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Numerical Calculations and Time Evolution of Coherent States Wave Functions of Charged Oscillator in Magnetic Field

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Abstract

The wave functions of the coherent states of the charged oscillator in magnetic field are obtained via a canonical transformation. The numerical calculations of these functions are made and then the space and time plots are obtained. It was shown that these states are Gaussians distributions of widths vary periodically in an opposite way with their peaks. We interpret that is due to the mutual actions of the spreading effect of the wave packet and the reaction of the magnetic field.

Introduction

The dynamics of charged particles in electric and magnetic fields is of both academic and practical interest. The areas where this problem finds applications include the development of cyclotron accelerators (1), free electron lasers (2), plasma physics (3) and so on (4). The problem of charged particles moving in an anisotropic three-dimensional harmonic oscillator potential in the presence of a constant external magnetic field has received much attention (5-14). This may be attributed to the fact that this problem can be considered as a model representing different situations in physics. For example, electrons in an isotropic metal lattice subjected to an external constant magnetic field can be represented by such a model (5). The present work is concerned with the space and time plots of coherent states wave functions of a charged oscillator in a magnetic field. The canonical transformation (well known in classical mechanics) is used to convert the charged oscillator problem from an old canonical variables and Hamiltonian of three coupled oscillators to that of three uncoupled harmonic oscillators in new canonical variables with new masses and frequencies (15,16). The new Hamiltonian of three uncoupled oscillators facilitates the construction of the coherent states for the problem in terms of its energy states $| n_i \rangle$ in the usual way (16). Then we convert the representation of the coherent states from the fock (energy states) representation to coordinate one, i.e., coherent states wave functions. Then expression for the modulus squared (probability distribution) is derived. Finally, we program the numerical calculations of the absolute values of the wave functions in order to plot them in coordinate space at various values of magnetic field and times.

The Hamiltonian and the canonical transformation

The Hamiltonian of a spineless non-relativistic charged oscillator of mass (m) and charge (q) moving in an anistropic 3-D harmonic oscillator, in the presence of a constant external magnetic field ($\vec{B}$) directed along the x_1-axis, is (16)

$$\hat{H} = \frac{1}{2} m \sum_{i=1}^{3} \omega_i^2 x_i^2 + \frac{1}{2m} (\vec{P} - \frac{q}{c} \vec{A})^2 \quad ....[1]$$

where $\vec{A} = \vec{A}(\vec{r}, t)$ is the vector potential associated with the magnetic field ($\vec{B}$), $\frac{1}{2} m \sum_{i-1}^{3} \omega_i^2 x_i^2$ is the harmonic oscillator potential and $x_i (i = 1,2,3)$ are the cartesian coordinate of the particle. The magnetic field component ($\vec{B}$) is along x_1-axis, therefore, the symmetric gauge is

$$\vec{A} = \frac{B}{2} (0, -x_3, x_2) \quad ....[2]$$

The cyclotron frequency (ω_c) associated with the particle motion is related with Larmor frequency (ω_L) by the following relation:

$$\omega_L = \frac{\omega_c}{2} = \frac{qB}{mc} \quad \text{.......[3]}$$

Using equation [2] and [3], one get from equation (1)

$$\hat{H} = \left(\frac{p_1^2}{2m} + \frac{1}{2}m\omega_1^2 x_1^2\right) + \left(\frac{p_2^2}{2m} + \frac{1}{2}m\omega_2^2 x_2^2 + \frac{1}{2}m\omega_L^2 x_2^2\right) + \left(\frac{p_3^2}{2m} + \frac{1}{2}m\omega_3^2 x_3^2 + \frac{1}{2}m\omega_L^2 x_3^2\right) - \frac{1}{2}\omega_L (x_2 p_3 - x_3 p_2) + \frac{1}{2}\omega_L (p_2 x_3 - p_3 x_2) \quad \text{....[4]}$$

where

$L_1 = x_2p_3 - x_3p_2$

$-L_1 = p_2x_3 - p_3x_2$ ....[5]

are the positive and negative components of the angular momentum along the x_1- direction

Defining the angular frequency (ω'^2_i) by (16)

$$\omega'^2_i = \omega_i^2 + \omega_L^2 \quad (i=1,2,3)\text{........[6]}$$

$$\hat{H} = \left(\frac{p_1^2}{2m} + \frac{1}{2}m\omega_1^2 x_1^2\right) + \left(\frac{p_2^2}{2m} + \frac{1}{2}m\omega'^2_2 x_2^2\right) + \left(\frac{P_3^2}{2m} + \frac{1}{2}m\omega'^2_3 x_3^2\right) - \omega_L L_1 \quad \text{.......[7]}$$

$$= \hat{H}_1 + \hat{H}\,\omega_L \text{ ....[8]}$$

where $\hat{H}_1 = \frac{P_1^2}{2m} + \frac{1}{2} m\omega_1^2 X_1^2$ ....[9]

$$\hat{H}\omega_L = (\frac{P_2^2}{2m} + \frac{1}{2} m\omega'^2_2 x_2^2) + (\frac{p_3^2}{2m} + \frac{1}{2} m\omega'^2_3 x_3^2) - \omega_L L_1 \text{ ....[10]}$$

