

A MODIFIED TOROIDAL MODEL OF PROTON

JAYESH SURESH

ABSTRACT

In quantum mechanics, the zitterbewegung is a rapid oscillatory movement of quantum particle in single plane. It is a motion which can give idea about the sub structure of quantum particles. It is believed to be the reason for magnetic moment of the quantum particle. In 2023, a new toroidal model of proton has been proposed by Kovacs et al. In this article, a modification of the model has been proposed with the concept of physical wave function and using the phenomenon of nuclear magnetic resonance. The analysis of zitterbewegung within the limits of the physical wave function has shown that, using zitterbewegung and the concept of Larmor precession, a model for generation of radiant energy during nuclear magnetic resonance can be derived.

Key words- ontic; quantum; wave function;
precession;zitterbewegung

A MODIFIED TOROIDAL MODEL OF PROTON

In this article, the concept of zitterbewegung is considered as the reason for magnetic moment of proton. It has been described as the reason for magnetic moment of quantum particles like electron previously also. It is a back-and-forth rapid circulatory motion of quantum particle in a plane orthogonal to its propagation[1,2]. The maximum radius or amplitude of the zitterbewegung is found as equal to reduced Compton wavelength. Therefore, $r=\lambda/2\pi$ where r is the maximum radius of zitterbewegung.[3]. A toroid model has been described for proton by Kovacs et al[4]. It is described that the zitterbewegung has a helical pattern with uniform diameter which precess and forms a toroid in external magnetic field. Here in this article, a variable diameter (increasing and decreasing) of zitterbewegung has been considered in the presence of radiofrequency, which is used to tilt the magnetic moment orthogonally in nuclear magnetic resonance. The radiofrequency has a varying electric and magnetic field. This can

explain nuclear magnetic resonance more accurately and can describe the generation of electromagnetic wave.

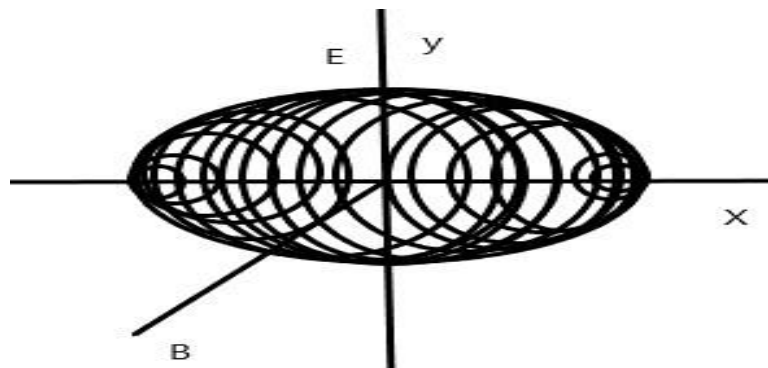


Fig 1. The zitterbewegung of quantum particle

The relationship exists between the externally applied orthogonal magnetic field and Larmor precession frequency is described as: $\omega = \gamma B$ where ω represents the frequency of the Larmor precession; B is the external magnetic field intensity and γ represents the gyro-magnetic ratio of the quantum particle [5]. Here the angular frequency of precession should be equal to the angular frequency of the wave for generation of an electromagnetic wave.

In nuclear magnetic resonance, external magnetic field is applied which orient the magnetic moment to its direction. The radiofrequency pulse given orthogonally tilt the magnetic moment of the proton orthogonally and give it a precession which generates the electromagnetic wave once it goes back to the original alignment. The Larmor precession frequency will be the same as the frequency of radiofrequency pulse and the generated electromagnetic wave will also have the same frequency. This is a scientifically proven fact with experiments [6].

The equation for Larmor frequency is $\omega = \gamma B$. B is the magnetic field of radiofrequency pulse creating precession. Then $E = cB$ is the electric field of the radiofrequency pulse. The Larmor frequency is equal to the angular frequency of the electromagnetic wave. Therefore the equation can be written as $ck = \gamma B$, $\gamma = gq/2m$ where q is the charge of proton and m is the mass. Therefore, $ck = gBq/2m$. Here $k = 2\pi/\lambda = 1/r$. We know that r is the maximum radius of zitterbewegung.

