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Original Research

Dependence of energy eigenvalue on magnetic field, AB flux and Temperatures of two electron quantum dot (anti dot) confined in Mie potential

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Abstract

The characteristics and energy of a system in an eigenvalue problem can be approximated through different mathematical formalisms, so as we have preferred and employed the Nikiforov-Uvarov formalism to solve for the Mie potential. The energy spectrum is calculated numerically and exposed to external magnetic field intensity, temperature, and AB flux intensity considering material parameters GaAs quantum dot (antidot) confined in Mie potential. The magnetic field and AB flux intensity affect additional confinement potential, which plays a great role in tuning the potential model fit to different applicability and enhances the study of different properties of the system. In our study, we investigated energy spectrum dependence on the repulsive radius, applied magnetic field, AB flux intensity, and rovibrational state to enhance the energy spectrum over dominating the potential confinement, and however, the effect of temperature is governed by the form of confinement potential in maintaining the attractive and repulsive phases. The energy spectrum is highly influenced by the presence of a repulsive anti-dot radius due to electron-electron interactions in the systems.

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INTRODUCTION

The precise binding energy state value of the SE in scientific studies plays a notable role in quantum mechanics (Oyewumi, 2008). Intensive attention has been given by many researchers for many decades to solving SE through different approaches to approximate the precise possible results due to its multidimensional importance for enhancing the energy eigenvalue and wave function simultaneously. The difficulties made by intricate N-dimensional SE have been separately solved by different scholars with its unique algebraic expression by its value in D-dimensionality. The N-dimensional pseudo-harmonic oscillator was discussed by Oyewumi et al. (2008). Investigation of 3D harmonic oscillators has elevated a significant aggregate intellectual curiosity due to its

considerable scientific meaning in the structural behaviour of physical phenomena (Sever, 2007; Macke, 1961; Weissman, 1979).

Other potential systems researchers usually experience in physical chemistry have a well-known Kratzer potential. In addition, it is applicable for the depiction of the structures of molecular features in quantum mechanics (Sadeghi, 2007). It plays a significant role as a long-range attractive and short-range repulsive play in providing the existence as a part of structural interactions that elucidate the Kratzer potential in validating terms of its rovibrational ground state energy (LeRoy, 1970) (Bayrak, 2007). The Kratzer potential tends to infinity as the distance between intra-molecules is agitated to become nearer to each other. As a result, the potential value tends to zero; this is due to the existence of a repulsion force between the molecules. That is why intra-molecular space tends to increase; then, the potential value decays (Edet, 2020; Hassanabadi, 2012). It has been found that the Kratzer potential is actually appropriate for the portraiture of molecular features and interactions between two nuclei of atoms (Ikot, 2019; Hajigeorgiou, 2006; Durmus**,** 2007). The NU method was protracted for scientific communities by admirable scholars. Nikiforov and Uvarov established mathematical formalism, which enabled researchers to apply their sophisticated mechanisms to solve the reliable solution of SE based on reduced SODEs changing into linear differential equations.

It is newly fashioned that the state of being of external fields used to explore almost all physical properties of low-dimensional systems has accepted great remark both theoretically and experimentally. Thus, intensive attention has to be given to the newly emerging as the main subject of study that has to be taken into great consideration since it is the groundwork for technological development. Meanwhile, scientific communities are imposed to deal with artificial atoms (QDs) as low-dimensional systems. That opens a window to revealing many physical properties, like optical, thermal, magnetic, and electrical, of materials that have been the focus of extensive theoretical studies. It also required more effort in order to contribute to revealing and exploring capabilities in their applications in nanodevices and nanotechnological development. The analysis of the energy eigenvalues of artificial atoms is key to probing the physical properties of the system as a whole. Thus, applying an external magnetic field is virtually equivalent to announcing a supplementary binding potential that alters the electron or hole's transport and optical properties.

Mathematical methods

The Nikiforov-Uvarov method

Recently, the NU formalism has made it simpler to solve SE for many recognised potentials. The reduction principle has to be applicable for linear forms of mathematical equations with a reliable algebraic expression in mapping s = s(r); therefore, it can be given as follows:

$$\frac{\partial^2\psi}{\partial s^2}(s) = \frac{\tau(s)}{\sigma(s)}\frac{\partial\psi}{\partial s}(s) + \frac{\tilde{\sigma}}{\sigma^2}\psi(s) = 0 \quad (1)$$

Since α(s)=$\frac{\tau(s)}{\sigma(s)}$ and β(s)=$\frac{\tilde{\sigma}(s)}{\sigma^2(s)}$ in equation(1) $\sigma(s)$ and $\tilde{\sigma}$(s) both are polynomials at most second degree while $\tilde{\tau}$(s) is at most first degree. The wave function is represented as a component of two separable parts,

$$\psi(s) = \varphi(s)y(s) \quad (2)$$

And equation

$$\sigma(s)y(s) + \tau(s)\frac{\partial\psi}{\partial s}(s) + \lambda y(s) = 0 \quad (3)$$

And

$$\sigma(s) = \pi(s)\frac{d}{ds}\left(ln\left(\varphi(s)\right)\right) \quad (4)$$

