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# Velocity-dependent potential effects on two interacting electrons in Cornell quantum dot planted in plasma medium

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## Abstract

In this study, the energy levels of two-electron Cornell quantum dot (TECQD) immersed in Debye and quantum plasma mediums are probed. To model plasma mediums, the more general exponential cosine screened Coulomb (MGECSC) is suggested. The presence of TECQD in plasma environment and velocity-dependent potential (VDP) effect in the system render very difficult to solve the relevant wave equation. Since the analytical solution of the relevant wave equation is very difficult, the numerical asymptotic iteration method (AIM) is used. As well as the effects of the encompassing parameters on the energy levels and possible radiations of TECQD, the effects of VDP and quantum (and Debye) plasma medium are also presented in detail. In addition, the alternativeness of VDP, quantum (and Debye) plasma and encompassing parameters to each other on these effects are also discussed.

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## 1. Introduction

Quantum dots are systems that are very popular and studied intensively due to their wide range of uses in technology. Studies on quantum dots consist of two basic points: experimental production and the control of the frequency of the light emitted afterwards. Plasma medium provides great advantages in experimental production, and it is also an effective experimental argument for modification of the quantum dot. External fields such as electric, magnetic and laser fields provide a highly functional control mechanism for the radiations produced by the quantum dot. Considering the complicated structure of the plasma medium and the complex correlations of the plasma particles, it is clear that the velocity-dependent potential (VDP) effects will also have important effects. The restricting effects of electrons in the quantum dot are very important for the electronic, optical and statistical properties displayed by the quantum dot. The encompassing effects affect directly the possible radiation frequencies of the quantum dot. These frequencies can be finely tuned by changing the size, shape, encompassing effects, and material of the quantum dot. Quantum dots can be generated using many methods. With the development of nanofabrication technology, it has been possible to manufacture quantum dots containing one, two or more electrons, and such structures have been extensively studied theoretically and experimentally [1]. However, the use of plasma for production processes of quantum dots is also an important experimental argument. The size, shape and surface composition of quantum dots can be controlled in a non-thermal plasma medium [2,3]. Quantum dots that contain two electrons are the simplest structures to study the electron-electron interactions involving exchange and correlation [4]. Due to the fact that plasma screening effects have very important effects on atomic systems immersed in the plasma medium, remarkable studies have been carried out in recent years on the examination of atomic systems in plasma mediums [5-10]. Atomic excitation and ionization processes play an important role in the interpretation of various phenomena associated with hot plasma physics, astrophysics, and experiments with positively charged ions. Excitation processes have attracted great attention in the history of plasma, as the emission line formed by excitation provides detailed information about the physical processes of the plasma. In this manner, the results obtained in these studies contain accurate atomic data ready to use in the literature for atomic systems in various plasma medium, and these data are of great importance for the technological applications that have been and will be made in the future.

VDPs were first considered to study the scattering of mesons off the complex nucleus [11]. These potentials

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can be used in the field of nuclear and atomic physics, such as nucleon-nucleon interactions and scattering of electrons off atoms [12-14]. Soylu et al. [15], using AIM, the effect of VDPs on the energy eigenvalues of Morse potential; Bayrak et al. [16], using AIM, the VDP effect on energy eigenvalues of Coulomb and harmonic oscillator potentials; Jaghoub [17], Schrödinger equation with the VDP in consideration of scattering cases in the framework of perturbative theory; Eed [18], using a variation iteration method, Schrödinger equation with the VDP for scattering states has investigated. Bahar [19] has examined the VDP effect on the energies of the hydrogen atom in Debye and quantum plasma, modeled by the MGECSC potential, using AIM. The Schrödinger equation involving the velocity-dependent interaction can be rearranged into a form that describes a particle with position dependent effective mass. The Schrödinger equation with position-dependent mass has been an important model in defining the dynamics of electrons in semiconductor heterostructures such as quantum dots [20], liquid crystals [21] and graded crystals [22]. It is noteworthy that some external effects (for example, perturbative effects) that are not included in the model potential on two electrons interacting in the plasma medium can be included in the study by modeling with a VDP, in short, to examine the VDP effect.