It is clearly shown from equations [7] and [8] that the Hamiltonian of the system under consideration is the same as the Hamiltonian of three coupled oscillators due to the magnetic field. In order to overcome this difficulty and transform the Hamiltonian of the problem to that of three uncoupled oscillators, a canonical transformation(16,17) in the phase space of the problem must be used to obtain the transformed Hamiltonian (H') with different frequencies (Ω_i) and masses (m_i):

$$H' = \sum_{i-1}^{3} (\frac{p'^2_i}{2m} + \frac{1}{2} m_i \Omega_i^2 x'^2_i) \text{ ....[11]}$$

The coherent states wave functions

The Hamiltonian (H′) of three uncoupled oscillators facilitates the construction of its coherent states in terms of the number states | n_i ⟩ (16,5). The coherent states of (H′) can be parameterized by three complex quantities α_i(i=1,2,3).

$$|\{\alpha_i\},t\rangle = \prod_{i=1}^{3} e^{-\frac{|\alpha_i|^2}{4b_i^2}} \sum_{n_i=0}^{\infty} \left(\frac{\alpha_i}{\sqrt{2}b_i}\right)^{n_i} \times \left(\frac{1}{\sqrt{n_i!}}\right) e^{-i\Omega_i(n_i+1/2)t} |n_i\rangle \text{ ....[12]}$$

where:

$$b_i = \left(\frac{\hbar}{|m_i|\Omega_i}\right)^{1/2}, \quad \text{i=1,2,3 ....[13]}$$

Ignoring the motion in x_1- direction since it is decoupled from x_2,x_3 motion and is not affected by the rotation, the unprimed coordinate representation of the coherent states reads

$$\langle\{x_i\}|\{\alpha_i\},t\rangle = \prod_{i=2,3} e^{\frac{|\alpha_i|^2}{4b_i^2}} \sum_{n_i=0}^{\infty} \left(\frac{\alpha_i}{\sqrt{2}b_i}\right)^{n_i} \left(\frac{1}{\sqrt{n_i!}}\right) e^{-i\Omega_i(n_i+\frac{1}{2})t} \langle\{x_i\}|\{n_i\}\rangle \cdots\text{[14]}$$

Equation [14] can be written as:

$$\langle x_2,x_3 \mid \alpha_2,\alpha_3;t\rangle = \prod_{i=2,3} e^{\frac{|\alpha_i|}{4b_i^2}} \sum_{n_i=0}^{\infty}\left(\frac{\alpha_i}{\sqrt{2}b_i}\right)^{n_i}\left(\frac{1}{\sqrt{n_i!}}\right)e^{-i\Omega_i(n_i+\frac{1}{2})t}\langle x_2,x_3 \mid n_2,n_3\rangle \text{..[15]}$$

The eigen functions of $\langle x_2 x_3 | n_2 n_3\rangle$ can be written as (17,18)

$$\langle x_2 x_3 \mid n_2 n_3\rangle = \int_{-\infty}^{\infty} dx'_2 \int_{-\infty}^{\infty} dx'_3 \langle x_2 x_3 \mid x'_2 x'_3\rangle\langle x'_2 x'_3 \mid n_2 n_3\rangle \text{......[16]}$$

The functions $\langle x'_2 x'_3 \mid n_2 n_3\rangle$ are the known oscillator eigen functions in the primed system, thus

$$\langle x'_2\, x'_3 \mid n_2 n_3\rangle = (2^{n_2+n_3} n_2! n_3! b_2 b_3 \pi)^{-1/2} \times Hn_2\left(\frac{x'_2}{b_2}\right)Hn_3\left(\frac{x'_3}{b_3}\right)e^{-\left(\frac{x'^2_2}{2b_2^2}+\frac{x'^2_3}{2b_3^2}\right)} \text{...[17]}$$

The eigen functions $\langle x_2 x_3 \mid x'_2 x'_3\rangle$ are given by Glas et.al.(17) and Habeeb(18).

$$\langle x_2 x_3 \mid x'_2 x'_3\rangle = (2\pi\hbar \mid B \mid)^{-1} \times e^{\frac{i}{\hbar B}(-Ax_2x_3+x_2x'_3+x_3x'_2-x'_2x'_3)} \text{......[18]}$$