And

$$\tau(s) = \tilde{\tau}(s) + 2\pi(s) \quad (5)$$

λ is defined as

$$\lambda_n + n\tau' + \frac{[n(n-1)]\sigma''}{2} = 0 \quad (6)$$

One can describe $\pi(s)$ and $\sigma(s)$ as follows

$$k = \lambda - \pi'(s) \quad (7)$$

Quadratic solution of equation (4) and (5) in tem of $\pi(s)$can be given as:

$$\pi(s) = \frac{\left(\sigma' - \tilde{\tau}\right)}{2} \pm \sqrt{\left(\frac{\sigma' - \tilde{\tau}}{2}\right)^2 - \tilde{\sigma} + k\sigma} \quad (8)$$

Equation (8) $\pi(s)$ is used to justify 1st degree of polynomial function, so the mathematical terms subjected to the square root could be justified as the solution of first degree of Polynomial Square. Thus it is evitable if and only if $(\frac{\sigma'-\tilde{\tau}}{2})^2 - \tilde{\tilde{\sigma}} + k\sigma = 0$. Following the decision made on value of k, we can obtain $\pi(s), \tau(s)$ and $\psi(s)$. Additionally, from equation (4) one can relate with the Rodrigues form as:

$$y_n(s) = \frac{d_n}{\rho(s)}\frac{d^n}{d\rho^n}\sigma^n(s)\sigma(s) \quad (9)$$

Since c_n is defined as constant magnitude and the weight function shows good agreement with following form of equation:

$$\left(\sigma(s)\rho(s)\right)' = \tau(s)\rho(s) \quad (10)$$

Where

$$\frac{\varphi'(s)}{\varphi(s)} = \frac{\pi(s)}{\sigma(s)} \quad (11)$$

Eigenvalues of the Mie-Type Potential under external fields

Diatomic confinement, trapped in Mie potential, had been studied through Nikiforov-Uvarov formalism (Nikiforov & Uvarove, 1988).

Polynomial approaches (Ikhdair, S. M., 2008) and mathematical assumptions of wave function were studied (Hamzavi, 2011). Generally, one can describe the Mie-type potential as reduced to the Coulombic-potential type. It had been investigated taking into account D dimensions using the polynomial solution and assumed to be the state function formalisms with standard Morse (Morse, 1929). The Mie-type potentials account for a 2D single electron, e, with an effective mass, interacting via a radially in proportionate arrangement dot (electron) and antidot (hole) exposed to external a uniform magnetic field, and assumed internal synthetically impact of solenoid as additional magnetic force emerged due to electron motion as it is known an AB flux field that possibly put its own impact simultaneously. Thus, SE can be taken as a reference (Ikhdair, S. M. 2008)

$$\left[\frac{1}{2\mu}\left(\vec{p}+\frac{e}{c}\vec{A}\right)^2+V_{conf}(s)\right]\psi(r,\varphi) = E\psi(s,\varphi) \quad (12)$$

Since, E is the ground energy state, first term of equation (12) is kinetic energy and V_{conf} is Mie potential interaction defined by

$$V(r)=V_0\left[\frac{1}{2}\left(\frac{r_0}{2}\right)^2-\frac{r_0}{r}\right] \quad (13)$$

Since r_0 is the central radius, and V_0 is the ground characteristics energy moreover, the vector potential $\vec{A}$ exhibited as a totality of two possible terms i.e.,$\vec{A}=\vec{A}_1+\vec{A}_1=\left(\frac{Br}{2}+\frac{\Phi_{AB}}{2\pi}\right)\phi$ having the azimuthal components.

Equation of 2D cylindrical the wave functions is given as:

$$\psi(r,\varphi)=\frac{1}{\sqrt{2\pi}}exp(im\varphi)g(r) \quad (14)$$

Where m =0,$\pm1,\pm2,\ldots$ such that m indicates the orbital orientation. Plugging equation (14) into equation (12) , one can obtain the equation that satisfying g(r)

$$\frac{d^2}{dr^2}+\frac{2}{r}\frac{d}{dr}+\frac{1}{r^2}(\epsilon^2r^2-\beta r-\gamma)R_{n,m}(r) \quad (15)$$

Defining parameters in equation (15)

$$\epsilon=\frac{2\mu V_0}{\hbar^2{r_0}^2}+\left(\frac{\mu\omega_c}{2\hbar}\right)^2 \quad (16a)$$

$$\beta=\frac{2\mu V_0}{\hbar^2}(E+V_0)-\frac{\mu\omega_c}{\hbar}(m+\alpha) \quad (16b)$$

$$\gamma=(m+\alpha)^2+a^2 \quad (16c)$$

Where $\alpha=\frac{\Phi_{AB}}{\Phi_0}$ with the flux quantum$\Phi_0=\frac{\hbar c}{e}$, $\omega_c=\frac{eB}{\mu c}$ is the resonance of electron that gyrates around applied magnetic fields and $a=k_Fr_0$ with $k_F=\sqrt{\frac{2\mu V_0}{\hbar^2}}$ is radius of Fermi sphere. The orbital quantum number **m** relates to the quantum number β in equation (16b)