Most of the plasmas found in nature such as solar chromosphere, ionosphere and laboratory produced plasmas such as fusion reactor, methane gas pulse discharge ($10^6$-$10^{14}$ $cm^{-3}$ electron density and $10^{-1}$-$10^4$ eV temperature) are weakly coupled (classical or Debye) plasmas. The Debye model and the related screened Coulomb (SC) potential is a suitable model for studying the interactions of atomic systems embedded in such classical plasmas. As the plasma density increases, it is more convenient to use exponential cosine screened Coulomb (ECSC) and MGECSC potentials to model interactions [23,24]. In the literature, except for the studies by Bahar and/or Soylu, the potentials used to model interactions in plasmas are SC and ECSC potentials. The potential model used in this study is the MGECSC potential which is given by

$$V_{MGECSC}(r) = \frac{e^2}{r}(1+br)\exp(-r/\lambda)\cos(ar/\lambda), \quad (1)$$

where, e is the electron charge; a, b and λ are the plasma screening parameters. Thanks to these parameters in the structure of MGECSC potential, it can be reduced to SC, ECSC and pure Coulomb (PC) (only Coulomb) potentials, so it has a more compact structure. Also, the MGECSC potential is more physical and advantageous for modeling Debye and quantum plasma environments [25].

Due to the fact that plasma mediums modeled by MGECSC potential has both the experimental advantage and the ability to create a new encompassing mechanism, the two-electron interaction is an important basic model, and the VDP effects model some factors that are in the plasma medium but not modeled by the MGECSC potential, and affect two-electron interaction, and the confinement characteristic of the Cornell quantum dot is the main motivation for the present study. In this context, the effect of plasma, VDP and encompassing on energy levels of TECQD will be examined in detail.

The study is organized as follows: In the Section 2, the theoretical model and method are presented. In Section 3, the results obtained are discussed. The last paragraph is devoted to the conclusions.

## 2. Theoretical Model and Computation Method

The velocity-dependent total potential as a superposition of the local potential ($V_{eff}(r)$) and the isotropic velocity-dependent local potential ($V(r,p)$) is given by [26-30]:

$$V_{total}(r,p) = V_{eff}(r) + \frac{\hbar^2}{2\mu}(F(r).\nabla^2 + \nabla F(r).\nabla), \quad (2)$$

where F (r) is the isotropic form factor function of the radial variable r. On the other hand, Hamiltonian for two-electron interacting in plasma medium is expressed as $H=H_{cm}+H_{rm}$, where $H_{cm}$ associates with the motion of the center-of-mass and $H_{rm}$ is for the relative motion, and they are written by:

$$H_{cm} = \frac{1}{2M}\boldsymbol{P}^2 + V_{dot}(\boldsymbol{R}), \quad (3)$$

$$H_{rm} = \frac{1}{2\mu}\boldsymbol{p}^2 + V_{dot}(r) + V_{MGECSC}(|\boldsymbol{r}|), \quad (4)$$

where, while ($R$, $P$) is center-of-mass coordinates; ( $r$, $p$) is the relative coordinates. $H_{cm}$ does not contain plasma effects and therefore it is easy to find eigenvalues within the VDP effect. However, since our purpose is to investigate the VDP effects in the plasma environment, we focus on finding the eigenvalues of $H_{rm}$ with VDP. Being the total wave function of two-electron system is $\Psi(r,R) = \varphi(r)\theta(R)$, its energy is $E = E_{cm} + E_{rm}$, the Schrödinger equation is $H\Psi(r,R) = E\Psi(r,R)$. The wave equation to be solved is $H_{rm}\varphi(r) = E_{rm}\,\varphi(r)$. In this case, within the VDP, the wave equation becomes:

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V_{total}(r,p) - E_{rm}\right]\varphi(\boldsymbol{r}) = 0, \quad (5)$$

where, by employing $\varphi(\boldsymbol{r}) = r^{-1}u(r)$, and then considering $F(r) = \gamma\rho(r)$ (γ is a constant), the following equation is obtained in units of 2μ=ħ=1:

$$u''(r) - \left[u'(r) - \frac{u(r)}{r}\right]\frac{\gamma\rho'(r)}{1-\gamma\rho(r)} + \frac{E_{rm}-V_{eff}(r)}{1-\gamma\rho(r)}u(r) = 0\,, \quad (6)$$

where, $V_{eff}(r)$ is the effective potential, and it is given by

$$V_{eff}(r) = \frac{l(l+1)}{r^2} + V_{dot}(r) + V_{MGECSC}(r) \quad (7)$$

The quantum dot confinement is chosen as parabolic-linear-Coulomb (that is, Cornell) as follows:

$$V_{dot}(r) = a_1 r^2 + b_1 r - \frac{c_1}{r}, \quad (8)$$

where, $a_1$ , $b_1$ and $c_1$ are the quantum dot parameters. $\gamma = 1$ is taken throughout the VDP investigations. The isotropic form factor, in other words, the VDP term is chosen in the harmonic oscillator type, as $\rho(r) = \rho_0 r^2$. $\rho_0$ is a constant, and determines the strength of the isotropic dependence of the VDP. The following physical transformation is proposed by examining the asymptotic behaviors of Eq.(6):

$$u(r) = r^{\iota+1}e^{-\beta_1 r - \beta_2 r^2} f(r), \quad (9)$$

where, $\beta_{1,2}$ are important constants that affect the stabilization and speed of solution iterations as mentioned before. Details on the use of asymptotic iteration method (AIM) are detailed below.

Analytically solving the Schrödinger equation for Hamiltonians given in Section 3 is currently not possible. Therefore, numerical computation will be carried out by considering AIM [31-33]. This method was developed the secod-order differential equations in the following form:

$$p_n''(r) = \lambda_0(r)p_n'(r) + s_0(r)p_n(r). \quad (10)$$

$s_0(r)$ and $\lambda_0(r)$ are differentiable functions, as well as $\lambda_0(r) \neq 0$. $s_0(r)$ and $\lambda_0(r)$ are defined in $C_\infty[a,b]$. At sufficiently large values of k, it is

$$(s_k/\lambda_k) = (s_{k-1}/\lambda_{k-1}) = \alpha(r) \quad (11)$$

and, for $\lambda_k$ and $s_k$, it is obtained

$$\lambda_k = \lambda_{k-1}' + s_{k-1} + \lambda_0\lambda_{k-1}, \qquad s_k = s_{k-1}' + s_{k-1} + s_0\lambda_{k-1}, \qquad k = 1,2,3,\ldots,n \quad (12)$$

The relevant wave equation for the system to be examined is converted to Eq.(10) form. Then $s_0(r)$ and $\lambda_0(r)$ are determinated, $s_k(r)$ and $\lambda_k(r)$ expressions are obtained using Eq.(12). Eigenvalues are calculated using the quantization condition in Eq.(11). In this case, the quantization condition of the model is determined as follows:

$$\delta_k = \lambda_k s_{k-1} - \lambda_{k-1}s_k = 0, \quad (13)$$

where, k is iteration number, and in form of k=1,2,3,… An appropriate $r_0$ point should be chosen for the fundamental quantum number considered in eigenvalue equation calculations that require numerical solutions. This point can be obtained from the maximum value of the proposed wave function to obtain the form Eq.(10), which is essential for the speed and convergence of these iterations. In other words, the solution should be sought where the probability of the wave function of the relevant particle is greatest. The success of AIM in examining such quantum dot-external (or internal) field-plasma combined systems is undeniable [34-36].

## 3. Results and Discussion

In this study, the effects of the VDP on the energies of the two-electron Cornell quantum dot are investigated. There are seven parameters on the energies of the TECQD as plasma shielding parameters (a, b, λ); quantum dot confinement parameters ($a_1, b_1, c_1$), and the intensity of the isotropic dependence of the VDP (in other words, the form factor) ($\rho_0$). Throughout the study, different values of λ parameter from 10 to 1000, b parameter from 0.1 to 7, and a parameter from 0.1 to 7 are taken into consideration. As can be seen from Table 1, λ parameter causes the energies to increase monotonously, while the a parameter causes them to decrease monotonously. On the other hand, b parameter causes a significant increase in energies.

