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The Wave Function Of The Tritium Atom In The Representation Of Momentum Space Using The Schrodinger Equation On Quantum Numbers

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Abstract

Particle wave dualism explains that particles can behave as waves, and vice versa. Particle and wave cannot be distinguished when to behave as particles and when to behave as waves because they have a very fundamental link. The purpose of this study was to determine the wave function of tritium atoms in the representation of momentum space using the Schrodinger equation on quantum numbers. type of research using non-experimental research which is a theoretical development. From the calculations performed to obtain the value of the wave function in the momentum space for n≤ 3 , obtained the value of the wave function at $n\ l\ m$ (1 0 0) of ; $\frac{2^{5/2}}{2\pi}\ \frac{1}{(p^2+1)^2}$ The value of the wave function at $n\ l\ m$ (2 0 0) is ; $\frac{32}{\sqrt{\pi}}\ \frac{(4p^2-1)}{(4p^2+1)^3}$ The value of the wave function at $n\ l\ m$ (2 1 0) is equal $\frac{128\sqrt{3}}{2\pi\sqrt{3}}\ \frac{p}{(4p^2+1)^3}\cos\theta$ and so on. Mwill know that the greater the price (*n*), the greater the electron power and the greater the price *(l)* the higher the angular velocity price.

Keywords: Wave Function; Tritium Atom; Momentum Space; and Schrodinger's Equation

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Introduction

The Schrodinger equation, discovered by Erwin Schrodinger, is a second-order differential equation used to describe the wave character of a particle expressed in terms of the wave function. The solution of the Schrodinger equation is known as the Schrodinger wave function which has linear, single and finite properties (Saputra et al., 2019). Schrodinger's equation can be used to determine the characteristics of electrons in atoms expressed in combinations of quantum numbers (n, l, m_l) (Supriadi et al., 2018). The method of separation of variables in a steady state can be used to find the solution of the wave function using the Schrodinger equation approach at spherical coordinates which is written as follows:

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\psi+\frac{2m}{\hbar^2}(E-V)\psi=0 \quad (1)$$

(Supriadi et al., 2022)

An atom is often thought to have spherical symmetry, so the Schrodinger equation is used to describe a hydrogen atom with spherical coordinates. Therefore, the Schrodinger equation for the hydrogen atom can be divided into two parts, namely the radial and angular parts, similar to the Schrodinger equation for spherical coordinates.Here is the Schrodinger equation for an atom in the coordinates of a 2-particle sphere:

$$\left(\frac{p^2}{2\mu}+V(r)\right)\psi = E\psi \quad (2)$$

(Maulana, 2019)

Where V(r) is the potential energy for the interaction force between an atomic nucleus and an electron, it can be written:

$$V\,(r) = -\frac{1}{4\pi\varepsilon_0}.\frac{e^2}{r} \quad (3)$$

(Maulana, 2019)

From equations (1) and (2), the Schrodinger equation in spherical coordinates becomes:

$$\frac{h^2}{2\mu}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\mu\phi^2}\right]\psi_{(r,\theta,\phi)}+[E-V(r)]\psi_{(r,\theta,\phi)}=0 \quad (4)$$

(Supriadi et al., 2022).

Based on the results of research (Makmum et al., 2020) the Hydrogen atom is a very simple atom and has a light mass because it consists of one proton and one electron in its orbital. Meanwhile, Helium is one of the atoms of the noble gas group that has two protons, two neutrons, and two electrons distributed in its orbitals. However, if one of the electrons in a Helium atom can be ionized it will become a Helium ion which will then behave like hydrogenic atoms. As explained by (Supriadi et al., 2018) the electron wave function in hydrogenic atoms is a form of complex quantity that includes radial and angular functions. In previous studies, there has been a solution to the problem of wave function in the position space with the Schrodinger approach. In research (Makmum et al., 2020) which examines the solution of the helium ion wave function in the representation of positional space using the Schrodinger equation. In addition, research (Fuadah et al., 2018) on deuterium atoms that have been carried out includes the solution of the Schrodinger equation of deuterium atoms in position space. The results stated that the radial equation depends on the variable r as well as the angular equation which consists of the polar equation which depends on the variable teta and the azimuth equation which depends on the variable. On research ψ(Utami et al., 2019). In addition to being able to be expressed in positional space, the atom can also be expressed in momentum space.