From equation (15) it is obviously known, that $\tilde{\tau}=2,\tilde{\sigma}=\epsilon^2r^2-\beta r-\gamma$. we find $\pi(r)$ as is the $\sigma(r)$ coefficient of first order derivatives.

$$\pi(r)=\frac{-1}{2}\pm\begin{cases}i\epsilon r+\frac{1}{2}\sqrt{4\gamma+1}, for\wedge k_1=-\beta+\epsilon\sqrt{-1-4\gamma}\\ i\epsilon r-\frac{1}{2}\sqrt{4\gamma+1}, for\wedge k_2=-\beta-\epsilon\sqrt{-1-4\gamma}\end{cases} \quad (17)$$

and $\tau(r)$ mathematically justified as:

$$\tau(r)=\frac{-1}{2}\pm\begin{cases}1+i2\epsilon r+\sqrt{4\gamma+1}, for\wedge k_1=-\beta+\epsilon\sqrt{-1-4\gamma}\\ 1+2i\epsilon r+\sqrt{4\gamma+1}, for\wedge k_2=-\beta-\epsilon\sqrt{-1-4\gamma}\end{cases} \quad (18)$$

It provides fittest result if and only if $\tau'(r)<0$, so as one can apply:

$k_2=-\beta-\epsilon\sqrt{-1-4\gamma}$, $\pi_2=\frac{-1}{2}-i\epsilon r-\frac{1}{2}\sqrt{1+4\gamma}$ and $\tau(r)=1-2i\epsilon r+\sqrt{1+4\gamma}$ for having energy state and state functions we use equation (6) and (7)

$$E_{n,m+\alpha}=\hbar\omega_c\left(2n+1+\sqrt{(m+\alpha)^2+a^2}\right)+\frac{\hbar\omega_c}{2}(m+\alpha)-\frac{2\mu V_0^2r_0^2}{\hbar^2}\left(n+\frac{1}{2}+\sqrt{(m+\alpha)^2+a^2}\right)^{-2} \quad (19)$$

Assuming external magnetic field ($B = 0$) and AB flux intensity ($\alpha = 0$), one can acquire the following:

$$E_{n,m} = \frac{-2\mu V_0^2 r_0^2}{\hbar^2}\left(n + \frac{1}{2} + \sqrt{(m)^2 + a^2}\right)^{-2} \quad (20)$$

The 3D vibrational solutions for energy spectrum in the case of a character experienced by Mie potential is acquired by setting;($m = \ell + \frac{1}{2}$) Where ℓ is the rotational quantum number to obtained from reference (Ikhdair S.M, 2015)

$$E_{n,\ell} = \frac{-2\mu V_0^2 r_0^2}{\hbar^2}\left(n + \frac{1}{2} + \sqrt{\left(\ell + \frac{1}{2}\right)^2 + a^2}\right)^{-2} \quad (21)$$

Equation (21), as justified in reference (Berkdemir, 2006), has a similarity with Mie molecular potential. Indisputably, it requires a reliable change in the input variables, and thus the rotational energy eigenvalue for any atom, electron, or electron could be computed through NU formalism. In this paper, we computed the energy eigenvalue of specifically identified material parameters of GaAs quantum dot (antidot) confined in Mie potential with and without external fields in 2D and 3D confinement potentials.

Dependence of Temperature

From equation established by Varshni (Aspnes, 1976)provided experimental values for various semiconductors including Si, Ge, and GaAs, are expressed as:

$$E_g(T) = E_g(0) - \frac{\upsilon T^2}{T + \chi} \quad (22)$$

$E_g(T)$ is band gap in (eV) depends on the temperature that shows uniquely material-based properties. While the parametric value reveals the expansion of the lattice due to the effect of temperature in a similar pattern, the parametric value indicates the electron interaction within the lattice. On the other hand, effective mass and imbibing the radiant energy lower limit frequency with the different values of temperature as provided in reference (Ehrenreich, 1961), which is the relation.

$$\frac{\mu_e}{\mu(T)} = \frac{1}{f(T)} = 1 + E_p^{\Gamma}\left(\frac{2}{E_g(T)} + \frac{1}{E_g + \Delta_0}\right) \quad (23)$$

Whereμ_e electronic mass, $E_p^{\Gamma} = 7.51eV$ is the energy related to the momentum matrix element, $\Delta_0 = 0.341eV$ is the spin-orbit splitting and E_p^{Γ} is the temperature-dependence of the energy gap (in eV units) at the Γ point. Hence the temperature dependence energy spectrum formula can be expressed as.

$$E_{n,m}(B,T) = \frac{\hbar\omega_c}{f(T)}\left(2n + 1 + \sqrt{(m+\alpha)^2 + a^2 f(T)}\right) + \frac{\hbar\omega_c}{2f(T)}(m+\alpha) - \frac{f(T)a^2 V_0}{\left(n + \frac{1}{2} + \sqrt{(m+\alpha)^2 + a^2 f(T)}\right)^2} \quad (24)$$