**Table 1:**Under the influence of the VDP ($\rho_0$=0.2-2), the energies of some quantum states of TECQD ($a_1$=0.1-2, $b_1$=0.1-2, $c_1$=0.1-2) immersed in the quantum plasma modeled by the MGECSC potential (a = 0.1-7, b = 0.1-7, l = 10-1000), in atomic units.

| $a_1=b_1=c_1=1,a=1,b=1,\rho_0=0.5$ | | | | | | |
|---|---|---|---|---|---|---|
| (n,l) | λ=10 | λ=50 | λ=150 | λ=250 | λ=500 | λ=1000 |
| (0,0) | 2.931564 | 3.088418 | 3.114647 | 3.119893 | 3.123828 | 3.125795 |
| (1,0) | 7.816014 | 7.927719 | 7.998968 | 8.004219 | 8.008157 | 8.010127 |
| (2,0) | 16.749875 | 16.903294 | 16.928980 | 16.934118 | 6.937972 | 16.939899 |
| (0,1) | 5.334427 | 5.504695 | 5.533211 | 5.538916 | 5.543194 | 5.545333 |
| (1,1) | 11.936109 | 12.096445 | 12.123292 | 12.128663 | 12.132691 | 12.134705 |
| (2,1) | 22.827264 | 22.983708 | 23.009899 | 23.015138 | 23.019067 | 23.021032 |
| (0,2) | 8.541594 | 8.718016 | 8.747583 | 8.753498 | 8.757934 | 8.760153 |
| (1,2) | 17.075597 | 17.240152 | 17.267709 | 17.273222 | 17.277356 | 17.279423 |
| (2,2) | 29.921006 | 30.080717 | 30.107456 | 30.112805 | 30.116817 | 30.118823 |
| $\lambda=300,a_1=b_1=c_1=1,a=1,\rho_0=0.5$ | | | | | | |
| (n,l) | b=0.1 | b=0.5 | b=1 | b=3 | b=5 | b=7 |
| (0,0) | 2.224106 | 2.622817 | 3.121205 | 5.114756 | 7.108305 | 9.101853 |
| (1,0) | 7.108439 | 7.507147 | 8.005532 | 9.999070 | 11.992609 | 13.986149 |
| (2,0) | 16.038184 | 16.436948 | 16.935403 | 18.929224 | 20.923044 | 22.916865 |
| (0,1) | 4.643759 | 5.042240 | 5.540342 | 7.532747 | 9.525152 | 11.517556 |
| (1,1) | 11.233048 | 11.631696 | 12.130005 | 14.123245 | 16.116485 | 18.109725 |
| (2,1) | 22.119342 | 22.518056 | 23.016448 | 25.010016 | 27.003584 | 28.997153 |
| (0,2) | 7.858631 | 8.257007 | 8.754977 | 10.746856 | 12.738734 | 14.730612 |
| (1,2) | 16.377801 | 16.776378 | 17.274600 | 19.267485 | 21.260370 | 23.253255 |
| (2,2) | 29.217603 | 29.615819 | 30.114142 | 32.107436 | 34.100730 | 36.094024 |
| $\lambda=300,a_1=b_1=c_1=1,b=1,\rho_0=0.5$ | | | | | | |
| (n,l) | a=0.1 | a=0.5 | a=1 | a=3 | a=5 | a=7 |
| (0,0) | 3.121216 | 3.121213 | 3.121205 | 3.121117 | 3.120940 | 3.120676 |
| (1,0) | 8.005543 | 8.005540 | 8.005532 | 8.005440 | 8.005256 | 8.004980 |
| (2,0) | 16.935414 | 16.935411 | 16.935403 | 16.935316 | 16.935142 | 16.934881 |
| (0,1) | 5.540355 | 5.540352 | 5.540342 | 5.540232 | 5.540012 | 5.539682 |
| (1,1) | 12.130017 | 12.130014 | 12.130005 | 12.129910 | 12.129720 | 12.129434 |
| (2,1) | 23.016459 | 23.016456 | 23.016448 | 23.016358 | 23.016178 | 23.015908 |
| (0,2) | 8.754992 | 8.754988 | 8.754977 | 8.754856 | 8.754614 | 8.754252 |
| (1,2) | 17.274612 | 17.274609 | 17.274600 | 17.274499 | 17.274294 | 17.273994 |
| (2,2) | 30.114154 | 30.114151 | 30.114142 | 30.114048 | 30.113860 | 30.113578 |
| $\lambda=300,a_1=b_1=c_1=1,a=1,b=1$ | | | | | | |
| (n,l) | $\rho_0$=0.2 | $\rho_0$=0.3 | $\rho_0$=0.5 | $\rho_0$=1 | $\rho_0$=1.5 | $\rho_0$=2 |
| (0,0) | 4.283639 | 3.836447 | 3.121205 | 2.323289 | 1.999651 | 1.821674 |
| (1,0) | 7.547317 | 7.141334 | 8.005532 | 17.170975 | 16.874575 | 21.716203 |
| (2,0) | 10.832108 | 12.337350 | 16.935403 | 30.146865 | 43.858615 | 57.703652 |
| (0,1) | 6.365500 | 5.833800 | 5.540342 | 6.532451 | 8.147853 | 9.939589 |
| (1,1) | 9.248909 | 9.625825 | 12.130005 | 20.266625 | 28.949201 | 37.778209 |
| (2,1) | 13.280956 | 16.028588 | 23.016448 | 42.201187 | 61.900465 | 81.738399 |
| (0,2) | 8.357383 | 8.047013 | 8.754977 | 12.641884 | 17.225630 | 22.001442 |
| (1,2) | 11.384459 | 12.799661 | 17.274600 | 30.356719 | 44.016430 | 57.832941 |
| (2,2) | 16.220 | 20.359728 | 30.114142 | 56.261547 | 82.945828 | 109.775512 |
| $\lambda=300,b_1=c_1=1,a=1,b=1,\rho_0=0.5$ | | | | | | |
| (n,l) | $a_1$=0.1 | $a_1$=0.5 | $a_1$=0.75 | $a_1$=1 | $a_1$=1.5 | $a_1$=2 |
| (0,0) | 2.152254 | 2.594734 | 2.861671 | 3.121205 | 3.618290 | 4.086863 |
| (1,0) | 7.032230 | 7.458709 | 7.730214 | 8.005532 | 8.567339 | 9.143173 |
| (2,0) | 16.009750 | 16.419311 | 16.676779 | 16.935403 | 17.456152 | 17.981634 |
| (0,1) | 4.305607 | 4.860285 | 5.202204 | 5.540342 | 6.204880 | 6.853170 |
| (1,1) | 11.113172 | 11.563297 | 11.846048 | 12.130005 | 12.701893 | 13.279607 |
| (2,1) | 22.059060 | 22.483605 | 22.749722 | 23.016448 | 23.551753 | 24.089858 |
| (0,2) | 7.381410 | 7.995012 | 8.375996 | 8.754977 | 9.506713 | 10.249775 |
| (1,2) | 16.183036 | 16.667980 | 16.971210 | 17.274600 | 17.882042 | 18.490673 |
| (2,2) | 29.109256 | 29.555450 | 29.934661 | 30.114142 | 30.673943 | 31.234908 |