One of the atoms that can be expressed in momentum space is the tritium atom. According to (Prastowo et al., 2018) tritium is one of the isotopes of hydrogen with two neutrons in its nucleus and an electron surrounding the nucleus. Tritium atoms are composed of constituent components of 2 neutrons, 1 proton, and 1 electron. According to (Malacca, 2019) Tritium is also one of the natural radioactive elements that has a role as an internal radiation source. According to (Prastowo et al., 2018) Tritium emits beta rays with radioactive energy of 0 - 18.6 keV (average 5.7 keV) and has a half-life of 12.323 years. The kinetic energy of beta radiation is used as one of the power sources for semiconductor betavoltaic batteries. Betavoltaic batteries have the advantage of being able to last for a long time and in extreme conditions. In addition, according to (Supriadi et al., 2018) Betavoltaic batteries have advantages such as long service life, high energy density, and maintenance-free. According to (Malacca, 2019) in the form of HTO, Tritium can enter the body through the respiratory tract, food and drink. (Prastowo et al., 2018) along with the times, humans have begun to utilize tritium atoms such as ocean transient trackers.

Based on the description above, researchers will study further about the wave function of Tritium atoms in the representation of momentum space using the Schrodinger equation on quantum numbers. $n \leq 3$. Therefore, the researcher took the title "The Wave Function of Tritium Atoms in the Representation of Space Momentum by Using the Schrodinger Equation on Quantum Numbers$n \leq 3$. This study aims to examine the wave function of the Tritium atom in the representation of momentum space using the Schrodinger equation on quantum numbers.$n \leq 3$

Methods

Based on the research objectives, the type of research used in this study is non-experimental research, which is a theoretical development of existing theoretical research methods through theoretical research methods. This study is one semester in the academic year 2023/2024, in the advanced physics laboratory of the physics education study program, Faculty of Teacher Training Science and Education located at Jember University. These research steps include preparation, theoretical development, validation of theoretical development results, results/data collection, discussion and conclusions. To express the wave function in space the position of a hydrogenic atom can be expressed in the form of spherical coordinates as follows:

$$\frac{h^2}{2\mu}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\mu\phi^2}\right]\psi_{(r,\theta,\phi)}+[E-V(r)]\psi_{(r,\theta,\phi)}=0 \quad (5)$$

(Supriadi et al., 2022)

The method of separation of variables in the steady state can be used to find the solution of the wave function by applying the Schrodinger equation approach to the coordinates written as follows:

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\psi+\frac{2m}{\hbar^2}(E-V)\psi=0 \quad (6)$$

(Supriadi et al., 2022)

As well as laplacian operators :

$$\nabla^2=\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\phi^2} \quad (7)$$

(Marchelia et al., 2020)

By substituting the equations to (4) and (5), the equation will be obtained :

$$\frac{h^2}{2m}\frac{1}{r^2}\left[\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)+\frac{1}{sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\frac{\partial}{\partial\theta})+\frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\mu\phi^2}\right]\psi_{(r,\theta,\phi)}+[E-V(r)]\psi_{(r,\theta,\phi)}=0 \quad (8)$$

(Singh, 2009)

From equation (6), the equation of the radial function in the position space with the variable separation method is $\psi_{(r,\theta,\phi)}=R(r)\Theta(\theta)\phi(\phi)$ as follows :

$$R_{n,l}=\sqrt{\left(\frac{2}{na_0}\right)^2\cdot\frac{(n-l-1)!}{2n((n+1)!)^2}}\left(\frac{2r}{na_0}\right)^l\cdot e^{-\frac{r}{na_0}}\cdot l_{n+1}^{2l+1}\cdot\left(\frac{2r}{na_0}\right) \quad (9)$$

(Singh, 2009)

