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Particle Spin and Magnetic Moment as Quantum Field Effects

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In a prior paper the author explained how the physical constants arise due to the polarizability and van der Waals torque of the quantum field of standard model quantum field theory. A more detailed development of how spin and magnetic moment arise from the quantum field is presented here. Recognizing that a central charge causes polarization of the quantum field, it is a simple matter to explain how the polarization process, rather than being random, leads to quantum dipole rotation on a common axis. This leads to spin and magnetic moment even when the central charge is static. This model also shows why the g-factor is approximately two instead of one, and how a semi-classical electron model can avoid the speed of light limit problem. This model can also be applied to protons by considering that a proton's magnetic moment is due to its actual radius rather than its Compton wavelength. The neutron magnetic moment is also predicted by this model more accurately than the quark model by assuming an orthogonal combination of the electron and proton magnetic fields.

1. Introduction

In a recent paper the author explained how the physical constants arise from the quantum field of standard model quantum field theory due to the polarizability and van der Waals torque of the quantum field.[1] A more detailed discussion of the physical origin of particle spin and magnetic moment is presented here.

Standard model quantum field theory treats the quantum field as a sea of particle pairs that are short-lived and thus often described as virtual particles. In practice this means that they are quantum resonators consistent with Planck's theory of quantum harmonic oscillators where their energy ($\boldsymbol{E}$) is equal to Planck's constant ($\boldsymbol{h}$) times their frequency ($\boldsymbol{f}$), ($\boldsymbol{E = hf}$).

Due to the existence of the Casimir effect, which exists because of van der Waals forces between quantum fluctuations, we know that quantum fluctuations behave like electric charge dipoles.[2] In Casimir theory, quantum dipoles are normally treated as Dirac-Fermion particle pairs. They are consistent with the Dirac equation and obey Fermi statistics. The electron-positron pair is the best-known representation of a Dirac-Fermion particle pair.

In a sea of quantum dipoles, those dipoles are polarized in the presence of an electric charge. When a charge moves, the quantum dipoles rotate becoming quantum magnets. In this way the polarizability and magnetizability of space and the related constants $\boldsymbol{\varepsilon_0}$ and $\boldsymbol{\mu_0}$ are physically due to the polarizability and magnetizability of the quantum field.[3]

Whenever there is a sea of dipoles, including those of the quantum field, they participate in van der Waals forces. One of those forces which receives little attention is van der Waals torque. In order for polarization and magnetization of space to occur, quantum dipoles must rotate. The inertia of the dipoles resists rotation and this resistance causes van der Waals torque. The van der Waals torque of the quantum field limits linear and rotational motion of any electric charge or electric dipole, including the motion of the quantum dipoles themselves.

2. Unit of Electric Charge

When we consider the quantized electric charge of particles we have extraordinary difficulty explaining how charge is physically quantized. At the heart of the problem is that particles come in many different masses, and hypothetical compositions, structures, and sizes. It seems impossible for every particle to have precisely the same electric charge.

We find a path forward by considering Gauss's law. Based on Gauss's Law, when we have a volume of space polarized by a unit charge ($\boldsymbol{e}$) within that volume, the surface integral of the flux of the polarization ($\boldsymbol{P}$) for that unit charge over the surface area ($\boldsymbol{A}$), gives us Equation 1. This equation gives the relationship between the polarizability of the quantum field and the quantized unit for electric charge.

Equation 1

$$e = \oint_S P \cdot dA$$

We can then note that the quantum field is uniform in free space. As such, the polarizability of free space is uniform. And, the unit electric charge is uniform given a single polarizer—charge.

If we consider particles as unit polarizers then the quantized nature of charge is readily explained by the uniform polarizability of the quantum field in free space. This interpretation moves the idea of electric charge from a property of a particle to the property of the quantum field surrounding the particle. Then instead of asking how a particle has charge we ask how it polarizes quantum dipoles. Note that there was additional discussion of issues related to this approach to understanding unit charge and its advantages in the prior paper.[1]

3. Particle Spin Quantum

As with electric charge it is difficult to conceive of a physical mechanism that allows particles of varying mass, and hypothetical size and structure to have the same quantized spin. And as with charge, the most obvious path forward is to consider spin as a property of something other than the particle that is uniform throughout space. Given the above approach to understanding charge, we can consider that spin and magnetic moment somehow arise from the polarization of the quantum field due to a unit polarizer.