| λ=300,$a_1$=$c_1$=1,a=1,b=1, $\rho_0$=0.5 | | | | | | |
|---|---|---|---|---|---|---|
| (n,l) | $b_1$=0.1 | $b_1$=0.5 | $b_1$=0.75 | $b_1$=1 | $b_1$=1.5 | $b_1$=2 |
| (0,0) | 2.236842 | 2.633289 | 2.878317 | 3.121205 | 3.600489 | 4.071045 |
| (1,0) | 7.139139 | 7.522755 | 7.763682 | 8.005532 | 8.492060 | 8.982429 |
| (2,0) | 16.103396 | 16.472623 | 16.703839 | 16.935403 | 17.399577 | 17.865156 |
| (0,1) | 4.509396 | 4.969034 | 5.255120 | 5.540342 | 6.108131 | 6.672276 |
| (1,1) | 11.218208 | 11.623253 | 11.876562 | 12.130005 | 12.637348 | 13.145386 |
| (2,1) | 22.148896 | 22.534293 | 22.775313 | 23.016448 | 23.499069 | 23.982174 |
| (0,2) | 7.656047 | 8.145092 | 8.450234 | 8.754977 | 9.363239 | 9.969827 |
| (1,2) | 16.313696 | 16.740861 | 17.007759 | 17.274600 | 17.808126 | 18.341476 |
| (2,2) | 29.209936 | 29.611222 | 29.862673 | 30.114142 | 30.617141 | 31.120229 |
| λ=300,$a_1$=$b_1$=1,a=1,b=1, $\rho_0$=0.5 | | | | | | |
| (n,l) | $c_1$=0.1 | $c_1$=0.5 | $c_1$=0.75 | $c_1$=1 | $c_1$=1.5 | $c_1$=2 |
| (0,0) | 4.168043 | 3.712976 | 3.420554 | 3.121205 | 2.498743 | 1.838832 |
| (1,0) | 9.264837 | 8.709131 | 8.358519 | 8.005532 | 7.293198 | 6.574156 |
| (2,0) | 18.390545 | 17.747343 | 17.342443 | 16.935403 | 16.115296 | 15.287957 |
| (0,1) | 6.365889 | 6.000598 | 5.770994 | 5.540342 | 5.075711 | 4.606314 |
| (1,1) | 13.145904 | 12.695701 | 12.413263 | 12.130005 | 11.561024 | 10.988759 |
| (2,1) | 24.169570 | 23.658221 | 23.337693 | 23.016448 | 22.371808 | 21.724319 |
| (0,2) | 9.510186 | 9.175027 | 8.965158 | 8.754977 | 8.333652 | 7.910993 |
| (1,2) | 18.184099 | 17.780463 | 17.527715 | 17.274600 | 16.767253 | 16.258403 |
| (2,2) | 31.135729 | 30.682242 | 30.398365 | 30.114142 | 29.544654 | 28.973769 |