Thus, an integral representation of the normalized eigen functions $\langle x_2 x_3 \mid n_2 n_3\rangle$ is given by

$$\langle x_2 x_3 \mid n_2 n_3\rangle = (2\pi\hbar \mid B \mid)^{-1}(2^{n_2+n_3} n_2! n_3! b_2 b_3 \pi)^{-1/2} \times e^{-i\frac{Ax_2x_3}{\hbar B}} \int_{-\infty}^{\infty} dx'_2 \int_{-\infty}^{\infty} dx'_3 Hn_2\left(\frac{x'_2}{b_2}\right)Hn_3\left(\frac{x'_3}{b_3}\right)\times e^{-\frac{x'^2_2}{2b_2^2}-\frac{x'^2_3}{2b_3^2}+\frac{i}{\hbar B}(x'_2x_3+x_2x'_3-x'_2x'_3)} \text{.......[19]}$$

The coherent staties wave functions of equation[15]

$$\psi_{\alpha_2\alpha_3}(x_2,x_3,t) = e^{-\frac{|\alpha_2|^2}{4b_2^2}} \sum_{n_2=0}^{\infty}\left(\frac{\alpha_2}{\sqrt{2}b_2}\right)^{n_2}\left(\frac{1}{\sqrt{n_2!}}\right)\left(2^{n_2} n_2! b_2\sqrt{\pi}\right)^{-1/2}$$

$$e^{-i\Omega_2(n_2+1/2)t} e^{-\frac{|\alpha_3|^2}{4b_3^2}} \sum_{n_3=0}^{\infty}\left(\frac{\alpha_3}{\sqrt{2}b_3}\right)^{n_3}\left(\frac{1}{\sqrt{n_3!}}\right)\times$$

$$(2^{n_3} n_3! b_3\sqrt{\pi})^{-1/2} e^{-i\Omega_3(n_3+1/2)t}(2\pi\hbar \mid B\mid)^{-1}\times$$

$$e^{\frac{iAx_2x_3}{\hbar B}} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{\frac{i}{\hbar B}(x_2x'_3+x_3x'_2-x'_2x'_3)-\frac{x'^2_2}{2b_2^2}-\frac{x'^2_3}{2b_3^2}}\times \qquad \text{.........[20]}$$

$$H_{n_2}\left(\frac{x'_2}{b_2}\right)H_{n_3}\left(\frac{x'_2}{b_3}\right)dx'_2\,dx'_3$$

Numerical calculation and time evolution of coherent states wave function

Multiplying both sides of equation[20] by its complex conjugate, one obtain the modulus squared of coherent states wave functions as follows:

$$|\Psi_{\alpha_2\alpha_3}(x_2,x_3,t)|^2 = e^{-\frac{|\varepsilon_2|^2}{4b_2^2}} \sum_{n_2=0}^{\infty}\left(\frac{\alpha_2}{\sqrt{2}b_2}\right)^{n_2}\left(\frac{1}{\sqrt{n_2!}}\right)^{\left(2^{n2} n_2! b_2\sqrt{\pi}\right)^{-1/2}}\times$$

$$e^{-i\Omega_2(n_2+\frac{1}{2})t} e^{\frac{|\alpha_3|^2}{4b_3^2}} \sum_{n_3=0}^{\infty}\left(\frac{\alpha_3}{\sqrt{2}b_3}\right)^{n_3}\left(\frac{1}{\sqrt{n_3!}}\right)\times$$

$$\left(2^{n_3} n_3! b_3\sqrt{\pi}\right)^{-1/2} e^{-i\Omega_3(n_3+\frac{1}{2})t}\times(2\pi\hbar \mid B\mid)^{-1}\times$$

$$e^{-\frac{!}{\hbar B}Ax_2x_3}\int_{-\infty}^{\infty}dx'_2\int_{-\infty}^{\infty}dx'_3 H_{n_2}\left(\frac{x'_2}{b_2}\right)H_{n_3}\left(\frac{x'_3}{b_3}\right)\times$$

$$e^{-\frac{x'^2_2}{2b_2^2}-\frac{x'^2_3}{2b_3^2}} e^{!/\hbar\beta(x'_2x_3+x_2x'_3-x'_2x'_3)}\times$$

$$e^{\frac{|\alpha_2|^2}{4b_2^2}} \sum_{m_2=0}^{\infty}\left(\frac{\alpha_2^{\bullet}}{\sqrt{2}b_2}\right)^{m_2}\left(\frac{1}{\sqrt{m_2!}}\right)\times$$

$$(2^{m_2} m_2! b_2 \sqrt{\pi})^{-1/2} e^{i\Omega_2(m_2+\frac{1}{2})t} e^{-\frac{|\alpha_3|^2}{4b_3^2}} \sum_{m_3=0}^{\infty} \left(\frac{\alpha_3^{\bullet}}{\sqrt{2}b_3} \right)^{m_3} \times$$

$$\left(\frac{1}{\sqrt{m_3!}} \right)^{(2^{m_3} m_3! b_3 \sqrt{\pi})^{-1/2}} e^{i\Omega_3(m_3+\frac{1}{2})t} (2\pi\hbar \,|\, B \,|)^{-1} \times$$