The effective mass of material GaAs known as $\mu = 0.067m_e$. We compare on temperature dependence in without of magnetic and AB flux intensity in 2D and 3D from equation (20) and (21) can be written:

$$E_{n,m} = a^2 V_0 f(T)\left(n + \frac{1}{2} + \sqrt{m^2 + a^2 f(T)}\right)^{-2} \quad (25)$$

$$E_{n,l} = a^2 V_0 f(T)\left(n + \frac{1}{2} + \sqrt{\left(l + \frac{1}{2}\right)^2 + a^2 f(T)}\right)^{-2} \quad (26)$$

RESULT AND DISCUSSION

We computed SE for confined electrons in different potentials, like under the Mie potential interaction consisting of solving the Schrödinger equation for an electron, the Mie potential confined electron in quantum dot (antidot) dependence on the exposure of a uniform magnetic field, AB flux, and temperature. We obtained bound state solutions including influences of magnetic field and AB flux energy spectrum from formula (19) and bound state energy spectrum without external field in 2D equation (20) and 3D equation (21). Moreover, energy eigenvalue dependence on temperature is computed in equation (24). In the case of our study, we explored the dependence of the energy eigenvalues on external magnetic field intensity, temperature, and internal AB flux intensity. We used material parameters and chemical potential ($V_0 = 0.68549\text{meV}$), $r_0 = 8.958 \times 10^{-6}\text{cm}$. Thus, $a = \sqrt{\frac{2\mu V_0 r_0^2}{\hbar^2}} \approx 12$, $\hbar\omega = 1.05243\hbar\omega_c$ and $\omega_0 = 0.16403805\omega_c$ we obtained and taken from reference (Ikhdair, S.M.,2012). Furthermore, we revealed the dependence of the energy levels on temperature, taking into account previously determined experimental parameters of the material $E_p^{\Gamma} = 7.51\text{eV}$ Thus, momentum matrix element, $\Delta_0 = 0.341\text{eV}$ is the spin-orbit splitting $\chi = 204$, and electron interaction within the lattice, $\upsilon = 5.405 \times 10^{-4}$ is the expansion of the lattice due to temperature changes (Liboff, 2003). We deal on the value of effective mass decreases$f(T) = \mu(T)/\mu_e$ due to increment or decrement of temperature. As a kinetic energy of electron decrease consequently, lowered the bound state energy has to be occurred. As the effective mass dependence on temperature for GaAs pseudo dot is taken from reference (Elabsy, 2000).

Mie Potential of two electrons without external fields

As it depicted in Fig. 1-3, the antidote energy levels in the absence of external magnetic field in attention was given to the effect of repulsive radii 2D and 3D potential is plotted.

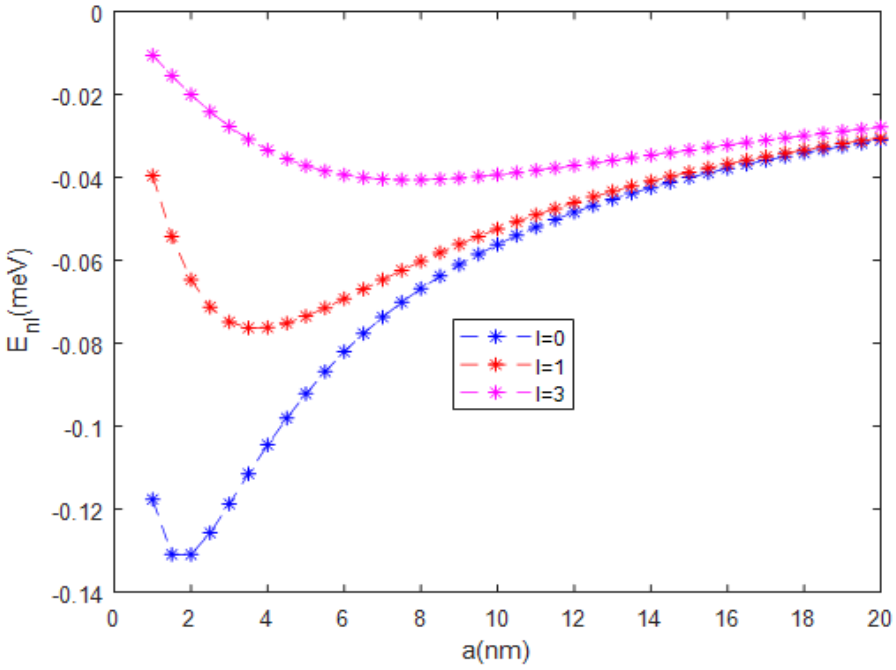

Figure 1, *Energy spectrum state 3D Mie potential GaAs as function the antidote repulsive radius for the various angular rotation momentum ($\ell = 0, \ell = 1, \ell = 3$)*

Fig.1 demonstrates a relative of energy spectrum versus antidot repulsive radii for various l state in 3D Mie potential ($(n = 0, \ell = 0, \ell = 1, \ell = 3)$ it shows bound state decreases and reaches its local minimum that shown as the tendency of attractive potential meanwhile begins to raise to its constant value in the same manner for ($\ell = 1$) more local minima where observed for ($\ell = 3$) the influence of rotational frequency create the higher bound state at very low repulsive radius then tend to decrease into its constant as repulsive radius increases.

