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EFFECT OF HYDROSTATIC PRESSURE ON DIAMAGNETIC SUSCEPTIBILITY OF A HYDROGENIC DONOR IMPURITY IN CORE/SHELL/SHELL SPHERICAL QUANTUM DOT WITH KRATZER CONFINING POTENTIAL

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Effect of hydrostatic pressure on diamagnetic susceptibility of on-center hydrogenic donor impurity in a $Ga_{1-x_1}Al_{x_1}As/GaAs/Ga_{1-x_2}Al_{x_2}As$ core/shell/shell structure with Kratzer confining potential have been theoretically investigated in the framework of the effective mass approximation. The diamagnetic susceptibility have been calculated as a function of the characteristic parameters of Kratzer confining potential. With the increase of the hydrostatic pressure, the diamagnetic susceptibility increases. The same dependence from the depth of the Kratzer potential with additional effect: the value of the diamagnetic susceptibility become saturated. The results show that as the potential minimum point increases the diamagnetic susceptibility increases until some critical value, after which it decreases.

Key words: *Spherical quantum dot, Kratzer potential, diamagnetic susceptibility*.

Introduction

Investigation of Coulomb systems in quantum dots (QD) constitute a subject of essential interest of specialists, due to the changings of geometrical shapes and sizes of QD it's possible to control physical properties, particularly imputiy and exiton states in zero-dimensional structures [1, 2]. With decreasing of the sizes of semiconductor the binding energy hydrogen-like system is increasing. Impurity states in QDs was investigated in many papers [3, 4].

At last years special fixedly attention given to spherical symmetric core/shell/shell systems [5, 6]. Essential prosperity of these systems is possibility of controlling of energetic spectrum of charge carriers through the changing of inner radius as well as outer. Wherein theoretical result obtaining for core/shell/shell system has generelized character, because by corresponding limit transition it can be realized spherical quantum dot as well as quantum well.

At the same time in number of papers [7, 8] are studied diamagnetic properties of impurity atoms in QD. Thereby it presents interest investigation of diamagnetic properties of impurity localized in center of spherical core/shell/shell system in that case, when confienment potential of structure described within model of Kratzer molecular potential [5]. The Kratzer potential have the following form

$$V_{conf}(r) = \frac{\alpha}{r^2} - \frac{\beta}{r} + U_0, \quad (1)$$

where α, β, $U_0 -$ are parameters of potential. This parameters are related with the height of confinement potential and the potential minimum point r_0 of $U(r)$ potential according to the relation: $\alpha = U_0 r_0^2$, $\beta = 2U_0 r_0$. Said at first caused by fact, that problem of impurity state with this potential is analytically exactly solvable and that's why it's possible to get a whole line of analitical reults and that let us present detailed picture diamagnetic characteristics of impurity atom.

Diamagnetic susceptibility

For diamagnetic susceptibility, χ_{dia} we can write [7]:

$$\chi_{dia} = -\frac{e^2}{6\mu c^2}\int_0^\infty \left\{ f^{(0)}_{n_r,\ell_0'}(r) \right\}^2 r^4 dr \,. \tag{2}$$

The integral in equation (2) was calculated in [5], and based on this we can write

$$\chi_{dia} = -\frac{e^2}{6\mu c^2} I_{n_r,\ell_0'} \,, \tag{3}$$

where

$$I_{n_r,\ell_0'} = \frac{1}{(2\gamma)^2}\frac{\Gamma(2\ell_0'+5)}{\Gamma(2\ell_0'+3)} \frac{\left\{\left(\frac{d^{n_r}}{dh^{n_r}}\right)\left[\frac{F\left\{\ell_0'+5/2,\ell_0'+3,2\ell_0'+2,A^2/D^2\right\}}{(1-h)^{2\ell_0'+2}D^{2\ell_0'+5}}\right]\right\}_{h=0}}{\left\{\left(\frac{d^{n_r}}{dh^{n_r}}\right)\left[\frac{F\left\{\ell_0'+3/2,\ell_0'+2,2\ell_0'+2,A^2/D^2\right\}}{(1-h)^{2\ell_0'+2}D^{2\ell_0'+3}}\right]\right\}_{h=0}} \,,$$

where are made next designations: $A^2 = 4h/(1-h)^2$, $D = (1+h/(1-h))$. From this expression, it can be written analytical expression for diamagnetic susceptibility for $1s$ and $2s$ states. So for 1s state

$$\chi^{0,0}_{dia} = -\frac{e^2}{3\mu c^2}\frac{\ell_0'(2\ell_0'+1)}{(2\gamma_0)^2} \,, \tag{4}$$

and for 2s state

$$\chi^{1,0}_{dia} = -\frac{e^2}{3\mu c^2}\frac{\ell_0'(2\ell_0'+1)(\ell_0'^2+7\ell_0'+9)}{(2\gamma_1)^2(\ell_0'+2)(\ell_0'+3/2)} \,. \tag{5}$$