Meanwhile, the equation of the radial function in momentum space is as follows :

$$F_{n,l}=\frac{2^{2l+4}\,l!\pi}{\left(\frac{1}{na_0}\right)^{3/2}h^{3/2}}\cdot\left(\frac{n(n-l-1)!}{(n+l)!}\right)^{\frac{1}{2}}\cdot\frac{\zeta!}{(\zeta^2+1)^{l+2}}\cdot C_{n-l-1}^{l+1}\cdot\left(\frac{\zeta^2-1}{\zeta^2+1}\right) \quad (10)$$

With value :

$$\zeta=\frac{2np}{\left(\frac{z}{na_0}\right)h}\ dan\ a_0=\frac{2\pi p_0}{h} \quad (11)$$

Then obtained radial function :

$$F_{n,l}=\frac{2^{2l+5/2}\,l!n^2}{\sqrt{\pi}}\cdot\left(\frac{(n-l-1)!}{(n+l)!}\right)^{\frac{1}{2}}n^lp^l\cdot\frac{{P_0}^{l+\frac{5}{2}}}{(n^2p^2{P_0}^2)^{l+2}}\cdot C_{n-l-1}^{l+1}\cdot\left(\frac{n^2p^2-{P_0}^2}{n^2p^2+{P_0}^2}\right) \quad (12)$$

(Marchelia et al., 2020)

In addition to obtaining the radial function equation both in position space and mometum space, it will also be related to the angular function equation.
The general functions of the wave function that include the radial and angular functions are written as follows :

$$\varphi(p,\theta_p,\phi_p) = F_{n,l}(p)Y_{lm}(\theta_p,\phi_p) \quad (13)$$

(Makmum et al., 2020).

$F_{n,l}(p)$is a radial function and is $Y_{lm}(\theta_p,\phi_p)$ an angular function.

The angular function refers to the wave equation that describes the propagation of waves angularly or rotating based on the polar angle (θ) and azimuth angle (φ). Because angular equations are fixed or independent of unknown functions or operators such as V(r) in radial equations, the angular equation in hydrogen atoms is the same as the angular equation in spherical coordinates.
The general form of the angular function is written:

$$Y_{lm}(\theta,\phi) = \Theta_{lm}(\theta)\Phi(\phi) \quad (14)$$

The angular function or equation (7) consists of a polar function and an azimuth function. $\Theta_{lm}(\theta)$ is a polar function and is $\Phi(\phi)$ an azimuth function. The general form of polar functions is written :

$$\Theta_{lm}(\theta) = (-1)^m \sqrt{\frac{2l+1}{2}\frac{(l-|m|)!}{(l+|m|)!}} P_l^m(\cos\theta) \quad (15)$$

(Makmum et al., 2020)

The form of equation (7) containing an associated series of legendre polynomials $P_l^m(\cos\theta)$ can be written as follows:

$$P_l^m(\cos\theta) = (1-\cos^2\theta)^{\frac{|m|}{2}} \left(\frac{d}{d\cos\theta}\right)^{|m|} P_l(\cos\theta) \quad (16)$$

Equation (7) $P_l(\cos\theta)$ is a legendary function with the following equation:

$$P_l(\cos\theta) = \frac{1}{2^l l!}\left(\frac{d}{d\cos\theta}\right)^l (\cos^2\theta - 1)^l \quad (17)$$

(Makmum et al., 2020)

The general form of the azimuth function is written as follows :

$$\Phi(\phi) = \sqrt{\frac{1}{2\pi}}\, e^{\pm im\phi} \quad (18)$$

General form of wave function in momentum space:

$$\varphi(p,\theta_p,\phi_p) = F_{n,l}(p)Y_{lm}(\theta_p,\phi_p) \quad (19)$$

The flowchart in the calculation of the tritium ion function in the momentum space is as follows: :

