Study of Unbound States of ^{15}Be using Supersymmetric Quantum Mechanics

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Introduction

Recently there has been a surge in interest in the neutron-unbound nucleus ^{15}Be. First observation of ^{15}Be was published in 2013 [1], where a resonance at 1.8 MeV $(5/2^+)$ was observed. Subsequently Kuchera *et al* [2] confirmed the existence of the $5/2^+$ state. It is very difficult to tackle theoretically the unbound states by conventional methods. In the present work, we resort to a very effective technique used earlier by us for study of weakly bound nuclear systems [3]. The theoretical procedure of supersymmetric quantum mechanics (SQM) is adopted to tackle the resonance states of unbound nuclei. We have been able to reproduce the unbound state energies without any modification in our constructed microscopic potential. Our procedure confirmed the existence of $5/2^+$ state and also reproduced the experimentally predicted unbound resonance energy [2].

Theory

The SQM was earlier applied to detect low-lying broad resonances of weakly bound nuclei [3]. Its success has prompted us to apply it effectively for unbound nuclei like ^{15}Be. Success of our theoretical procedure is due to its ability to circumvent the numerical challenges posed by the shallow potential of such nuclear systems. In our present work, we treat the ^{15}Be nucleus in the framework of a two-body model consisting of an inert core of ^{14}Be and a single valence neutron. The two-body potential $v(r)$ is generated microscopically in a single folding model using the density dependent M3Y (DDM3Y) effective interaction [3].

From this potential, SQM generates a family of isospectral potentials (IP), which has a normalizable positive energy solution at a selected energy. This is a lesser known result of SQM, namely a bound state in the continuum (BIC). Now this IP has desirable properties which can be utilized to extract information about unbound resonance states. The microscopic potential constructed from single folding calculation is in general a shallow well followed by a low and wide barrier. For a finite barrier height, in principle, a system may be temporarily trapped inside the shallow well when its energy is close to the resonance energy. In reality, there is a very high probability for tunnelling through the barrier which gives rise to broad resonance widths. Our technique bypasses this problem and obtains precise resonance energies.

An isospectral partner potential could be constructed by following the ideas extended by Pappademos *et al* [4] to scattering states with positive energy in the continuum. Wave functions in the continuum are non-normalizable but following Pappademos *et al* one can construct normlizable wave functions at a selected energy, which represents a BIC. The BIC represents a solution of the equation with an isospectral potential $\hat{v}(r, \lambda)$, where λ is a parameter which affects the strength of IP. It follows from theory as well as in practice that resonance energy does not depend on the choice of λ. So a suitable choice of λ ensures the stability of the resonance state. It preserves the spectrum of the original potential while

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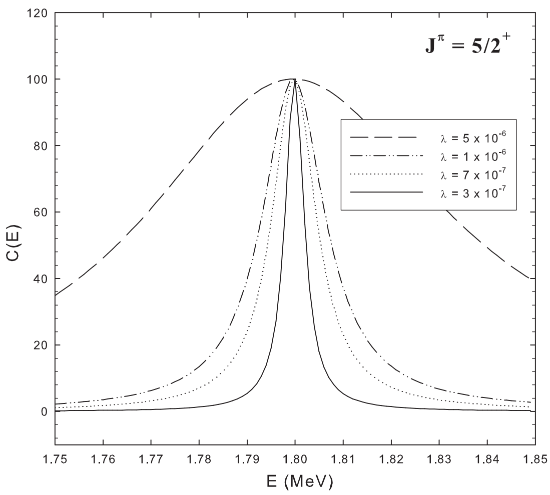

FIG. 1: Probability $C(E)$ as a function of energy E for $\lambda = 5\times10^{-6}, 1\times10^{-6}, 7\times10^{-7}$ and 3×10^{-7} for the $\frac{5}{2}^+$ state of ^{15}Be.

adding a discrete BIC at a selected energy. We solve the two-body Schrödinger equation for a positive energy E subject to the boundary condition $\psi_E(0) = 0$ and normalized to a constant (fixed) amplitude of oscillation in the asymptotic region. The obtained $\psi_E(r)$ is used to construct the isospectral potential $\hat{v}(r;\lambda)$. The $\hat{v}$ approaches v for $\lambda \to +\infty$ and develops a deep and narrow well followed by a high barrier near the origin for $\lambda \to 0+$. The deep well and high barrier combination effectively traps the system giving rise to a quasi-bound state. We calculate the probability of the system to be trapped within this enlarged well-barrier combination as,

$$C(E) = \int_0^{r_B} [\hat{\psi}_E(r')]^2 dr' . \qquad (1)$$

Results and Conclusions

Considering ^{15}Be to be a two-body system (^{14}Be + n), we investigated the $\frac{5}{2}^+$ resonant state. A plot of $C(E)$ as a function of E for various λ values shows how the trapping effect of $\hat{v}(r;\lambda)$ increases as λ decreases. For appropriate choice of λ, deep-welled isospectral potentials are constructed. Probability $C(E)$ of the system for $\frac{5}{2}^+$ state is plotted in Fig. 1. It is evident from the plot that there is a resonant state at energy $E = 1.8$ MeV for $\frac{5}{2}^+$ state. Since the present framework appears very promising we are working on further improvements.

References

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