Now let's consider the behavior of diamagnetic susceptibility in dependence on hydrostatic pressure and parameters of the QD. In all results, the units of length and energy are presented in Bohr radius $a_B^* = 104$ m and effective Rydberg constant $E_R^* = 5.275$ meV respectively. As for diamagnetic susceptibility, it is presented in $(a_B^{*2} \cdot r_e) = 4.362$ m^3, where $r_e = 4.194\times10^{-4}$ m is the classical radius of electron. Also it's necessary to notice, that in all calculations should be considered the dependence of the μ, ε and r_0 on hydrostatic pressure P [9,10]. The effective mass changes with P as

$$\mu(P) = \mu(0)e^{0.078P} \,, \tag{6}$$

where $\mu(0) = 0,067 * \mu_0$ (μ_0 is free electron mass). The variation of dielectric constant with pressure is given as:

$$\varepsilon = 13.13 - 0.088P \,. \tag{7}$$

In all expressions P is in GPa. The dependence of R_{out} (outer radius of QD) on P given as:

$$R_{out}(P) = R_0\left(1 - 1.5082 \cdot 10^{-3} P\right). \quad (8)$$

Note that the parameter r_0 correlated with outer radius of QD R_{out}. This correlation will be assumed as linear and the coefficient of proportionality $\lambda_{\exp}$ should be chosen from the experimental data. So dependence of r_0 on P could be written as:

$$r_0(P) = \lambda_{\exp} R_0\left(1 - 1.5082 \cdot 10^{-3} P\right). \quad (9)$$

It is obvious that the dependence of the geometrical parameter r_0 on pressure leads to the changes the profile form of the Kratzer potential. Fig. 1 *a)* shows the dependence of diamagnetic susceptibility of the electron on minimum point of Kratzer potential r_0. With increasing of r_0 curves monotonically fall wherein there is observed increasing of absolute value of diamagnetic susceptibility. The curve highest located curve corresponds to biggest value of pressure, because module of average value of r has the smallest value in this case. In addition, it should be noted, that with increasing of r_0 curves diverges from each other.

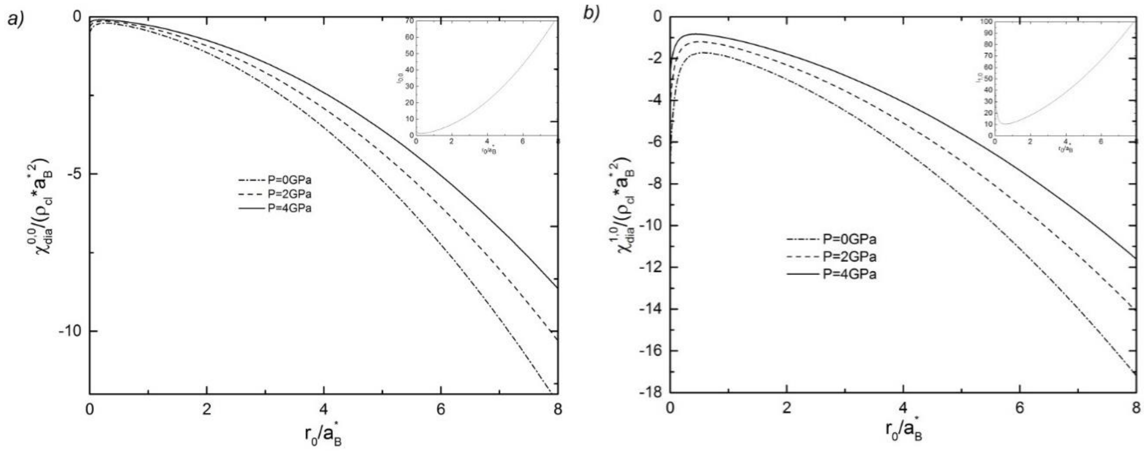

Figure 1. Dependencies of diamagnetic susceptibility χ_{dia} on parameter r_0 for different values of hydrostatic pressure for a) $1s$ and b) $2s$ states

On Fig. 2 *a), b)* are shown dependencies of diamagnetic susceptibility on depth of Kratzer confinement potential. As follows from this figures with increasing of U_0 absolute value of diamagnetic susceptibility decrease because of decreasing of localization area of electron. As in previous case for $2s$ state absolute value of diamagnetic susceptibility has bigger values than for $1s$ state.