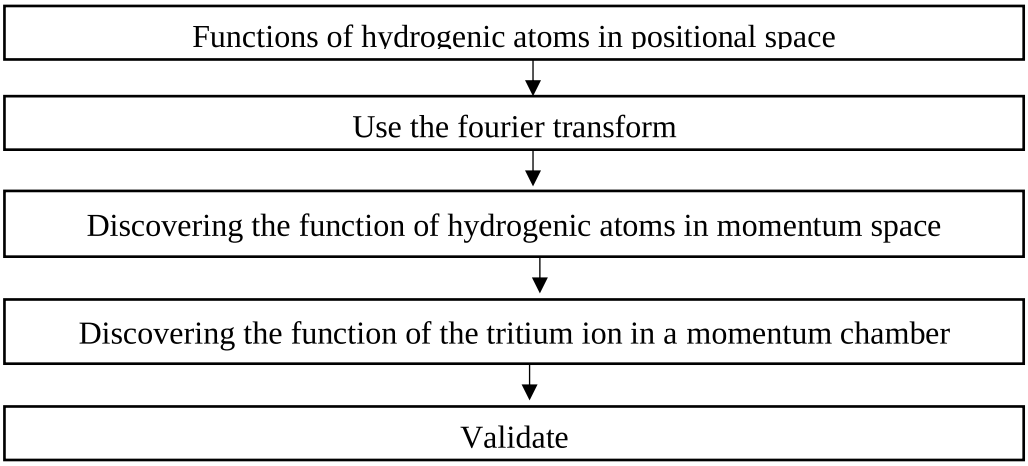

Figure 1. Tritium Ion Function Flow Table in the Momentum Chamber

The next stage is to obtain results. Results can be obtained from calculations mathematically from the development of theories. The results obtained at this stage will then be validated using the results of previous research. After the results are validated, the next step is to draw conclusions.

Results And Discussion

Tritium (T or 3H) is a radioactive isotope of hydrogen. The nucleus of tritium, also known as triton, has 1 proton and 2 neutrons, while the nucleus of protium, by far the most abundant isotope of hydrogen, consists of 1 proton and no neutrons. As explained by (National Center for Biotechnology Information, 2023) naturally occurring tritium is very rare on Earth, where small amounts are created from interactions between the atmosphere and cosmic rays, but tritium can be found in nuclear reactors when fusion occurs. In addition, (Utami et al., 2019) also explained that the tritium atom is one of the unstable hydrogen isotopes or in other words is radioactive.

In the Bohr atom, electrons in the tritium atom are expressed as particles orbiting the nucleus of the atom with total momentum and energy (E). The wave function in momentum space is expressed in terms of the Fourier transform of the wave function in position space (p) (Marchelia et al., 2020). Based on the results of the literature, data on the permanence$3H$ of Tritium () with $Z = 1$ (number of electrons) using reduced mass will be obtained, the wave function of Tritium atoms in space, position and momentum will be obtained based on table (1).