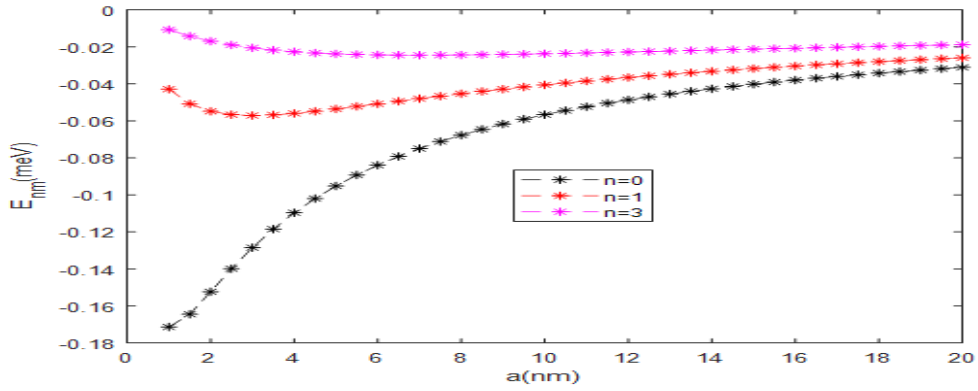

Figure 2, *the variation of bound energy spectrum function versus the antidote repulsive radius for in 2D Mie potential electron quantum (m=0).*

In Fig.2, the finite bound energy state versus the repulsive radius follows the same manner as in Fig.1 1. Here we are investigating the influence of variation frequency, that is, the bound energy is not the quickest to merge against the repulsive radius, as merely rotational frequency affects the energy bound state, which signifies there is more relaxation in variations than rotational frequency.

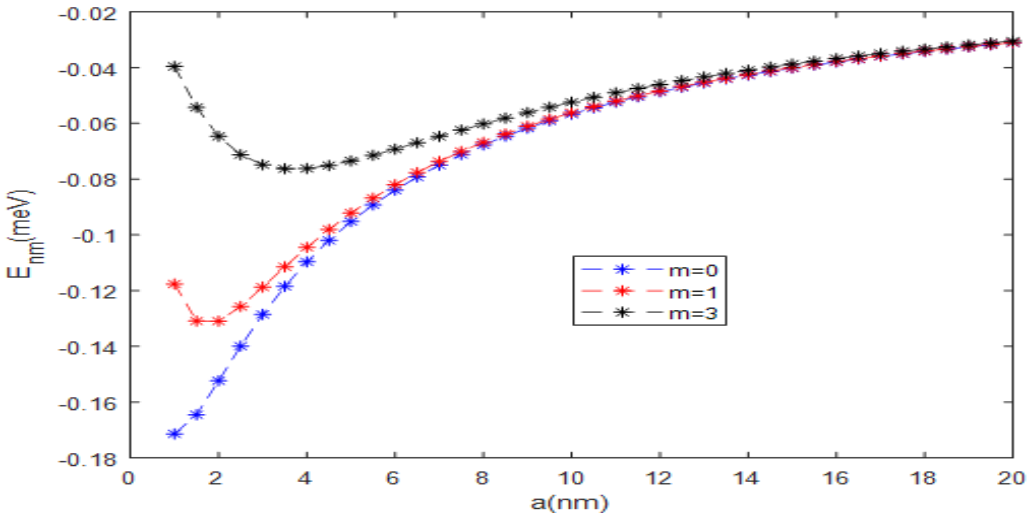

Figure 3, *Energy bound state as function of repulsive radius with various (m=0, m=1, m=3)*

In fig. 3 the ground energy bound state in 2D psuedodot as a function of anidot radius (a nm) with the various values of the azimuthal quantum state $(m = 0, m = 1, m = 3)$ the local minimum of energy bound state as repulsive potential increases the energy bound state merged to the same constant value due to its dominance over angular rotational frequency effects on the system.

Effects of external magnetic and AB flux intensity

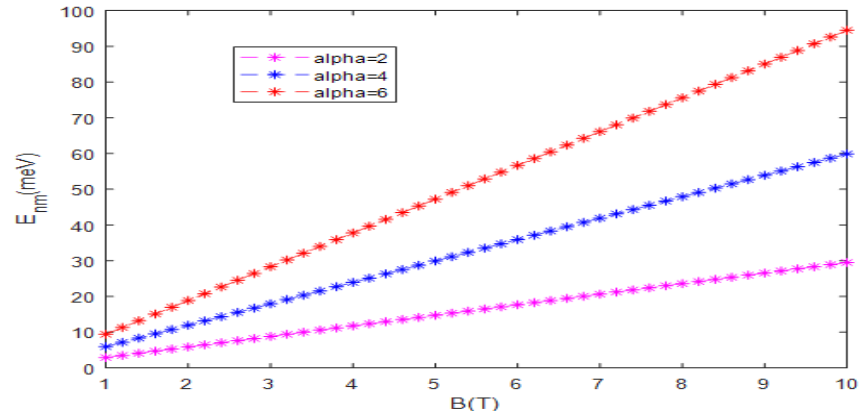

Figure 4 *Ground energy bound state* $(n = 0, m = 0)$ *versus magnetic field with various values of the AB flux intensity* $(\alpha = 2, \alpha = 4, \alpha = 6)$ *with the repulsive radius (a=12)*

As depicted in Fig.4 the bound energy spectrum versus to external magnetic field for different values of AB flux intensities in 2D Mie potential (α=2,α=4,α=6) it finite bound energy is directly proportional to the external magnetic field as well as AB flux intensity. Thus both parameters enhance rotational frequency that enhances energy bound state.