......[21]

$$e^{i/\hbar B(AX_2X_3)} \int_{-\infty}^{\infty} dx'_2 \int_{-\infty}^{\infty} dx'_3 H_{m_2}\left(\frac{x'_2}{b_2}\right) H_{m_3}\left(\frac{x'_3}{b_3}\right) \times$$

$$e^{\frac{x'^L_2}{2b_2^2} \frac{x'^2_3}{2b'^2_3}} e^{-(i/\hbar B)(x'_2 x_3 + x_2 x'_3 - x'_2 x'_3)}$$

Putting the two double integration as:

$$I_{n_2 n_3}(x_2, x_3) = \int_{-\infty}^{\infty} dx'_2 \int_{-\infty}^{\infty} dx'_3 H_{n_2}\left(\frac{x'_2}{b_2}\right) H_{n_3}\left(\frac{x'_3}{b_3}\right) \times$$

........[22]

$$e^{\frac{x'^2_2}{2b_2^2} \frac{x'^2_3}{2b_3^2}} e^{(+i/\hbar B)(x'_2 x_3 + x_2 x'_3 - x'_2 x'_3)}$$

$$I_{m_2 m_3}(x_2, x_3) = \int_{-\infty}^{\infty} dx'_2 \int_{-\infty}^{\infty} dx'_3 H_{m_2}\left(\frac{x'_2}{b_2}\right) H_{m_3}\left(\frac{x'_3}{b_3}\right) \times$$

.......[23]

$$e^{\frac{x'^2_2}{2b_2^2} \frac{x'^2_3}{2b_3^2}} e^{(i/\hbar B)(x'_2 x_3 + x_2 x'_3 - x'_2 x'_3)}$$

Rewriting equation [21], one has

$$|\Psi_{\alpha_2\alpha_3}(x_2,x_3,t)|^2 = e^{-|\alpha_2|^2/4b_2^2}\sum_{n_2=0}^{\infty}\left(\frac{\alpha_2}{\sqrt{2}b_2}\right)^{n_2}\left(\frac{1}{\sqrt{n_2!}}\right)\left(2^{n_2}n_2!b_2\sqrt{\pi}\right)^{-1/2}\times$$

$$e^{-i\Omega_2(n_2+1/2)t}e^{-|\alpha_3|^2/4b_3^2}\sum_{n_3=0}^{\infty}\left(\frac{\alpha_3}{\sqrt{2}b_3}\right)^{n_3}\left(\frac{1}{\sqrt{n_3!}}\right)\left(2^{n_3}n_3!b_3\sqrt{\pi}\right)^{-1/2}\times$$

$$e^{-i\Omega_3(n_3+1/2)t}I(x_2,x_3)*(2\pi\hbar|B|)^{-2}\times$$

$$e^{-|\alpha_2|^2/4b_2^2}\sum_{m_2=0}^{\infty}\left(\frac{\alpha_2^{\bullet}}{\sqrt{2}b_2}\right)^{m_2}\left(\frac{1}{\sqrt{m_2!}}\right)\left(2^{m_2}m_2!b_2\sqrt{\pi}\right)^{-1/2}\times$$

$$e^{i\Omega_2(m_2+1/2)t}e^{-|\alpha_3|^2/4b_3^2}\sum_{m_3=0}^{\infty}\left(\frac{\alpha_3^{\bullet}}{\sqrt{2}b_3}\right)^{m_3}\left(\frac{1}{\sqrt{m_3Q}}\right)$$

$$\left(2^{m_3}m_3!b_3\sqrt{\pi}\right)^{-1/2}e^{i\Omega_3(m_3+1/2)t}I_{m_2m_3}(x_2,x_3)\ \text{........[24]}$$

Using some mathematical treatment to recover the complexity from eqs. [22] and [23], one has

$$I_{n_2n_3}(x_2,x_3) = 4\int_0^{\infty}dx'_2\int_0^{\infty}dx'_3 H_{n_2}\left(\frac{x'_2}{b_2}\right)H_{n_3}\left(\frac{x'_3}{b_3}\right)\times$$

$$e^{-\frac{x_2'^2}{2b_2^2}-\frac{x_3'^2}{2b_3^2}}\cos\left(\frac{x_3x'_2}{\hbar B}\right)\cos\frac{(x_2-x'_2)}{\hbar B}x'_3 \quad \text{......[25]}$$

$$I_{m_2m_3}(x_2,x_3) = 4\int_0^{\infty}dx'_2\int_0^{\infty}dx'_3 H_{m_2}\left(\frac{x'_2}{b_2}\right)H_{m_3}\left(\frac{x'_3}{b_3}\right)\times$$

$$e^{-\frac{x_2'^2}{2b_2^2}-\frac{x_3'^2}{2b_3^2}}\cos\left(\frac{x_3x'_2}{\hbar B}\right)\cos\frac{(x_2-x'_3)}{\hbar B}x'_3 \quad \text{.......[26]}$$