Equation 2

$$S = \frac{1}{8\pi\epsilon_0}\frac{e^2}{\alpha c}$$

Spin quantization of particles occurs in increments of the reduced Planck's constant divided by two ($\pm\frac{1}{2}\hbar$), which can also be written in terms of Planck's constant as $\pm h/4\pi$. The spin quantum (S) is usually stated as simply ±½, with the $\hbar$ assumed and can be expressed in terms of electric charge, the permittivity of space (ε_0), the fine structure constant (α), and the speed of light (c) as shown in Equation 2.

Equation 2 can be simplified by expressing it in natural units where ε_0, and c are equal to one to obtain Equation 3. The spin quantum and Planck's constant are related to the ratio between the electric charge squared and the fine structure constant.

Equation 3

$$S = \frac{1}{8\pi}\frac{e^2}{\alpha}$$

It was also shown in prior papers that the fine structure constant is due to the volumetric polarizability of the quantum field due to a unit polarizer.[1][4] We can make that conclusion based on the relationship that $\alpha = e^2/2$ in one set of natural units. This result tells us the spin quantum, and consequently magnetic moment, arise due to physical processes related to the polarization of the quantum field.

Historically, it was unknown if spin is a physical kind of spin, or something else. But since Planck's constant appears when we consider angular momentum, treating the spin quantum as a physical spin of some kind is a good place to start. Given that charge arises as a property of quantum field polarization we can consider whether physical spin occurs as the quantum field is polarized around a polarizer.

4. How does the Quantum Field Spin?

A unit polarizer in free space causes the quantum dipoles in the surrounding space to be polarized. Our immediate reaction may be to think that no net rotation comes from that because the dipoles rotate in many directions such that the polarization process is neutral with respect to spin. However, that initial reaction is wrong.

To understand how quantized spin comes about we must first recognize that quantum dipoles undergoing polarization are continually being produced and annihilated. Polarization is an on-going process rather than a one-time event. Additionally, since there are vastly more quantum dipoles in space than are needed to form an electric field, only a few quantum dipoles need to rotate a fraction of a degree to achieve the correct field strength.

Most quantum dipoles are randomly oriented when produced, and we might assume that any reorientation with respect to a charged particle would also be random. In that case, however, adjacent dipoles would sometimes rotate in opposing directions.

If we envision two dipoles with similar wavelengths side-by-side, their like charges are near each other as they become polarized. As they rotate in opposite directions, one pair of like charges moves further apart while the other pair of like charges on the other end of the dipoles moves closer together. Energy is required for like charges to move toward each other as they naturally repel.

If on the other hand we imagine that the dipoles rotate the same direction when forming the electric field, the distance between the charges can remain relatively constant. Rotation of adjacent dipoles oriented with their axis of rotation in the same direction requires less energy than rotating similar dipoles in opposing directions. In a related situation it has been determined that a stable dipole on a rotating spherical surface tends to travel in a geodesic along the surface of that sphere.[5] So, it is expected that a collection of stable dipoles does the same.

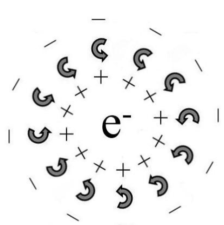

Fig. 1. Quantum dipoles around an electric charge, such as an electron, tend to rotate in a single direction in any given plane in order to achieve the correct state of polarization with the least amount of energy expended.

During quantum field polarization, nature automatically adapts to the process that requires the least amount of energy. This supports the idea that a group of quantum dipoles in a plane tend to rotate on a common axis as illustrated in Fig. 1.