As can be seen from Table 1, the increase of $a_1$ parameter increases the repulsion of the total interaction potential and causes an enhancement in the localizations of energy levels. The $b_1$ parameter also increases the repulsion of the total interaction potential and causes the localizations to enhance. The $c_1$ parameter exhibits the opposite behavior, increasing the attractiveness of the total interaction potential, causing a descend in localizations. However, according to the data of Table 1, the encompassing parameters do not have a significant effect on energy gaps. For quantum plasma environment in Table 1, the intensity of the isotropic dependence of the VDP, in other words, the intensity of the harmonic form factor ($\rho_0$) descends the localization of the (0,0) state and enhances the localizations of other statements. Therefore, it can be said that the inclusion of harmonic isotropic dependence in the system interaction causes an asymmetric situation in the total interaction potential. However, the increase of $\rho_0$ has a significant effect on energy gaps. According to the data of Table 1; $\Delta E=E_{10}-E_{00}$=3.304887 a.u. for $\rho_0$=0.3, ΔE=9.847686 a.u. for $\rho_0$=1, ΔE=19.894529 a.u. for ve $\rho_0$=2. As can be seen, the increment in the VDP effect causes to increase in the energy gaps of TECQD. Also, the most dominant influence on energy levels and energy gaps belongs to $\rho_0$ parameter (See Table 1).