Therefore, one can write equation [24] as:

$$|\Psi_{\alpha_2\alpha_3}(x_2,x_3,t)|^2=(2\pi\hbar\,|B|)^{-2}e^{-\frac{|\alpha_2|^2}{2b_2^2}-\frac{|\alpha_3|^2}{2b_3^2}}\times$$

$$\sum_{m_2=0}^{\infty}\left(\frac{\alpha_2^*}{\sqrt{2}b_2}\right)^{m_2}\frac{1}{\sqrt{m_2!}}(2^{m_2}m_2!b_2\sqrt{\pi})^{-1/2}\times$$

$$\sum_{n_2=0}^{\infty}\left(\frac{\alpha_2}{\sqrt{2}b_2}\right)^{n_2}\left(\frac{1}{\sqrt{n_2!}}\right)(2^{n_2}n_2!b_2\sqrt{\pi})^{-1/2}\times$$

$$e^{i\Omega_2(m_2-n_2)t}\sum_{m_3=0}^{\infty}\left(\frac{\alpha_3^*}{\sqrt{2}b_3}\right)\left(\frac{1}{\sqrt{m_3!}}\right)(2^{m_3}m_3!b_3\sqrt{\pi})^{-1/2}\times \quad\text{.......[27]}$$

$$\sum_{n_3=0}^{\infty}\left(\frac{\alpha_3^*}{\sqrt{2}b_3}\right)\left(\frac{1}{\sqrt{m_3!}}\right)(2^{m_3}m_3!b_3\sqrt{\pi})^{-1/2}\times$$

$$e^{i\Omega_3(m_3-n_3)t}I_{m_2m_3}(x_2,x_3)I_{n_2n_3}(x_2,x_3)$$

The final form of squared modulus of coherent states wave functions, eq.[27] is:

$$|\Psi_{\alpha_2\alpha_3}(X_2,X_3,t)|^2=(2\pi\hbar\,|B|)^{-2}e^{-\frac{|\alpha_2|^2}{2b_2^2}-\frac{|\alpha_3|^2}{2b_3^2}}\times$$

$$\sum_{m_2=0}^{\infty}\left(\frac{|\alpha_2|^2}{2b_2^2}\right)^{m_2}\left(\frac{1}{m_2!}\right)(2^{m_2}m_2!b_2\sqrt{\pi})^{-1}\times$$

$$\sum_{m_3=0}^{\infty}\left(\frac{|\alpha_3|^2}{2b_3^2}\right)^{n_2}\left(\frac{1}{m_3!}\right)(2^{m_3}m_3b_3\sqrt{\pi})^{-1}\times$$

$$I^2{}_{m_2m_2}(x_2,x_3)+4\sum_{\substack{m_2,n_2\\m_2>n_2}}^{\infty}\left(\frac{|\alpha_2}{\sqrt{2}b_2}\right)^{m_2+n_2}\left(\frac{1}{\sqrt{m_2!n_2!}}\right)\times$$

$$(2^{m_2+n_2}m_2!b_2^2\Pi)^{-1/2}\cos\quad\Omega_2(m_2-n_2)t\times$$

$$\sum_{\substack{m_3,n_3\\m_3>n_3}}^{\infty}\left(\frac{|\alpha_3|}{\sqrt{2}b_3}\right)^{m_3+n_3}\left(\frac{1}{\sqrt{m_3!n_3!}}\right)(2^{m_3,+n_3}m_3!n_3!b_3\pi)^{-1/2}\times$$

$$\cos\quad\Omega_3(m_3-n_3)t\times I_{m_2m_3}(x_2,x_3)I_{n_2n_3}(x_2,x_3)$$

Results and discussion

It is clearly shown from the previous sections that our system is physically more complicated, for example, than the system of one and two modes harmonic oscillators and that is due to the cranking term ($\omega_1 \hat{L}$) which is resulted from the magnetic field. The magnetic field is the most effective factor which has governed the construction of coherent states. Setting $\hbar$, oscillating mass (m) and oscillating frequency (ω_2) equal to unity, one can define the units of all coefficients and parameters of the system in term of them. The absolute value of equation [28] represents the coherent states wave functions of the system and figs. (1-6) show these functions at different values of the magnetic field.

It is obviously shown that these states are not localized and spreading out, therefore, the magnetic field and the associated parameters must be varied carefully in order to obtain the proper coherent states as shown in the next two figs.

Figs. (7-8) show the time evolution of the coherent states at various interval of the cycle time (T). These figs. have revealed that these states are Gaussians probability distributions. The widths of these distributions and the peaks of them vary periodically in an opposite way. We can interpret this behavior as a result of the action of wave packet to spread out and the reaction of the magnetic field which tries to localize the particle.