Hence, $c/r = gEq/2mc$

Rearranging the equation, $mc^2/2g = qEr$

qEr in general means the work done by displacing a charge q over a distance r in an electric field E

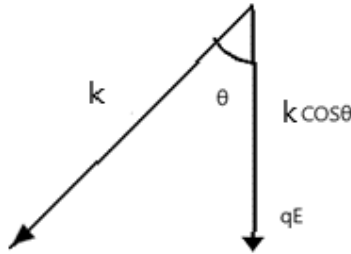


Fig 2. Work done by electric field of radiofrequency by flipping proton

The work done by the radiofrequency pulse to move proton to orthogonal plane is given by $W = Fk \cos \theta$. If the radiofrequency flips the zitterbewegung to orthogonal plane in a toroidal model of proton, $r = k \cos \theta$. The work done, $W = qEr$ is equal to $W = 1/2g (mc^2)$. $E = 1/2g (mc^2)$ is the energy required to flip the zitterbewegung to orthogonal plane. This energy is released as the radiant energy including the radiofrequency waves generated by Larmor precession. This same principle applies for electron magnetic resonance. There microwaves are utilised instead of radiowaves.

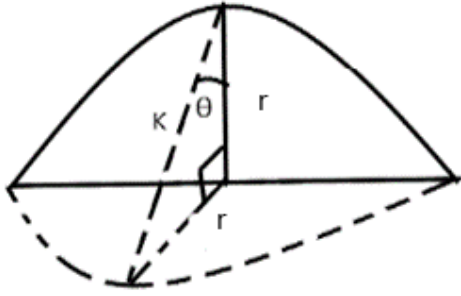


Fig 3. Flipping of plane of zitterbewegung to orthogonal plane by external magnetic field

The zitterbewegung of a charged particle in the way depicted in figure1 can create orthogonal magnetic field, which will be varying in magnitude. It can in turn create a varying orthogonal electric field. This magnetic field increases to the maximum value when the particle makes the largest circle. If the frequency of Larmor precession equals that of two cycles of zitterbewegung, the magnetic moment will reverse its direction in orthogonal axis after one cycle of zitterbewegung. The magnitude of magnetic moment due to zitterbewegung changes in direction but continues to increase and decrease in a sinusoidal wave pattern. It means that there is a generation of magnetic field and electric field as sine waves due to this process. Therefore it is possible to explain the generation of

electromagnetic wave using the concept of Zitterbewegung and Larmor precession.

The potential application of such a concept is that it can explain the source of heat energy other than the mechanisms like conductive loop and antenna effect in nuclear magnetic resonance. It is a known fact that both these phenomena are not able to explain completely the tissue heat generation[7]. The model described above gives the concept of release of radiant energy during relaxation in magnetic resonance and it can explain why there is higher chance of burn injury with higher electric field of radiofrequency pulse. It also explains the increased chance of burns with the higher static magnetic field as it necessitates higher energy required to flip the zitterbewegung to orthogonal plane because the amplitude of zitterbewegung is increased by the external static magnetic field[8]. This radiant energy can be a potential source of energy which can be used for ablation of tumours.

Wave function is used extensively in quantum physics to represent quantum particles in a probabilistic aspect. Here, a physical

meaning of wave function has been examined. This model can explain accurately the radiant energy generation in nuclear magnetic resonance including the radiofrequency. A geometrical analysis has been done to understand the physical meaning of the wave function [9,10].

$$\Psi(x,t)=e^{i(kx-wt)} = \text{Cos}(kx-wt) + i \text{Sin}(kx-wt).$$

$$e^{i(kx-wt)} = e^{i \pi^2 (x/\lambda - t/T)}$$

$$e^{\pi i} = -1, \text{ according to Euler's equation. } (e^{\pi i} + 1 = 0)$$

$$e^{\pi^2 i} = 1$$

So by complex analysis, when $kx-wt=0$, $x/\lambda - t/T=0$ and $e^{i(kx-wt)}=1$

In wave dynamics, when $kx - wt = 0$, $y=A\text{Cos}(kx-wt)$ or $y=A\text{Sin}(kx-wt)$ represents a nondispersive wave like an electromagnetic wave in vacuum.