All these reasonings are valid as well for $2s$ state (Fig. 1 *b)*). As it can be seen by absolute value $\chi^{1,0}_{dia}$ is bigger than $\chi^{0,0}_{dia}$ for every value of r_0, because in $2s$ state area of localization of electron is bigger than in case of $1s$ state as it can be seen from graphics for I_{0,ℓ'_0} and I_{1,ℓ'_0} in top right angles of both figures. In both cases, when increasing r_0 starting from some value of r_0 absolute value of diamagnetic susceptibility starting sharply increase. This fact caused by quantum emission of electron from QD, whereupon area of localization of electron becomes more larger, than QD sizes.

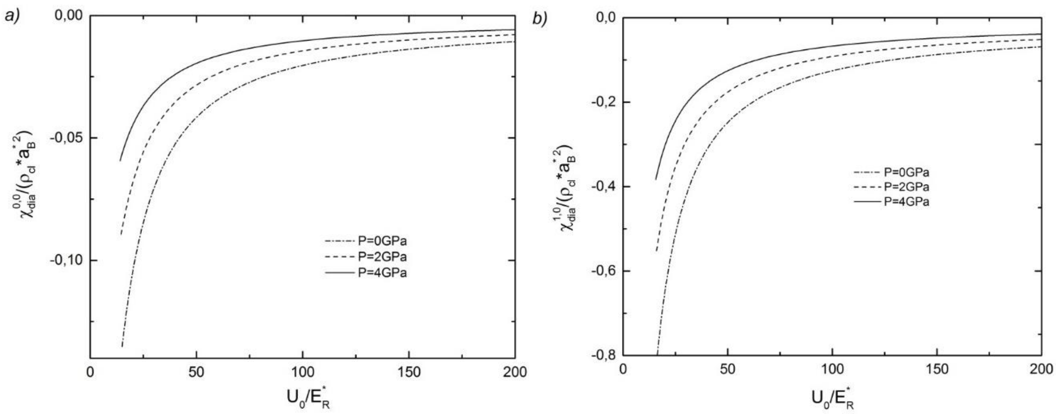

Figure 2. **Dependencies of diamagnetic susceptibility χ_{dia} on parameter U_0 for different values of hydrostatic pressure for a) $1s$ and b) $2s$ states**

On Fig. 3 *a), b)* are shown dependencies of diamagnetic susceptibility on hydrostatic pressure for different values of r_0. With increasing of P all three curves approach to each other (module of diamagnetic susceptibility decrease).

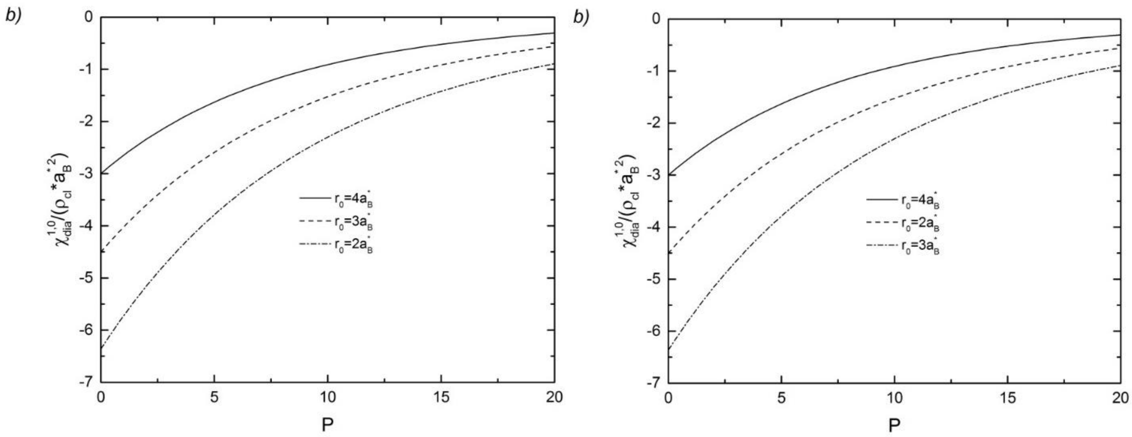

Figure 3. **Dependencies of diamagnetic susceptibility χ_{dia} on hydrostatic pressure P for different values of r_0 for a) $1s$ and b) $2s$ states**

Curve which corresponds to biggest value of r_0 ($r_0 = 4a_B^*$) located lower of all others, because in this case electron is localized on greatest distance from impurity. Null value of pressure corresponds to those value of diamagnetic susceptibility of impurity electron, when minimum of Kratzer potential has values $r_0 = 2a_B^*$, $r_0 = 3a_B^*$ and $r_0 = 4a_B^*$.