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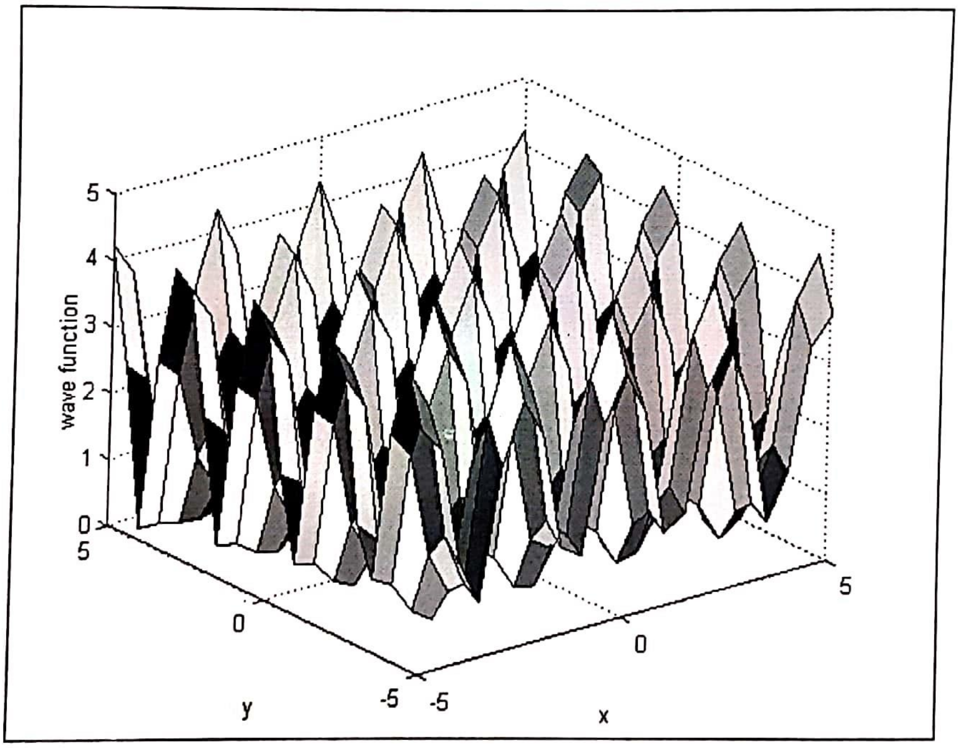

