Mass-imbalanced Three-body Systems in 2D: bound states and the analytical approach to the adiabatic potential

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We consider three-body systems in two dimensions with zero-range interactions for general masses and interaction strengths. The problem is formulated in momentum space and the numerical solution of the Schrödinger equation is used to study universal properties of such systems with respect to the bound-state energies.

The number of universal bound states in two dimensional three-body systems is strongly mass dependent and increases as one particle becomes much lighter than the others [1]. We have found an accurate analytical approximation to the Born-Oppenheimer (BO) potential for one light particle in the field of two heavy ones [2], as shown in figure 1.

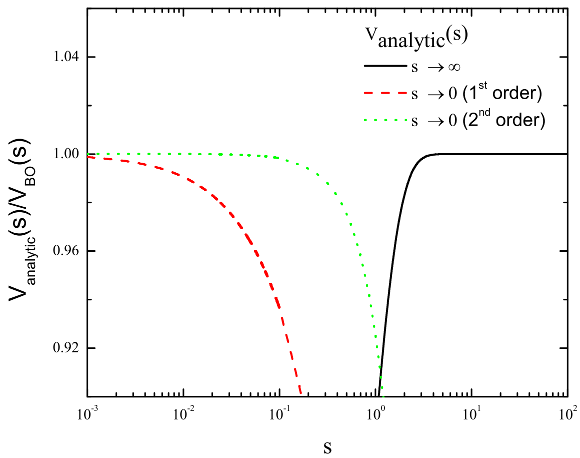

Figure 1: Ratio $V_{analytical}(s)/V_{BO}(s)$ as function of the dimensionless coordinate $s(R) = \sqrt{\frac{2\mu_{C,AB}|E_2|}{\hbar^2}}\, R$, showing the validity of the analytical approximation to the BO potential. The solid (black) and dashed (red) curves are the first order expansion of the analytical potential at large and small distances, respectively. The dotted (green) curve is the second order expansion at small distance.

We compute the number of bound states for a two dimensional system composed of two identical particles (A) and a distinct one (B) as function of the mass ratio $m = m_B/m_A$. Results from the BO potential and full calculations are found to agree for $m << 1$ (see figure 02). We applied the JWKB approximation in the analytical to the BO potential and found an analytical relation between the number of bound states and the mass ratio m [2].

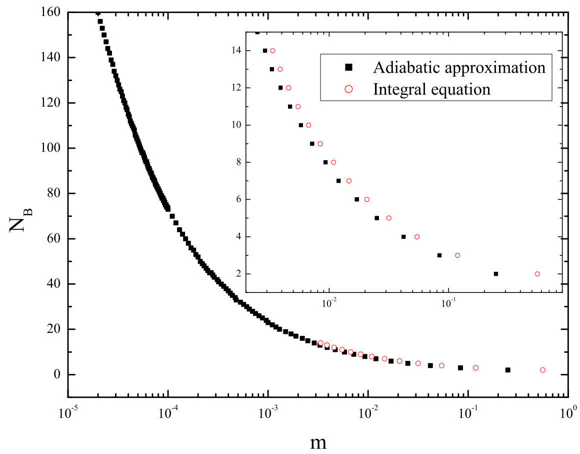

Figure 2: Number of bound states, N_B, for a system with mass ratio m. The (black) squares represent the mass ratio m where N_B states are bound, calculated from the adiabatic approximation. The (red) circles represent the full numerical solution. The inset shows the result on a different scale.

In order to discuss some properties of mass-imbalanced three-body systems, we consider two different systems that can be probed in laboratories in the near future: ^{133}Cs-^{133}Cs-^{6}Li and ^{87}Rb-^{87}Rb-^{6}Li. The adiabatic problem was handled for a non-interacting heavy-heavy system. This is close to the situation in ^{133}Cs-^{6}Li experiments, where three-body bound states are expected to be found when the subsystem ^{133}Cs-^{133}Cs is almost non-interacting.

We found that the most favorable scenario for a spectrum with many bound states for two dimensional three-body systems is the symmetric energy case, where all the subsystems are equally bound [3]. However, this scenario seems less likely in current experiments whereas a very promising scenario is the one where the heavy-heavy system does not interact and the two heavy-light systems have the same binding energy (for example, ^{133}Cs-^{133}Cs-^{6}Li). Except for the energy-symmetric case this is the most favorable scenario for a rich energy spectrum in 2D [2].

[1] F. F. Bellotti *et al.*, J. Phys. B: At. Mol. Opt. Phys. **46**, 055301 (2013).

[2] F. F. Bellotti *et al.*, J. Phys. B: At. Mol. Opt. Phys. **44**, 205302 (2011).

[3] F. F. Bellotti *et al.*, Phys. Rev A **85**, 025601 (2012).

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