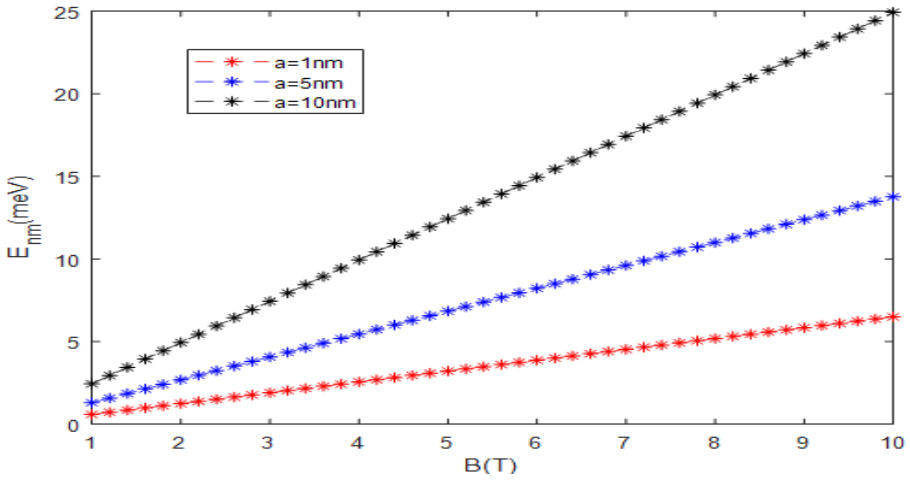

Figure 5 *Ground bound energy state versus the magnetic field (B in tesla) with various radii* $(a = 1, a = 5, a = 10\, n = 0, m = 0\, and\, \alpha = 2)$

As depicted in Fig. 5 electron-electron interactions put a great impact on the description of energy state as the magnetic field increases the bound state increases, in addition, repulsive radii in the antidot enhance the energy bound state, the higher repulsive radius possessed the energy bound state.

Magnetic field and dependence of Temperature

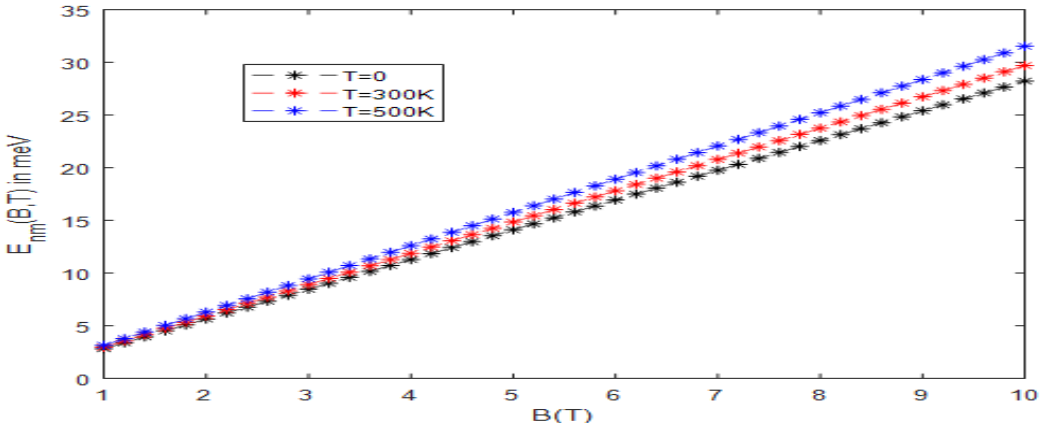

Figure 6 *variation of ground energy bound state (n=0,m=0) as function of magnetic field with various with various temperature.(T=0, T=300 ,T=500K).*

In Fig.6 energy bound state of GaAs quantum dot for repulsive radius (a=0) and AB flux intensity ($\alpha = 2$) as it rely on the external magnetic field revealed an increment in degeneracy, on other hand, one clearly can be observed at the low magnetic field, almost energy bound state likely tends to non-degenerate. The higher temperature possesses the upper phase of the bound state energy this phenomenon is due to the comprehensive dominance of the magnetic field and AB flux intensity that put their complimentary effect.