$$\text{Therefore, } \text{Cos}(kx-wt) + i \text{Sin}(kx-wt) = 1$$

$$\text{It can be rewritten as } 1 - i \text{Sin}(kx-wt) = \text{Cos}(kx-wt)$$

After taking the derivative with respect to dx ,

$$-ik \cos(kx - \omega t) = -k \sin(kx - \omega t)$$

Therefore, $-\cos(kx - \omega t) = i \sin(kx - \omega t)$.

When square of the equation is taken, an equation with no imaginary numbers is obtained. $\cos^2(kx - \omega t) = -\sin^2(kx - \omega t)$.

The concept of standing wave for quantum particle is one of the basic consideration in quantum physics.[11,12,13]. In that view point, the meaning of wave function may be that the waveform $i\sin(kx - \omega t)$ is an imaginary wave equal and opposite to a real $\cos(kx - \omega t)$ wave and the superposition of these wave forms may result in closed curves like a standing wave. One closed curve of the standing wave is taken as a quantum in this article.

In Cartesian Co-ordinates, if x represents the displacement of free particle in the X direction and A represents the amplitude of oscillation in Y direction, it can be assumed as zitterbewegung of quantum particle in two dimensions. Zitterbewegung was first predicted by Schrodinger for Dirac electron[14].

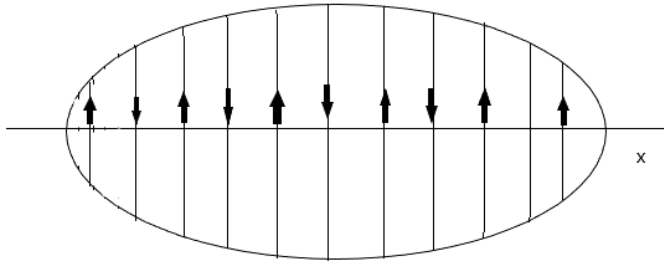


Fig4. Oscillating quantum particle forming an outline of a quantum of standing wave

$H = \frac{1}{2} m \frac{x^2}{t^2} + \frac{1}{2} m \omega^2 A^2 / t^2$. This equation can be visualised as an oscillating quantum particle within an outline of standing wave as in Fig 4.

But in this article, the zitterbewegung is considered to be a back-and-forth rapid circulatory motion of free quantum particle in XY plane rather than harmonic oscillation. Zitterbewegung of quantum particles has been considered as rapid circulatory motion previously[15]. In this article, it is examined using classical equations and geometry.

The hamiltonian can be written as $H = P^2/2m + \frac{1}{2} m \omega^2 r^2$.

This is similar to the harmonic oscillator equation described earlier.

The equation can be rewritten as, $H = \frac{1}{2} m v^2 + \frac{1}{2} m v r \omega$, where v is the linear velocity of the particle.

In expansion, $H = \frac{1}{2} m x^2 / t^2 + \frac{1}{2} m 2 \pi r x / t^2$

Taking derivative with respect to x , $dH/dx = (1/2m) t^2 d/dx(x^2 + 2 \pi r x)$

The total energy is constant for a quantum particle in harmonic motion.

$E = H = \text{Constant}$ (time independent hamiltonian)

Applying chain rule, $dH/dt = (dH/dx) (dx/dt) = 0$. Therefore $dH/dx = 0$

(dx/dt is a non zero term for a particle in motion)