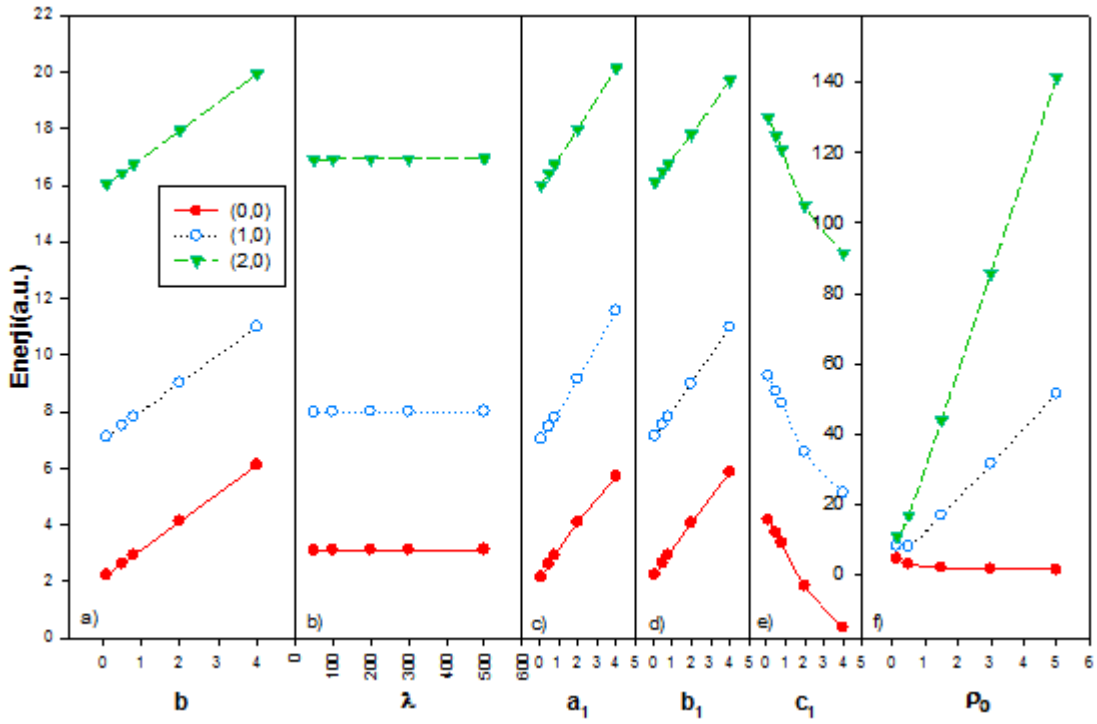


**Figure 1:** a) Under the influence of VDP ($\rho_0$=0.5), the energies of some quantum states of TECQD ($a_1$=$b_1$=$c_1$=1) in the quantum plasma modeled by the MGECSC potential (a=1, b=0.1-4, λ=500), in atomic units, b) Under the influence of VDP ($\rho_0$=0.5), the energies of some quantum states of TECQD ($a_1$=$b_1$=$c_1$=1) in the quantum plasma modeled by the MGECSC potential (a=1, b=1, λ=50-500), in atomic units, c) Under the influence of VDP ($\rho_0$=0.5), the energies of some quantum states of TECQD ($a_1$=0.1-4,$b_1$=$c_1$=1) in the quantum plasma modeled by the MGECSC potential (a=1, b=1, λ=500), in atomic units, d) Under the influence of VDP ($\rho_0$=0.5), the energies of some quantum states of TECQD ($a_1$=1,$b_1$=0.1-4,$c_1$=1) in the quantum plasma modeled by the MGECSC potential (a=1, b=1, λ=500), in atomic units, e) Under the influence of VDP ($\rho_0$=0.5), the energies of some quantum states of TECQD ($a_1$=1,$b_1$=1,$c_1$=0.1-4) in the quantum plasma modeled by the MGECSC potential (a=1, b=1, λ=500), in atomic units, f) Under the influence of VDP ($\rho_0$=0.15-5), the energies of some quantum states of TECQD ($a_1$=1,$b_1$=1,$c_1$=0.1) in the quantum plasma modeled by the MGECSC potential (a=1, b=1, λ=500), in atomic units.

Figure 1 shows the similarities of the parameters on the energies of TECQD in the quantum plasma environment described by MGECSC potential. As can be seen, b, $a_1$ and $b_1$ parameters can be alternatives to each other in this context since they behave similarly on energies. The parameter λ can be an alternative to the parameters b, $a_1$, $b_1$, with a monotonous effect. However, the main point here is that this alternativeness can be achieved through the temperature of the plasma environment and particle density. $\rho_0$ parameter behaves similarly to other parameters except the ground case. a parameter is not included in Figure 1 because it has a monotonous effect. However, as seen in Figure 1, a parameter can be an alternative to the dominant effect of $c_1$ parameter in reducing energies.