Table 1. Wave Function in Momentum Space $n \leq 3$

n	l	m	$F_{nl}(P)$	$Y_{lm}(\theta_p, \varphi_p)$	$\varphi(p, \theta_p, \phi_p)$
1	0	0	$\frac{2^{\frac{5}{2}}}{\sqrt{\pi}} p_0^{\frac{5}{2}} \frac{1}{(p^2+p_0^2)^2}$	$\frac{1}{2\sqrt{\pi}}$	$\frac{2^{5/2}}{2\pi} \frac{1}{(p^2+1)^2}$
2	0	0	$\frac{32}{\sqrt{\pi}} p_0^{\frac{5}{2}} \frac{(4p^2+p_0^2)}{(4p^2+p_0^2)^2}$	$\frac{1}{2\sqrt{\pi}}$	$\frac{32}{\sqrt{\pi}} \frac{(4p^2-1)}{(4p^2+1)^3}$
	1	0	$\frac{128}{\sqrt{3\pi}} p_0^{\frac{7}{2}} \frac{p}{(p^2+p_0^2)^3}$	$\frac{1}{2}\sqrt{\frac{3}{\pi}} \cos\theta$	$\frac{128\sqrt{3}}{2\pi\sqrt{3}} \frac{p}{(4p^2+1)^3} \cos\theta$
		± 1		$\mp\sqrt{\frac{3}{8\pi}} \sin\theta\, e^{i\phi}$	$-\frac{128\sqrt{3}}{2\pi\sqrt{6}} \frac{p}{(4p^2+1)^3} \sin\theta\ e^{i\phi}$
					$\frac{128\sqrt{3}}{2\pi\sqrt{6}} \frac{p}{(4p^2+1)^3} \sin\theta\ e^{-i\phi}$
3	0	0	$\frac{108\sqrt{2}}{\sqrt{3\pi}} p_0^{\frac{5}{2}} \frac{(81p^4-30p^2p_0^2+p_0^4)}{(9p^2+p_0^2)^4}$	$\frac{1}{2\sqrt{\pi}}$	$\frac{108\sqrt{2}}{2\pi\sqrt{3}} \frac{(81p^4-30p^2+1)}{(9p^2+1)^4}$
	1	0	$\frac{864}{\sqrt{3\pi}} p_0^{\frac{7}{2}} \frac{p(9p^2-p_0^2}{(9p^2+p_0^2)^4}$	$\frac{1}{2}\sqrt{\frac{3}{\pi}} \cos\theta$	$\frac{864}{2\pi\sqrt{3}} \frac{p(9p^2-1)}{(9p^2+1)^4} \cos\theta$
		± 1		$\mp\sqrt{\frac{3}{8\pi}} \sin\theta\, e^{i\phi}$	$-\frac{864\sqrt{3}}{2\pi\sqrt{6}} \frac{p(9p^2-1)}{(9p^2+1)^4} \sqrt{\frac{3}{8\pi}} \sin\theta\ e^{i\phi}$
					$\frac{864\sqrt{3}}{2\pi\sqrt{6}} \frac{p(9p^2-1)}{(9p^2+1)^4} \sqrt{\frac{3}{8\pi}} \sin\theta\ e^{-i\phi}$
	2	0	$\frac{5184}{\sqrt{3\pi}} p_0^{\frac{9}{2}} \frac{p^2}{(9p^2+p_0^2)^4}$	$\sqrt{\frac{5}{16\pi}} (3\cos^2\theta - 1)$	$\frac{5184\sqrt{5}}{4\pi\sqrt{15}} \frac{p^2}{(9p^2+1)^4} (3\cos^2\theta - 1)$
		± 1		$\mp\sqrt{\frac{15}{8\pi}} \sin^2\theta \cos\theta\, e^{i\phi}$	$-\frac{5184\sqrt{15}}{2\pi\sqrt{30}} \frac{p^2}{(9p^2+1)^4} \sin\theta\cos\theta\ e^{i\phi}$
					$\frac{5184\sqrt{15}}{2\pi\sqrt{30}} \frac{p^2}{(9p^2+1)^4} \sin\theta\cos\theta\ e^{-i\phi}$

n	l	m	$F_{nl}(P)$	$Y_{lm}(\theta_p, \varphi_p)$	$\varphi(p, \theta_p, \phi_p)$
		± 2		$\sqrt{\frac{15}{32\pi}}\, sin^2\theta\, e^{\pm 2i\phi}$	$\frac{5184\sqrt{5}}{4\pi\sqrt{15}}\ \frac{p^2}{(9p^2+1)^4} \sin^2\theta\cos\theta\ \ e^{2i\phi}$
		—			$\frac{5184\sqrt{5}}{4\pi\sqrt{15}}\ \frac{p^2}{(9p^2+1)^4} \sin^2\theta\cos\theta\ \ e^{-2i\phi}$