Therefore, the derivative become, $2x + 2 \pi r + 2 \pi x dr/dx = 0$

Solving the equation,

$$dr/dx = -1/\pi - r/x$$

$$r = -x(1/\pi + dr/dx)$$

$$|r| = x(1/\pi + dr/dx)$$

$$|r| = x/\pi + x \, dr/dx$$

This equation means that the quantum particle travels in helical motion with changing radius. Using the equation, a graph on X-Y coordinates can be plotted. x is the displacement in the equation. It ranges from 0 to λ . r is the changing radius with respect to the displacement. A graph (Fig.5) can be plotted in Cartesian co-ordinates by taking $Y = \pm r$. Y is similar to the amplitude of oscillation (A) in the case of harmonic oscillator (Fig 4). A closed curve like a standing wave can be plotted. The graph has been drawn using boundary conditions, from $X = -\lambda/2$ to $X = +\lambda/2$ and assuming when position of the particle is in the negative X axis, the value of r increases and dr/dx is positive. When the position of particle is in the positive direction, r decreases and dr/dx is negative. It is obvious that the amplitude of oscillation should increase and decrease symmetrically for the particle to travel as wave as in Fig5. R is the radius when the position co-ordinate is $X=0$ and displacement $x = \lambda/2$.

In this model, quantum particle forms a standing wave like structure with maximum radius R and wavelength λ .

When $x = \lambda$, $|r| = \lambda (1/\pi + dr/dx)$

So, $dr/dx = 0 - R - R - 0 / \lambda = -2R / \lambda$.

$r/x = 0/\lambda = 0$.

Therefore- $2 R / \lambda = -1/\pi$.

Therefore, $\lambda = 2\pi R$. This is equal to the predicted radius for zitterbewegung.[16]

The equation can be written as, $|r| = x(1/\pi + dr/dx)$.

Here $|r| = x/\pi + xdr/dx$. The graph can be drawn as the following.

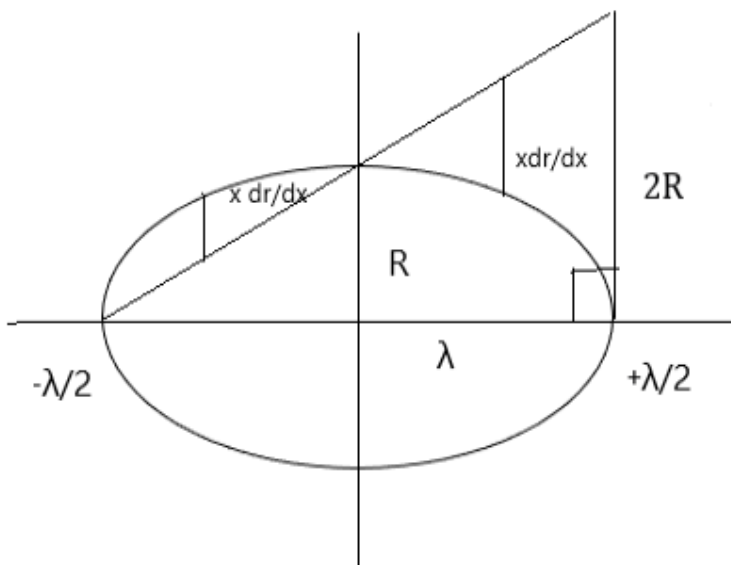


Fig 5. Outline formed by the quantum particle in one quantum

The equation can be written as $r = r^1 + x \, dr/dx$, (where $r^1 = x/\pi$ and $dr/dx = d\phi$ is the slope of the graph). The relation between the zitterbewegung and wave function can be proven using geometry (Fig3)

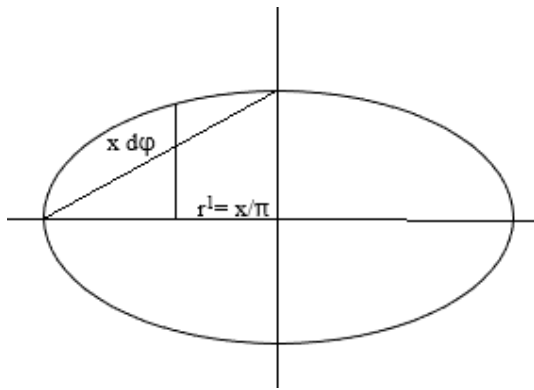


Fig 6. Relationship of one quantum with Cos wave

The slope of the graph, $dr/dx = d\phi$. It can be seen that the same right-angled triangle as in the graph can be drawn inside initial quarter of the cos wave $y = 1/2 \cos x$. The slope of the above graph and the Cos curve may be different. But all the other variables are the same for both the graphs. So, the difference between this graph and the Cos curve, $y = 1/2 \cos x$ is the variable $d\phi$. In the graph drawn

above, $d\phi$ ($dr/dx = d\phi$) represents the slope. If the difference of $d\phi$ in the curves is zero, the graph is exactly the initial quarter of the Cos curve.