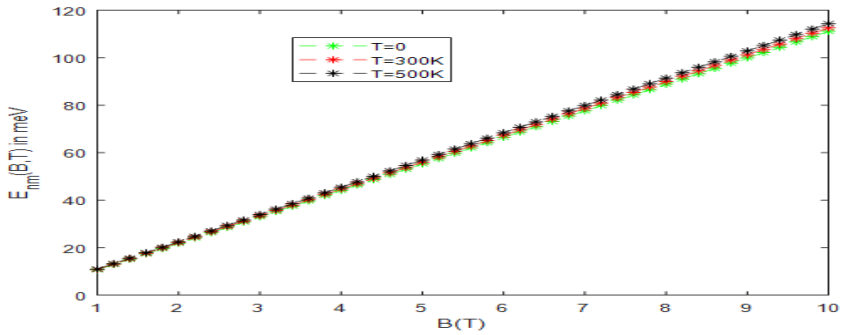

Figure 7 *Ground energy bound state (n=0, m=0) as function of magnetic field with various with various temperature (T=0, T=300, T =500K).*

It depicted in Fig. 7, the energy bound state of GaAs quantum antidot for repulsive radius (a=12) and AB flux intensity ($\alpha = 2$) it shows agreement with result in reference [26] that as the magnetic field increases the degeneracy of the state can be observed clearly while at the low magnetic field. Here the dominant magnetic field, AB fluxes intensity, and repulsive radius potential over-temperature notable physical phenomena.

For our comparison in the absence and presence of repulsive radius as depicted in figure 6 and figure 7 the energy bound state shown in Fig.7 is more enhanced due to the presence of repulsive radius potential over dominating temperature effect that is less degeneracy of the state is observed.

Dependence of energy eigenvalue on temperature at (B=0)

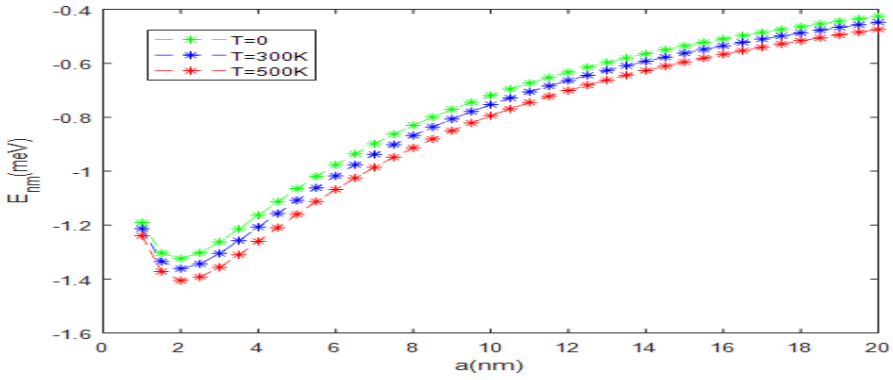

Figure 8 Ground state 2D pseudodot (in meV) versus the repulsive radius with various value of temperature (T=0, T=300K, T=500K).

As it depicted in figure 8 the minimum bound state value reached at radius value radius 2nm that signifies attractive phase for $a \leq 2nm$, and repulsive phase $a \geq 2nm$ until it reached its critical values depending on temperature values. The lower temperature possessed the upper bound energy value in contrary higher value of temperature agitate to lower bound state energy level.

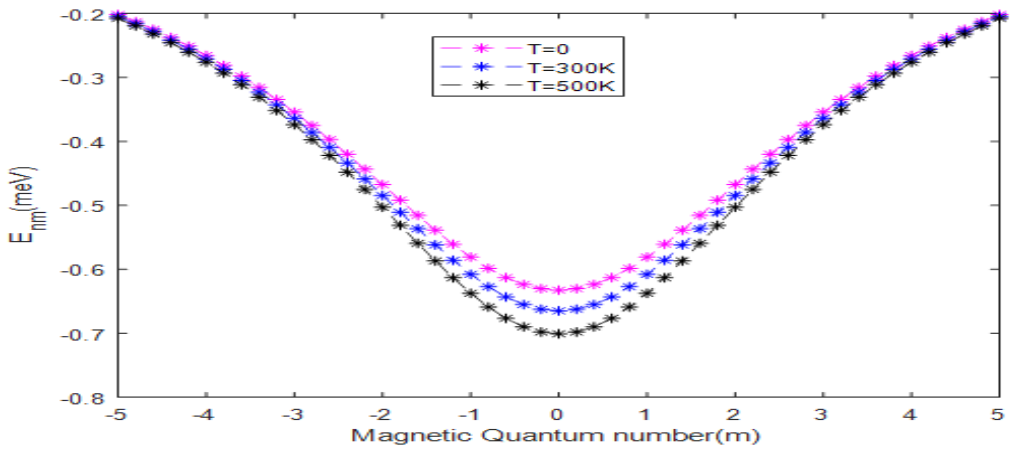

Figure 9 *Energy bound state 2D antidot (in meV) versus a magnetic quantum number with the various value of temperature (T=0, T=300K, T=500K).*

In Fig. 9, the energy levels as function m quantum numbers(m) with various temperature values (T=0, T=300K, T=500K) in case n=0 Fig. 9 shows the parabolic bound energy profile it's local minimum is found at (m=0) that indicate the ground bound state value. Thus in Fig 9, shows two different phases of the energy profile that are considered as attractively bound state phase for ($m \leq 0$), and repulsive potential profile for ($m \geq 0$). It also indicates the higher temperature possesses a lower bound energy level.