Conclusion

In this article the dependence of diamagnetic susceptibility values of the electron in $Ga_{1-x_1}Al_{x_1}As / GaAs / Ga_{1-x_2}Al_{x_2}As$ core/shell/shell structure with Kratzer potential and on-center hydrogenic impurity on hydrostatic pressure are considered. The same dependencies also obtained on the parameters r_0 and U_0 for different values of hydrostatic pressure. Due to the quantum emission of electron from core/shell/shell structure, starting from some value of r_0 the behavior of the value of diamagnetic susceptibility is changing sharply.

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ՀԻԴՐՈՍՏԱՏԻԿ ՃՆՇՄԱՆ ԱԶԴԵՑՈՒԹՅՈՒՆԸ ԿՐԱՏՑԵՐԻ ՍԱՀՄԱՆԱՓԱԿՈՂ ՊՈՏԵՆՑԻԱԼՈՎ ՄԻՋՈՒԿ/ՇԵՐՏ/ՇԵՐՏ ԳՆԴԱՁԵՎ ՔՎԱՆՏԱՅԻՆ ԿԵՏՈՒՄ ՋՐԱԾՆԱՆՄԱՆ ԴՈՆՈՐԱՅԻՆ ԽԱՌՆՈՒԿԻ ԴԻԱՄԱԳՆԻՍԱԿԱՆ ԸՆԿԱԼՈՒՆԱԿՈՒԹՅԱՆ ՎՐԱ

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Արդյունարար զանգվածի մոտավորության շրջանակներում տեսականորեն հետազոտվել է հիդրոստատիկ ճնշման ազդեցությունը Կրատցերի սահմանափակող պոտենցիալով $Ga_{1-x_1}Al_{x_1}As/GaAs/Ga_{1-x_2}Al_{x_2}As$ միջուկ/շերտ/շերտ գնդաձև քվանտային կետում ջրածնանման դոնորային խառնուկի դիամագնիսական ընկալունակության վրա: Դիամագնիսական ընկալունակությունը հաշվարկվել է որպես ֆունկցիա Կրատցերի պոտենցիալի բնութագրական մեծություններից: Հիդրոստատիկ ճնշման մեծանալուն զուգահեռ դիամագնիսական ընկալունակությունը աճում է: Նմանատիպ կախվածություն է նաև Կրատցերի պոտենցիալի խորությունից հավելյալ երևույթով՝ դիամագնիսկական ընկալունակության արժեքը հագենում է: Արդյունքները ցույց են տալիս, որ պոտենցիալի մինիմումի կետի աճին զուգընթաց դիամագնիսական ընկալունակությունը աճում է մինչև որոշակի արժեք, որից հետո նվազում է:

Բանալի բառեր՝ գնդաձև քվանտային կետ, Կրատցերի պոտենցիալ, դիամագնիսկան ընկալունակություն:

ЭФФЕКТ ГИДРОСТАТИЧЕСКОГО ДАВЛЕНИЯ НА ДИАМАГНИТНУЮ ВОСПРИИМЧИВОСТЬ ВОДОРОДОПОДОБНОЙ ДОНОРНОЙ ПРИМЕСИ В СФЕРИЧЕСКОЙ КВАНТОВОЙ ТОЧКЕ ЯДРО/СЛОЙ/СЛОЙ С ОГРАНИЧИВАЮЩИМ ПОТЕНЦИАЛОМ КРАТЦЕРА

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В рамках теории эффективной массы теоретически исследован эффект гидростатического давления на диамагнитную восприимчивость водородоподобной донорной примеси в сферической квантовой точке $Ga_{1-x_1}Al_{x_1}As/GaAs/Ga_{1-x_2}Al_{x_2}As$ ядро/слой/слой с ограничивающим потенциалом Кратцера. Диамагнитная восприимчивость вычислена как функция характеристических параметров потенциала Кратцера. С увеличением гидростатического давления диамагнитная восприимчивость увеличивается. Такая же зависимость от глубины потенциала Кратцера с добавочным эффектом: величина диамагнитной восприимчивости становится насыщенной. Результаты показывают, что с увеличением точки минимума потенциала диамагнитная восприимчивость увеличивается до некоторого значения, после которого уменьшается.

Ключевые слова: сферическая квантовая точка, потенциал Кратцера, диамагнитная восприимчивость.