International Journal of Engineering and Basic Sciences
Volume 01, Issue 01, July 2025
www.ijebs.com

Polaron Energy Levels in a Parabolic Potential Well

C Kalapana
Department of Physics, Nagarjuna University, Guntur
Corresponding Author: kalapanaphynu@gmail.com

To Cite this Article
Kalapana, "Polaron Energy Levels in a Parabolic Potential Well", International Journal of Engineering and Basic Sciences, Vol. 01, Issue 01, July 2025, pp:16-18.

Abstract: *The energy levels of polaron states in a parabolic potential well has been discussed in this article and studied with particular reference to the interaction between quantum confinement and electron-phonon interaction. Polaron - Energy spectrum of a harmonic oscillator is studied by using the Feynman path integral. It is seen that confinement is involved in the shift in energy level which is strongly affected by the well parameters and polaron coupling constant. Binding energy and effective mass of the polaron can be altered through its increased localization in higher sided wells. These experimental findings help to understand the polaron behavior in low-dimensional semiconductor materials with implications on the use of the materials in devices of optoelectronic and quantum technologies.*

Keywords: *Polaron, Parabolic Potential Well, Electron-Phonon Interaction, Quantum Confinement, Energy Spectrum*

I. Introduction

Polarons are a kind of quasiparticle formed when charge carriers in a solid, such as electrons, interact with crystal vibrations (the phonons). To study various low-dimensional quantum and semiconductor systems, it is of essence to understand their behavior. The effects of quantum confinement of polaronic states can be analyzed in a synthetic setting in a parabolic potential well that is often used to model quantum dots or harmonic traps. In these systems both electron-phonon coupling and spatial confinement effects combine to radically change the polaron effective mass and energy levels. Those alterations impact the optical and transport properties of the material. The physic behind the restricted systems can be explained with the study of the polaronic energy levels in a parabolic potential trap. The analysis also finds use in nanoscale device design such as transistors, lasers and detectors. It is therefore the aim of this work, by using theoretical models and approximation methods to examine how the polaron energy spectrum is affected by the confinement potential and the strength of the interaction.

II. Energy Levels

Interaction of both electron-phonon interaction and quantum confinement is an important aspect in the determination of the energy of a polaron in a parabolic potential well. The spectrum of a non-interacting system resembles that of a simple harmonic oscillator due to discrete levels, which are determined by the strength of the confinement potential. These energy levels however vary with the introduction of electron-phonon interactions as there is the formation of a composite quasiparticle called polaron where the properties would differ. Besides renormalizing the effective mass of the carrier, the coupling also results in the reduction of energy levels, of polaron binding energy.

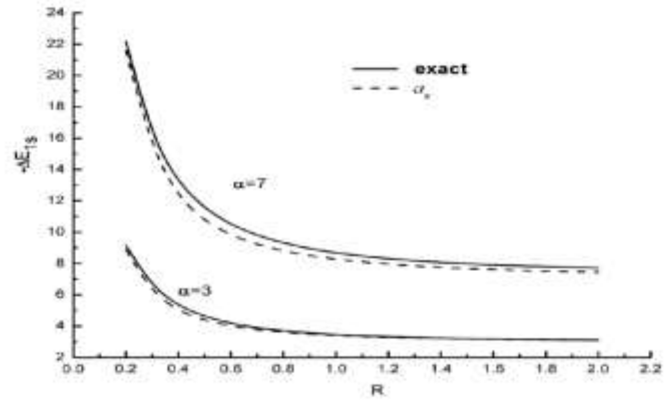

Fig 1: Polaron shift with reduced QD radius *R*

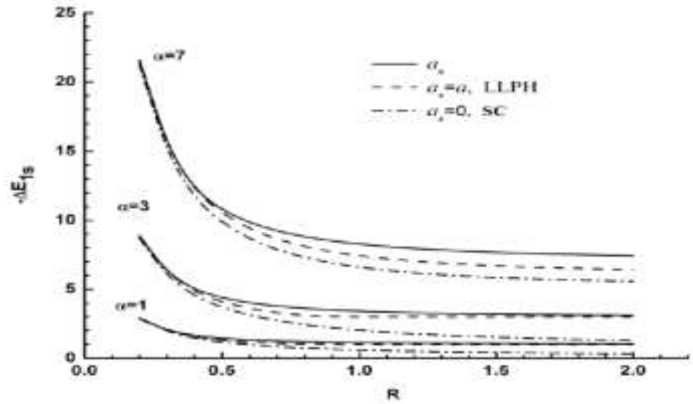

Fig 2: Polaron shift with reduced QD radius LLPH

To what extent a change in a level of energy takes place is decided by the magnitude of the electron-phonon interaction and the width of the potential well. Tighter confinement or stronger coupling leads to more localization and to more renormalization of energy. The polarization of semiconductors and quasi particles as well as low dimensional nanostructures including quantum dots needs comprehension of this transformation in the energy spectrum of polarons.

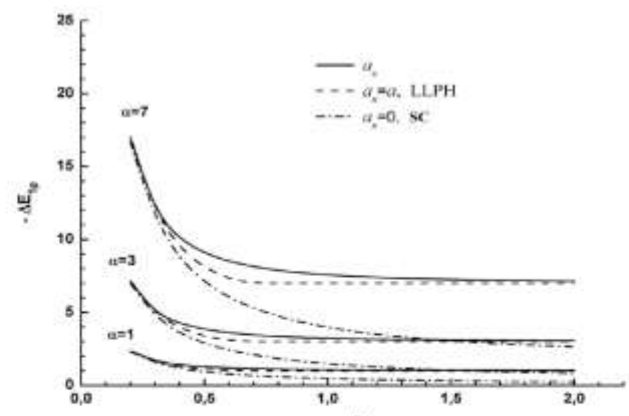

Fig 3: 1p -Polaron shift with reduced RD radius R

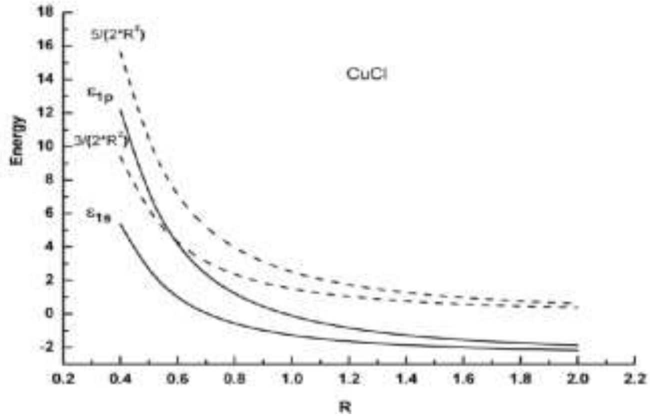

Fig 4: Eenergy levels of 1s 1p

III. Conclusion

Finally, it seems appropriate to add that the electron-phonon effects are very strong in the quantum confinement regime and polaron energies of a parabolic confinement potential well can be studied as an example. The mode shift and the effect of the confinement on the energy spectrum causes level shifts and changes in the effective mass and binding energy of the polaron. They worsen with the narrower wells and tighter coupling. An insight into these energy changes is important in predicting the behavior of polarons in nanostructures such as quantum dots and wells. The findings of the analysis are critical in enhancing the way the semiconductor devices are designed, improved transport and optoelectronic devices.

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