The equation of the graph can be written as $|r| = x (1/\pi + dr/dx)$

Therefore when $x = \lambda$, $r = 0$

$$d\phi = 1/\pi = 0.31$$

When $r = R$, $d\phi = 0$

So, the value of $d\phi$ ranges from 0 to 0.3. The slopes of the half Cos curve ranges from 0 to 0.5. The difference of $d\phi$ between the curves ranges from 0 to 0.19. Therefore, it is geometrically appropriate to approximate the difference of $d\phi$ at each point of both the curves to zero. So one cycle of zitterbewegung can be approximated to non-dispersive wave function.

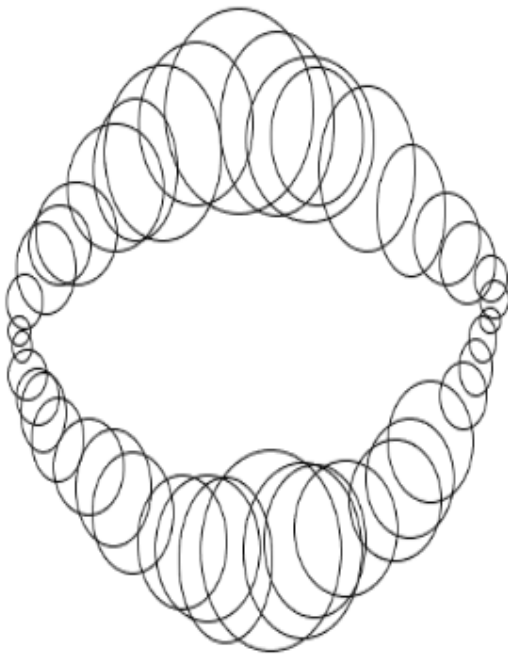
Therefore, the one quarter of the quantum is equivalent to the initial quarter part of $y = 1/2 \cos x$. In other words, the quantum may be considered as a superimposition of initial halves of two such Cos waves ($y = 1/2 \cos x$), considering symmetry about Y axis. The

upper half of quantum can be represented as part of the Cos wave,
 $y=R \cos kx$ which is shown to be equivalent to $y=1/2 \cos kx$. Here, k
 is the wavenumber, which is equal to $k=2\pi/\lambda^1$. It has to be noted
 that $\lambda^1=2\lambda$ where λ^1 is the wavelength of Cos wave.

The standing wave is formed by superimposition of
 the Cos waves in opposite direction. The standing wave can be
 mathematically represented by the superposition of Cos waves as,
 $\Psi(x)=R(\cos kx+ -\cos kx)$. Both the waves have same frequency and
 amplitude. It has been found in the earlier part of this article that $-$
 $\cos(kx-wt) = i\sin(kx-wt)$. Hence, $\Psi(x)=R(\cos kx+ i\sin kx)$. This is
 equivalent to $\Psi(x)=Re^{ikx}$. Therefore the wave function can be derived
 from the zitterbewegung using minor approximation.