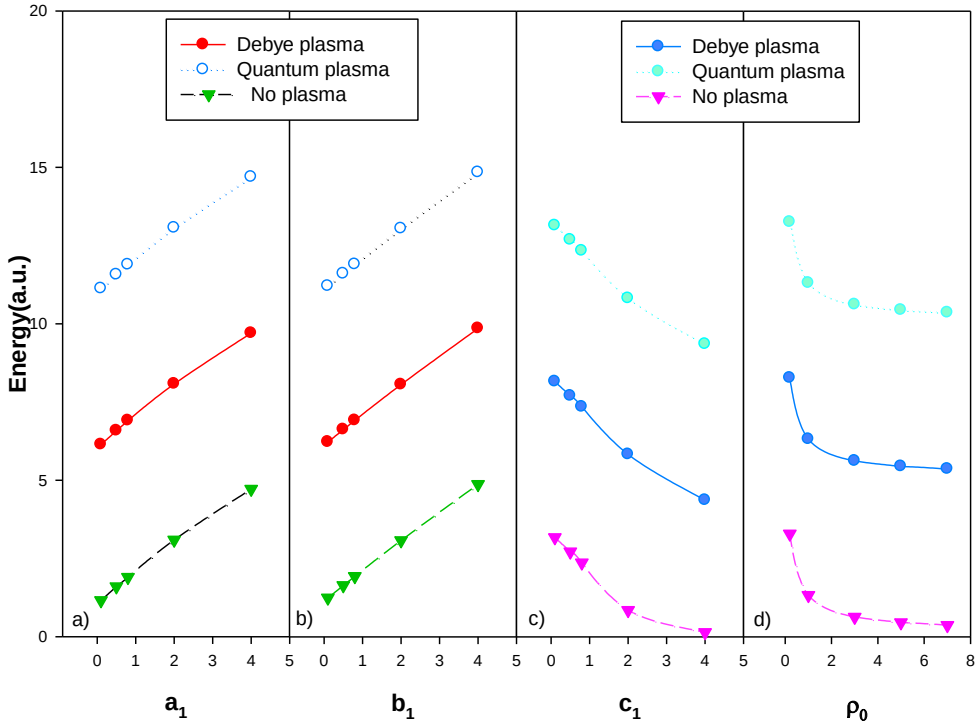


**Figure 2:** Comparison of the ground state energies, in atomic units, of a) TECQD ($a_1$=0.1-4, $b_1$=1, $c_1$=1) immersed in Debye plasma environment (a=0, b=5, λ=350), quantum plasma environment (a=1, b=10, λ=350), and free-plasma environment, when $\rho_0$ =0.5, b) TECQD ($a_1$=1, $b_1$=0.1-4, $c_1$=1) immersed in Debye plasma environment (a=0, b=5, λ=350), quantum plasma environment (a=1, b=10, λ=350), and free-plasma environment, when $\rho_0$ =0.5, c) TECQD ($a_1$=1, $b_1$=1, $c_1$=0.1-4) immersed in Debye plasma environment (a=0, b=5, λ=350), quantum plasma environment (a=1, b=10, λ=350), and free-plasma environment, when $\rho_0$ =0.5, d) TECQD ($a_1$=1, $b_1$=1, $c_1$=1) immersed in Debye plasma environment (a=0, b=5, λ=350), quantum plasma environment (a=1, b=10, λ=350), and free-plasma environment, when $\rho_0$ =0.2-7.

In Figure 2, the effect of Debye plasma environment modeled by the potential with a = 0, b = 5, λ = 350 parameter set, quantum plasma environment modeled by the MGECSC potential with a = 1, b = 10, λ = 350 parameter set and a plasma-free environment on TECQD is shown. As can be seen, energy levels are the highest due to the strong shielding effect of the quantum plasma environment. In addition, the energies in the Debye plasma environment are higher than in the free-plasma environment. The main point here is that the localizations of energy levels can be adjusted by means of plasma screening parameters.

The important findings regarding the effects of the VDP on the energies of TECQD in the Debye and quantum plasma environment can be summarized as follows: **i)** b and λ plasma shielding parameters increase the energies while the a parameter decreases. The most dominant plasma shielding parameter on energies is b. All three parameters do not have a significant effect on energy gaps. **ii)** Cornell quantum dot parameters, as $a_1$ and $b_1$, exhibit a similar effect by increasing energies, while $c_1$ decreases the energies. Quantum dot parameters also do not have a significant effect on energy gaps. **iii)** The intensity ($\rho_0$ ) of the isotropic dependence of VDP (in other words, the form factor) decreases the ground state energies while increasing the other state energies. Therefore, the inclusion of VDP into the system causes an asymmetry in the total interaction potential. $\rho_0$ parameter is the most effective parameter on the system, and the increase of $\rho_0$ increases both the energies and energy gaps of the quantum dot. **iv)** The plasma environment provides an important control possibility for the localization of energy levels.

In this study, the VDP effect on the energies of TECQD in the plasma medium has been investigated. Various methods such as the use of plasma in parallel with the development of nanofabrication technology make possible to produce such quantum dots. Increasing the intensity of the harmonic form factor reduces the localization of the ground state in Cornell quantum dot the while enhancing the localization of other states. So, it can be said that VDP transforms an asymmetric case the total interaction potential.

However, in the Cornell quantum dot, it has been determined for $\rho_0$ that it has an increasing effect on the frequencies of possible radiations. It is also an important result that frequency control in the Cornell quantum dot can only be done through $\rho_0$ . In the light of all these findings, it is clear that uncovering the function of quantum dot parameters will play a very important role for experimental designs.

## Conflicts of interest

The authors state that did not have conflict of interests.

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