombarding energy. Complexity of states grows with number of two-body collisions. Statistical approach needed.



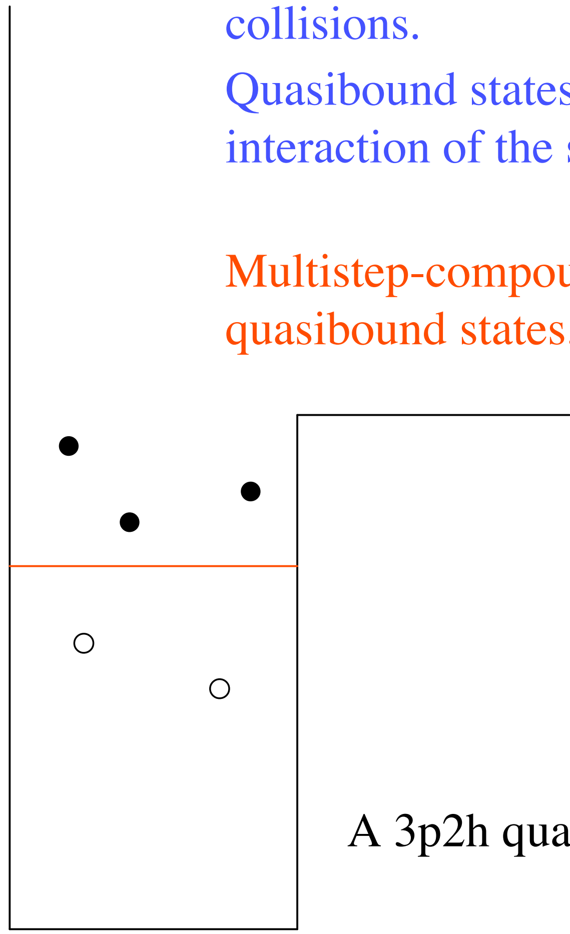
A 3p2h scattering state.

Quasibound states: All nucleons occupy bound states of the single-particle shell-model.

Quasibound states are coupled with each other by the residual interaction of the shell model. Complexity of states increases with number of two-body collisions.

Quasibound states and scattering states are also coupled by the residual interaction of the shell model: Origin of resonances.

Multistep-compound reactions: All states populated in course of collision are quasibound states.



Multistep-direct and multistep-compound chains are coupled. Only at low energies multistep-compound dominates: The first obvious extension of compound-nucleus model. Number of np(n-1)h states is huge: A statistical approach required.

A 3p2h quasibound state

3. Multistep-compound Reactions.

Higher yield of fast particles than predicted by compound-nucleus model. Angular distributions retain symmetry about 90 degrees c.m.

Hierarchy of states: Classes with m “excitons” (particles + holes). Two-body interaction connects only neighboring classes m-2 , m , m+2 (Feshbach’s “chaining hypothesis”).

Levels within each class obey GOE statistics. Coupling matrix elements connecting classes have Gaussian distribution. States also statistically coupled to channels.

Statistical assumptions justified in terms of time scales:

$$d_m \ll \Gamma_{cm}, \Gamma^{+}_{m} \ll \Delta E_{response} .$$

D. Agassi, H. A. Weidenmüller, G. Mantzouranis, Phys. Rep. 22 (1975) 145
H. Feshbach, A. K. Kerman, S. Koonin, Ann. Phys. (N.Y.) 125 (1980) 429

Central result:

$$<|S^{fl}_{ab}|^2> = (1 + \delta_{ab}) \sum_{m,n} T^a_m \Pi_{mn} T^b_n$$

where matrix Π_{mn} obeys

$$\Pi_{mn} \{2\pi\Gamma_n / d_n\} - \sum_l \Pi_{ml} T_{ln} = \delta_{mn} .$$

Coefficients $T_{kl} = 4\pi^2 V^2_{kl} / (d_k d_l)$ describe mixing of neighboring classes. Width Γ_n is sum of decay width and spreading width in class m.

Hauser-Feshbach formula obtained if Γ^+_ms sufficiently large.

FKK: Simplification in terms of "never come back" approximation.

Parameters of optical model and level-densities of states with m excitons uniquely determine parameters of the model.

M. Herman, G. Reffo, H. A. Weidenmüller, Nucl. Phys. A 536 (1992) 124

4. Multistep Direct Reactions

H. Feshbach, A. K. Kerman, S. Koonin, Ann. Phys. (N.Y.) 125 (1980) 429
T. Tamura, T. Udagawa, H. Lenske, Phys. Rev. C 16 (1982) 379
H. Nishioka, J. J. M. Verbaarschot, H. A. Weidenmüller, S. Yoshida, Ann. Phys. (N.Y.) 172 (1986) 67
H. Nishioka, H. A. Weidenmüller, S. Yoshida, Ann. Phys. (N.Y.) 183 (1988) 166
A. J. Koning and J. M. Akkermans, Ann. Phys. (N.Y.) 208 (1990) 216

Strongly forward-peaked angular distributions due to memory effect. Significant contributions only from first few collisions. Emission of high-energy particles.

The three main quantum-statistical approaches use different statistical assumptions. This implies different ratios of time scales (Koning and Akkermans). Results do not seem to differ significantly.

Several phenomenological approaches based on semiclassical concepts simplify the quantum-statistical approaches.

Relevant time scales:

Time of particle-hole creation -- time for configuration mixing.

Theories differ in assuming dominance of one of these (adiabatic versus sudden approximation).

For 1st step (which yields roughly 80 % of total cross section) all three approaches give same answer, and even for 2nd and 3rd step, results not too different.

So in practice there is not much room for disagreement.

Above about 100 MeV, these quantum-statistical theories to be replaced by semiclassical approaches.