The application of the above geometrical
 approximation is that a modified toroidal model can be derived to
 explain the generation of electromagnetic wave by proton. The wave
 function is formed by increasing and decreasing diameter
 zitterbewegung which precess and forms a toroid. The modified
 toroidal model can accurately explain the generation of

electromagnetic wave in nuclear magnetic resonance. The anapole magnetic moment changes its magnitude in a sinusoidal fashion and changes its direction with 180 degree precession.



jFig 7. The Modified toroidal model of Proton

In this article, an equation for zitterbewegung was derived using hamiltonian. It was plotted in XY Cartesian plane using appropriate boundary conditions. The graph was shown to be similar to the non-dispersive wave function geometrically using minor approximation. The zitterbewegung and wavefunction represent the

propagation of quantum particle in single cartesian plane. This interpretation of zitterbewegung allow for derivation of a model for generation of electromagnetic wave from particle motion. The concepts of zitterbewegung and Larmor precession allow for derivation of a modified toroidal model for proton. The practical application of such an interpretation is nuclear magnetic resonance and generation of radiofrequency photons and the associated radiant energy. This concept can explain the unknown cause of burns during MRI imaging other than the usual mechanisms. The potential application of such a hypothesis is its application in multifocal tumor ablation using non ionising radiation.

REFERENCES

1. Hestenes, D., 1990. Zitterbewegung Interpretation of Quantum Mechanics. Foundations of Physics, pp. 1213-1232
2. Riewe, F., 1972. Relativistic classical spinning-particle mechanics. Il Nuovo Cimento, Volume 8B, pp. 271-277

3. Huang K; On the Zitterbewegung of the Dirac Electron. American Journal of Physics 1 November 1952; 20 (8): 479–484. <https://doi.org/10.1119/1.1933296>
4. Vassallo G , Kovacs A. 2023 J. Phys.: Conf. Ser. 2482 012020
5. Zhai Y, Yue Z, Li L and Liu Y (2022), Progress and applications of quantum precision measurement based on SERF effect. Front. Phys. 10:969129. doi: 10.3389/fphy.2022.969129
6. Ruh, A, Kiselev, VG. Calculation of Larmor precession frequency in magnetically heterogeneous media. *Concepts Magn Reson Part A* 2019; 47A:e214729.
7. Tang M, Yamamoto T. Progress in Understanding Radiofrequency Heating and Burn Injuries for Safer MR Imaging. Magn Reson Med Sci. 2023 Jan 1;22(1):7-25. doi: 10.2463/mrms.rev.2021-0047. Epub 2022 Feb 26. PMID: 35228437; PMCID: PMC9849420
8. Vaseghi, B., Rezaei, G., Moini, Z., Hendi, S. H., and Taghizadeh, F., “Effects of external magnetic field on the electron Zitterbewegung in the quantum dots and wires with Rashba spin-

- orbit interaction”, *Superlattices and Microstructures*, vol. 49, no. 4, pp. 373–381, 2011. doi:10.1016/j.spmi.2010.12.004.
9. Schrödinger, E. (1926) An Undulatory Theory of the Mechanics of Atoms and Molecules. *Physical Review*, 28, 1049-1070
 10. Heller, E., Crommie, M., Lutz, C. *et al.* Scattering and absorption of surface electron waves in quantum corrals. *Nature* **369**, 464–466 (1994).
<https://doi.org/10.1038/369464a0>
 11. Hyungjin Huh; Standing waves of the Schrödinger equation coupled with the Chern-Simons gauge field. *J. Math. Phys.* 1 June 2012; 53 (6): 063702. <https://doi.org/10.1063/1.4726192>
 12. Adilbek Kairzhan *et al* 2022 *J. Phys. A: Math. Theor.* **55** 243001
 13. Auluck, F. (1945). The quantum mechanics of a bounded linear harmonic oscillator. *Mathematical Proceedings of the Cambridge Philosophical Society*, 41(2), 175-179.
doi:10.1017/S0305004100022520
 14. Barut, A. O. & Bracken, A. J. *Zitterbewegung* and the internal geometry of the electron. *Phys. Rev. D* **23**, 2454–2463 (1981).

15. Riewe, F., 1972. Relativistic classical spinning-particle mechanics. *Il Nuovo Cimento*, Volume 8B, pp. 271-277
16. Kerson Huang; On the Zitterbewegung of the Dirac Electron. *American Journal of Physics* 1 November 1952; 20 (8): 479–484. <https://doi.org/10.1119/1.1933296>

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article, as no datasets were generated or analysed during the current study.

FUNDING

No funding is there for this manuscript.

COMPETING INTEREST

No conflicts of interest.