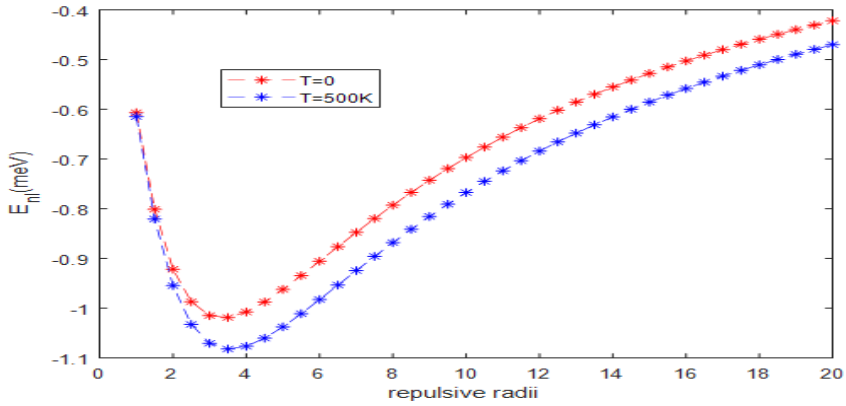

Figure 10 *Energy eigenvalue 3D antidot (in meV) as a function repulsive radius with various temperature (T=0, T=500K)*

As shown in Fig. 10, the local minimum is observed at a lower radius (a≤4nm). Thus, the attraction phase of the electron-electron comes to an end at local minimum potential values and repulsive potential, which begins to be notable as repulsive potential increases until it reaches a critical value at which it tends to keep constant bound state energy even though the repulsive radius continuously increases. As it is merely temperature-dependent, the higher temperature possesses the lower energy-bound state phase.

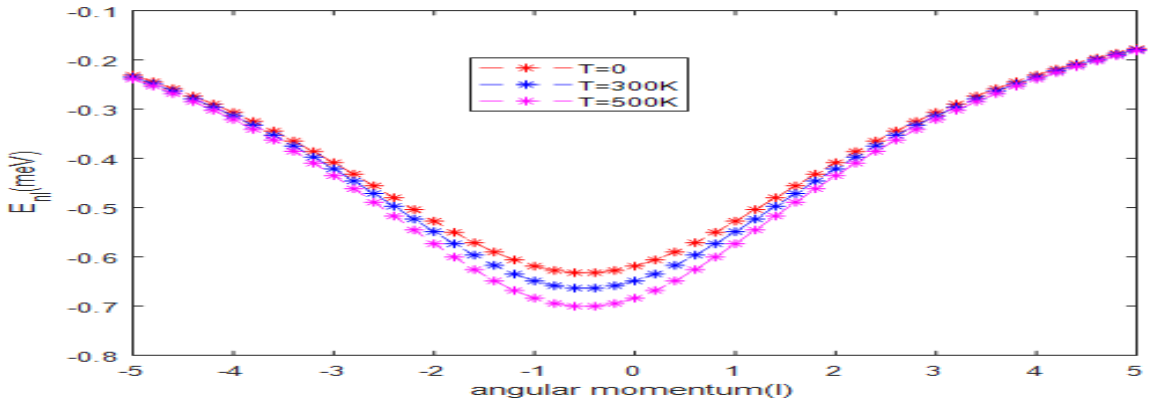

Figure 11 *Energy eigenvalue 3D antidot (in meV) versus angular quantum number with various value of temperature (T=0, T=300K, T=500K).*

In Fig. 11 the energy levels as function m quantum numbers(m) with various temperature values (T=0, T=300K, T=500K) in case n=0 Fig. 8 shows the parabolic bound energy profile it's local minimum is found at ($-1\geq\ell\leq 0$) that indicate the ground bound state value. Thus in Fig.11, it shows two different phases of energy profile that are considered as attractively bound state phase for ($\ell \leq 0$), and repulsive potential profile for ($\ell \geq 0$). It also indicates the higher temperature possesses the lower bound energy level with the same pattern in the figure. 9. But in case Fig. 11 is the quickest to reach its maximum constant value this is due to the dimensionality effect of the system.

CONCLUSIONS

In this study, we have simulated the energy-bound state for a quantum dot and a pseudo-dot confined in MIE potential, considering the material parameters of the GaAs semiconductor nanostructure. Furthermore, it enhances further in probing the physical properties of the nonrelativistic atom, molecules, electrons, and/or holes; thus, almost all physical quantities fundamentally rely on eigenvalues and the corresponding state of functions of a system. The temperature dependence of the energy levels is simulated with and without an external magnetic field and AB flux intensity. Our investigation shows agreement, as worked out by Bahar (2020), that the external magnetic field and AB flux interrelation giveaway have a high influence on the confinement potential of the system and credibly arranges the orientation of the system. These phenomena required more intensive attention to be

studied; furthermore, almost all physical, chemical, thermal, optical, and magnetic properties of materials were affected. We investigated that temperature dependence of bound energy level (Rajabi, 2013) without external magnetic fields and AB flux intensity did not affect the confinement potential structure.

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The authors report there are no conflicts of interest.

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Contribution of authors:

Drafting, designing, and writing the manuscript as well as computational simulations and discussion performed by Alemu.

Drawing theoretical concept, supervising and providing necessary correction in all steps of manuscript preparation conducted by Menberu and Senbeto

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