Role of noncollective excitations in low-energy heavy-ion reactions

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1. **Introduction**

   - Heavy-ion reaction
   - Nucleus is composed of protons and neutrons
   - Excitations during the scattering process (channel coupling effect)
   - Large enhancement of fusion cross sections at sub-barrier energies

2. **Quasi-elastic scattering (elastic + inelastic + transfer)**

   - Experiment for $^9Na + ^{90}Zr$

   - Quasi-elastic quasi-barrier distributions show different behavior
   - Much more smeared distribution for $^{20}Ne + ^{90,92}Zr$ system

   - On the other hand, C.C. calculation (which includes rotation in $^{90}Na$ and vibration in $^{90}Zr$) yields similar barrier distributions between two systems
   - Dominates the contribution from highly deformed $^{90}Na$

   - Conventional C.C. calculation (which takes into account only the collective excitations) cannot account for the experimental data!

3. **Energy spectrum for Zr isotopes**

   - Different level density
     - $^{92}Zr$: 75 levels up to 5.7 MeV are included

   - Noncollective (single-particle) excited states appear in $^{92}Zr$ spectrum

   - Important role of the noncollective excitations for $^{20}Ne + ^{90,92}Zr$ reaction?

4. **Description of noncollective excitations**

   - Coupled-channels equations
     - In the iso-centrifugal approximation
     - Random matrix theory (RMT) for couplings to noncollective states

5. **Coupled-channels calculation for $^{90}Na + ^{90,92}Zr$ included channels (model space)**

   - Collective excitations for $^{90}Na$ and $^{92}Zr$
   - $^{90}Na$: $l = 0$, 2, 4; $d$ (rotational states), 3 (octupole phonon state)

6. **Results**

   - Quasi-elastic scattering for $^{90}Na + ^{90,92}Zr$ systems

   - For $^{90}Na + ^{90}Zr$ system, the effect of the noncollective excitations is small

   - For $^{90}Na + ^{92}Zr$ system, the barrier distribution is drastically smeared

7. **Summary**

   - Role of noncollective excitations in low-energy heavy-ion reactions
     - Conventional coupled-channels analysis for heavy-ion reactions takes into account only collective excitations
     - Random matrix model for the description of noncollective excitations
     - Different magnitude of the noncollective effect between $^{90}Na + ^{90,92}Zr$ systems
     - Difference in the barrier distribution can be expected for $^{90}Mg + ^{90,92}Zr$ reactions

   - Quantum mechanical study of friction