Fig (1):Magnetic field gives ω_1=0.6

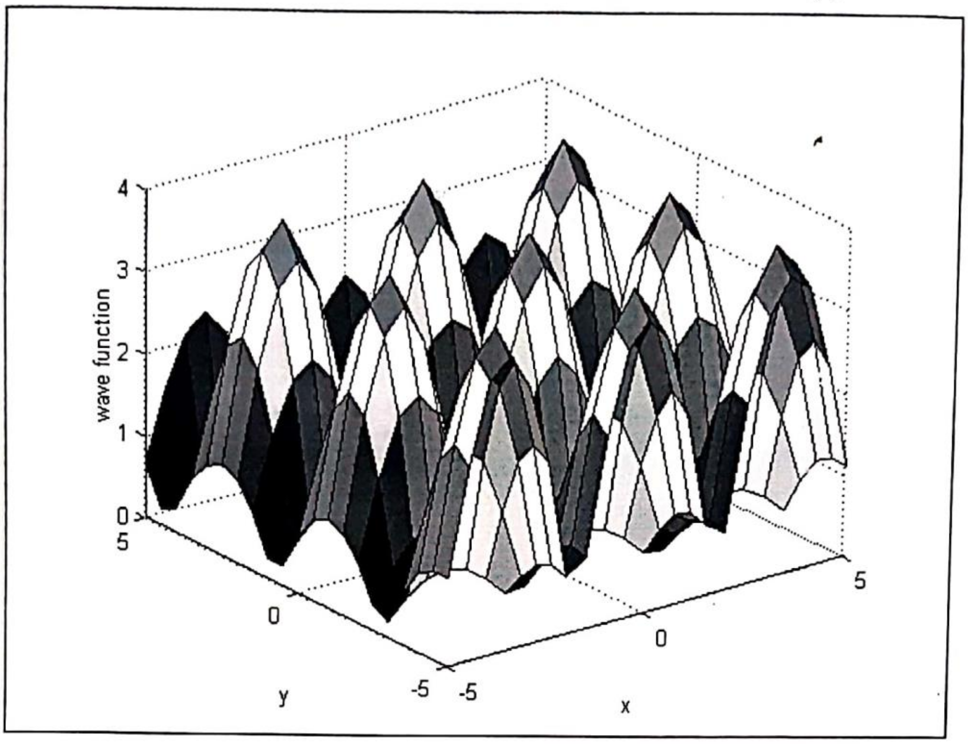

Fig (2):Magnetic field gives ω_1=0.65

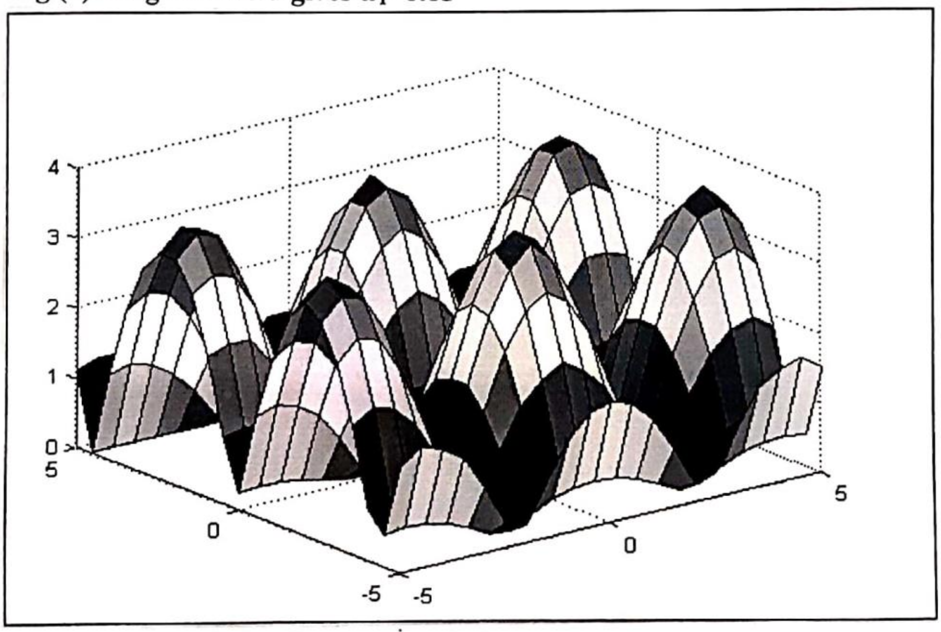

Fig. (3):Magnetic field gives ω_1=0.675

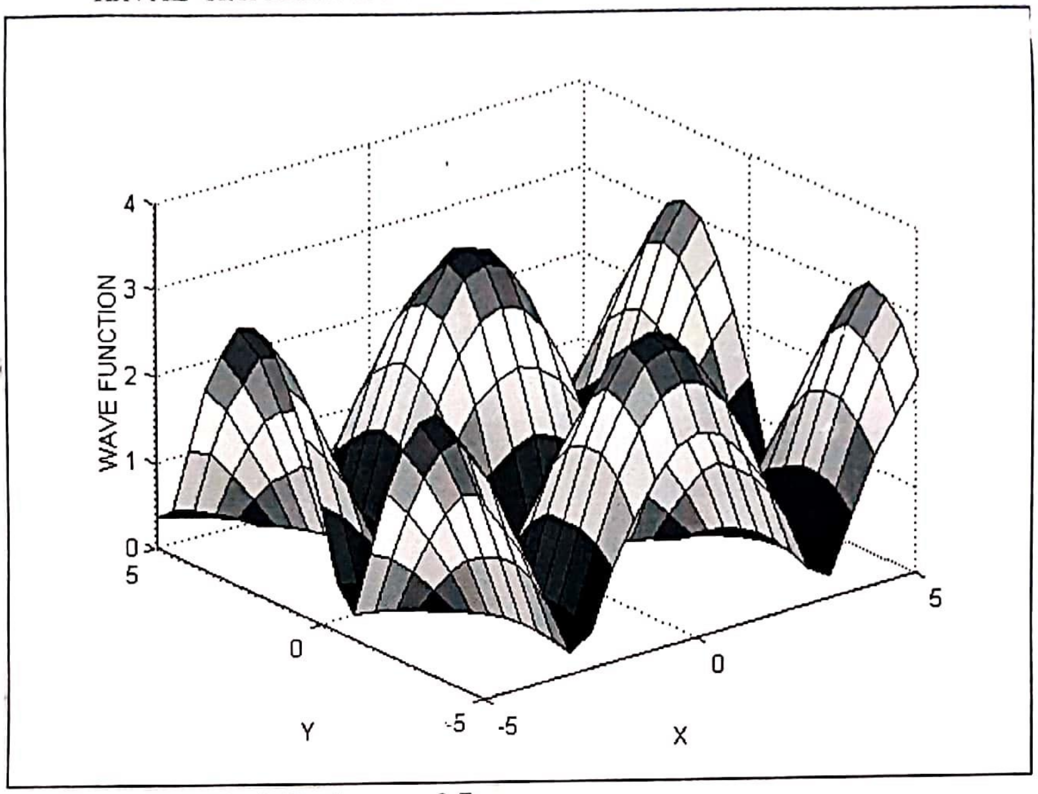

Fig. (4):Magnetic field gives ω_1=0.7

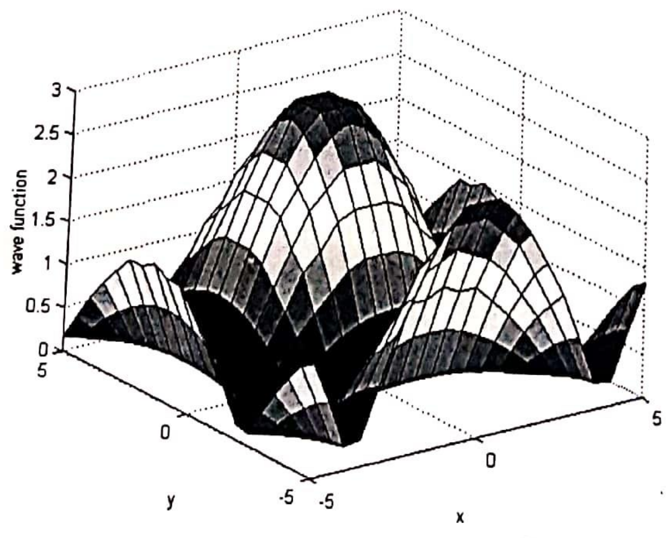

Fig (5):Magnetic field gives ω_1=0.725

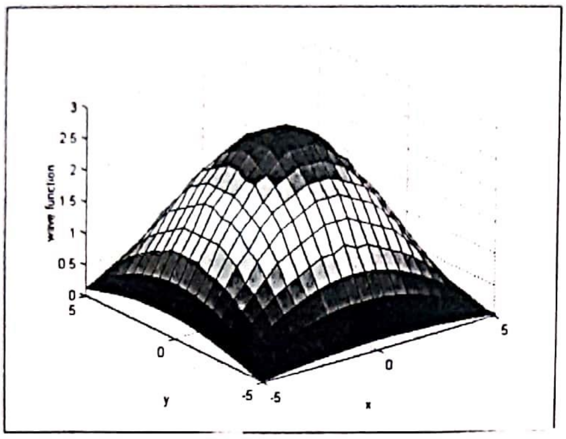

Fig. (6):Magnetic field gives ω_1=0.750

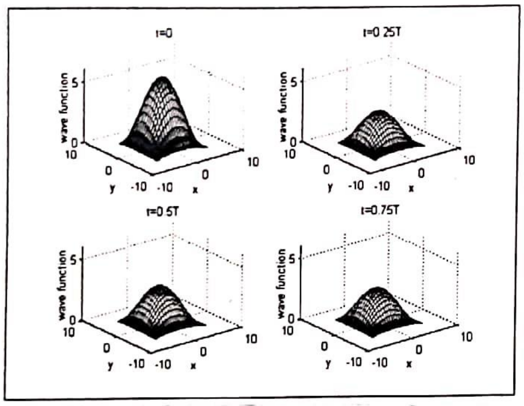

Fig. (7):The coherent states of charged oscillator in magnetic field at various intervals of cycle time

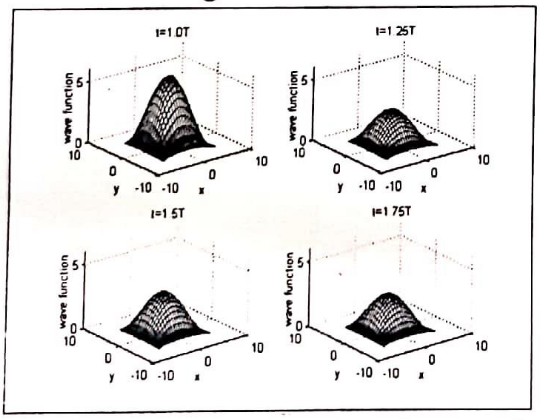

Fig. (8):The coherent states of charged oscillator in magnetic field at various intervals of cycle time

الحسابات العددية والتطور الزمني للدوال الموجية للحالات المتشاكهة للمتذبذب المشحون في مجال مغناطيسي

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المستخلص

تـم الحصـول علـى الـدوال الموجية للحالات المتشاكهة للمتذبذب المشحون الموضـوع داخـل مجـال مغناطيسي من خلال التحويلات المشروعة، وتم ايضاً اجراء الحسـابات العددية اللازمة باستخدام برامج حاسوبية لرسم المخططات الفضائية والزمنية لتلك الدوال. لقد اتضح ان تلك الحالات عبارة عن توزيعات كاوس يتغير عرضها بصورة دوريـة مـع قممهـا ونحن نعلل ذلك الى التأثير المتعاكس لكل من الحزمة الموجية التي تحاول ان تنتشر وتتوسع والمجال المغناطيسي الذي يحاول ان يركزها في منطقة معينة.