From the calculations performed to obtain the wave function in the momentum space for n , obtained the value of the wave function at (1 0 0) of ; $\leq 3n\ l\ m \frac{2^{5/2}}{2\pi}\ \frac{1}{(p^2+1)^2}$ The value of the wave function at (2 0 0) is ; $n\ l\ m\ \frac{32}{\sqrt{\pi}}\ \frac{(4p^2-1)}{(4p^2+1)^3}$ The value of the wave function at (2 1 0) is ; $n\ l\ m\ \frac{128\sqrt{3}}{2\pi\sqrt{3}}\ \frac{p}{(4p^2+1)^3}\cos\theta$ The value of the wave function at (2 1) is ; $n\ l\ m \pm\ 1 \pm \frac{128\sqrt{3}}{2\pi\sqrt{6}}\ \frac{p}{(4p^2+1)^3}\ \sin\theta\ \ e^{i\phi}$ The value of the wave function at (3 0 0) is ; $n\ l\ m\ \frac{108\sqrt{2}}{2\pi\sqrt{3}}\ \frac{(81p^4-30p^2+1)}{(9p^2+1)^4}$ The value of the wave function at (3 1 0) is ; $n\ l\ m \frac{864}{2\pi\sqrt{3}}\ \frac{p(9p^2-1)}{(9p^2+1)^4}\cos\theta$ The value of the wave function at (3 1) is ; $n\ l\ m \pm 1 \pm \frac{864\sqrt{3}}{2\pi\sqrt{6}}\ \frac{p(9p^2-1)}{(9p^2+1)^4}\sqrt{\frac{3}{8\pi}}\sin\theta\ \ e^{i\phi}$ The value of the wave function at (3 2 0) is equal to the value of the wave function at (3 2) of ; $n\ l\ m \frac{5184\sqrt{5}}{4\pi\sqrt{15}}\ \frac{p^2}{(9p^2+1)^4}\ (3\cos^2\theta - 1)$; $n\ l\ m \pm 1 \frac{5184\sqrt{15}}{2\pi\sqrt{30}}\ \frac{p^2}{(9p^2+1)^4}\sin\theta\cos\theta\ \ e^{i\phi}$ The value of the wave function at (3 2) is . $n\ l\ m \pm 2 \frac{5184\sqrt{5}}{4\pi\sqrt{15}}\ \frac{p^2}{(9p^2+1)^4}\sin^2\theta\cos\theta\ \ e^{2i\phi}$ Based on these calculations, it can be known that the greater the value *(n)*, the greater the electron power and the greater the price *(l),* the higher the price of angular velocity. The fundamental difference between the wave function of the Tritium ion in the momentum space and the wave function of the hydrogenic atom in another momentum space is in the value of the radial function caused by the difference in the value of (z) or atomic number.

The solution of the Tritium atomic equation can be obtained by combining the equations of the radial function and the angular function. The wave function consists of a polar function and an azimuth function, which forms part of the angular function. By combining the two equations, we get the wave function for the Tritium atom. Radial waves prove that electrons can be found at the distance of the electron's orbit (r) as it circles in the nucleus measured from the center of the atom. While the polar wave function proves the shape of electron orbitals based on the tetha angle (θ) that intersects the plane (x, y). Later, azimuth waves proved the motion of electrons rotating at periodic angles (ϕ) around the (z) axis. The solution of the Tritium ion is to combine the radial wave function and angular wave that proves the position of electrons and the shape of orbitals around the nucleus.

Radial wave functions and angular waves can be used to determine wave functions. These radial waves are influenced by the principal quantum number (n) and the orbital quantum number (l). Then the polar wave function is influenced by the orbital quantum number (l) and the magnetic quantum number (m) while the azimuth function relies on magnetic quantum numbers (m) The principal quantum number (n), orbital quantum number (l) and magnetic quantum number (m) prove the orbital energy level, orbital shape, and orbital space orientation. Associated lagendre polynomials exist in radial and polar wave functions.

Bohr's theory states that quantum numbers with the symbol n (principal quantum numbers) can be associated with solving radial equations. In addition, this quantum number is also a valuable positive integer $1,2,3,\ldots$ and so on to determine the electron energy of an atom that has more than one electron in its shells. The greater the price of n, the greater the electron power. The determination of the angular velocity of an electron can use the quantum number of orbitals (l). This quantum number deals with solving polar equations. The greater the price (l), the higher the angular velocity price. Electrons can also trigger an electric current that can cause a magnetic field due to the movement of electron orbitals. The quantum number related to this is a magnetic quantum number and (m) can also be referred to as an orbital orientation quantum number related to solving the azimuth equation (Marchelia et al., 2020).

Conclusion

Based on the results of research that has been carried out from the completion of the wave function of the tritium atom in the representation of momentum space using the Schrodinger equation on quantum numbers $n \leq 3$. The wave function can be obtained through the wave function formed from radial waves and angular waves. The fundamental difference between the wave function of the Tritium ion in the momentum space and the wave function of hydrogenic atoms in other momentum spaces is in the value of the radial function caused by the difference in the value of (z) or atomic number.

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