ARE MOLECULAR RESONANCES VIBRATION-ROTATIONAL STATES?

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Recently new approaches were proposed which seemed to give a unified explanation of resonances observed in lighter heavy ions reactions.[1,2] The purpose of this contribution is to notice an inherent difficulty of the approaches. All the resonances observed in the $^{12}C - ^{12}C$ system are surprisingly well reproduced by the formula of the anharmonic vibration- rotation spectrum,

$$E_{nL} = -D + a \cdot \left(n + \frac{1}{2}\right) - b \cdot \left(n + \frac{1}{2}\right)^2 + c \cdot L(L+1) \tag{1}$$

with suitable values of the four parameters D, a, b and c, where n and L are the quantum numbers of the vibration and of the angular momentum,respectively. Satpathy et al[3] tried to derive the molecular type spectrum, starting with Morse potential which is assumed to represent a sum of nuclear and Coulomb potentials. They utilized the approximate analytic solution of Schroedinger equation with a generalized Morse potential, which gave a vibration-rotational spectrum more general than the expression (1). They succeeded in reproducing the observed resonance energies, as shown in Fig. 1a. The deduced potential is of shallow depth and long range. Such a potential immediately reminds us of a strong rotation-vibration coupling, because the mean square distance between ions or the moment of inertia easily changes as vibrational quantum number n increases. Actually the calculated vibrational energy is very small and is equal to 1 ~ 2 MeV which is comparable to rotational energy. The rotation-vibration coupling should be extremely strong and even strong enough to destroy the anharmonic vibration-rotation picture itself. Calculated spectra, however, show almost no rotation-vibration coupling. (This is required to reproduce the observed states which could be plotted as straight lines in the excitation energy against $J(J+1)$ plane.) This is puzzling. Let us review an approximation assumed to derive the analytic solution. The essential approximation[4] is concerning the centrifugal potential,

$$\frac{\hbar^2 L(L+1)}{2\mu r^2} \cong \frac{\hbar^2 L(L+1)}{2\mu} \cdot \left(c_0 + c_1 \cdot e^{-\beta \cdot x} + c_2 \cdot e^{-2 \cdot \beta \cdot x}\right) \tag{2}$$

where $x = (r - r_0)/r_0$ and β, r_0 are the parameters of Morse potential. Coefficients c_0, c_1 and c_2 are obtained by the condition that the expression (2) is to give an accurate description up to the second order of x. Obviously this approximation are to be worse and worse as a vibrational and/or an angular momentum quantum numbers increase, because $\langle x\rangle$, $\langle x^2\rangle$ etc. are large in those states. In order to inspect the accuracy quantitatively, we solve the Schroedinger equation numerically with the same Morse potential. Energy spectra obtained are shown in Fig 1.b. Two spectra are completely different with each other except $L = 0$ states. Spectra obtained by Satpathy et al are false and completely due to the inappropriate approximation (2). A most striking feature of the present calculation is that there is no rotation-vibrational states at energies above 7 MeV, not only with low but also with high angular momenta. This is not due to a particular parametrization of bonding potential by Morse type, but is inherent to the vibration-rotation approaches. They need a small vibrational energy, which requires a flat slope and a long range of a bonding potential and hence centrifugal barriers disappear, otherwise they could work to keep quasi-bound states in higher angular momenta.

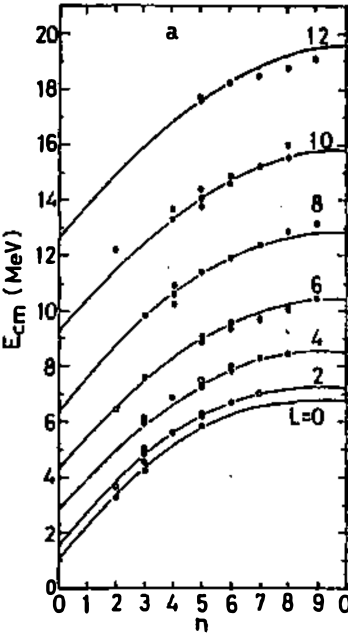

Fig. 1a

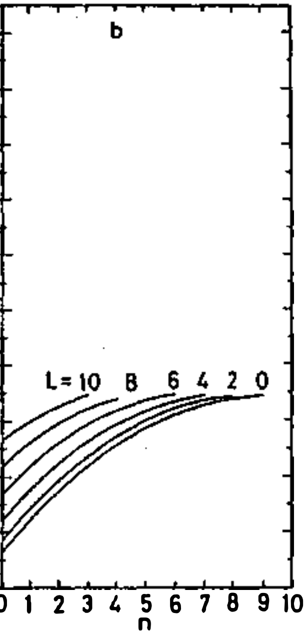

Fig. 1b

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