When we consider the physical volume of a sphere filled with a continuum of quantum dipoles, the dipoles cannot all rotate on the same axis. The axis must change as the latitudinal angle with respect to the electric polarizer changes. Nonetheless, quantum dipoles undergoing polarization in a spherical field must preferentially rotate in one direction.

The net effect of the quantum dipoles undergoing polarization having a preferred direction of rotation gives the appearance that the particle is rotating, even though the polarizer at the center may not be rotating. The center of each quantum dipole does not necessarily move with respect to the central polarizer either.

The natural quantum dipole rotation that must arise during the polarization process gives us an explanation of how particle spin and magnetic moment come about. In this way particle spin is independent of the particle and the particle's internal structure. Rotating quantum dipoles produce a magnetic field thus giving a particle its magnetic moment. So, spin and magnetic moment have the same axis of rotation.

5. The Speed of Light Problem

Classical models of electrons as a distribution of charge on a spherical shell ran into a problem. In order for a classically modeled spherical electron to have the correct magnetic moment, the velocity of the surface of the sphere has to exceed the speed of light. This problem has doomed many attempts at physically modeling the electron.

The quantum dipole spin model solves that problem. To understand how it is important to note that under the constraints of a Planck resonator, a quantum dipole can rotate 180 degrees during its existence without exceeding the speed of light limit or other physical limitations. It is also important to remember that only a small percentage of the dipoles are needed to produce a polarized field, and thus they also only need to rotate a small fraction of a degree.

Consequently, the polarization of the dipoles around a polarizer can progress very rapidly from one to the other such that they almost appear to be rotating in unison. This gives the physical appearance of charges rotating on a spherical surface at a rate faster than the speed of light, while in truth, the center of each of the dipoles may not be moving at all relative to the central polarizer. It can be thought of in the same way individual lights in a string of lights can be turned on and off in progression to make it look like a single light is moving very rapidly. And thus, the speed of light limit is not violated.

6. Why is the g-Factor ≈2

Another of the great unanswered questions in physics is; why is the g-factor approximately equal to two? The g-factor came about as something of a fudge factor that is necessary when computing the magnetic moment of an electron. In early modeling of the electron's magnetic moment, physicists considered the electron as a rotating spherical surface of charge and computed the magnetic moment accordingly. What they realized is that the electron's magnetic moment is slightly more than two times what we expect based on this simple model.

Equation 4

$$\mu_S = g\frac{-e}{2m_e}S = -g\mu_B\frac{S}{\hbar} \cong \mu_B$$

In Equation 4 the electron spin magnetic moment (***μ_s***) is expressed in terms of the g-factor (***g***), electric charge, spin quantum and mass of the electron (***m_e***). It can alternatively be expressed in terms of the Bohr magneton (***u_B***) and reduced Planck's constant. And it is approximately equal to the Bohr magneton since g=2.00231930436182, and ***S***/***ħ*** = ½.

The g-factor is not precisely equal to two as there is a small correction factor due to properties of the quantum field including the self-energy of the electron. Those correction terms unsurprisingly tell us that there is a close connection between the magnetic moment and the quantum field.

If we take another look at Fig. 1 we can see why the g-factor is close to two instead of one. In the quantum field spin explanation of an electron it is composed of quantum dipoles that are rotating as they are polarized. Dipoles have both a negative and positive charge, so we do not have a simple model of a collection of negative charges on a spherical surface that appear to rotate in one direction. Instead we would have to model it as two spherical surfaces with a negatively charged surface inside a positively charged surface. The negative charges rotate in one direction and positive charges rotate in the opposite direction effectively doubling the strength of the magnetic field for a given quantum of angular momentum. That is where the factor of two comes from.

7. How is Mass Electromagnetic?

We must also note when looking at Equation 4 that electron mass is related to the magnetic field. This tells us that mass is a fundamentally electromagnetic property, but it does not explain precisely how mass is electromagnetic. We must think of mass in terms of quantum field theory to get a better understanding of magnetic moment in terms of quantum field theory.

Equation 5

$$\lambda_e = \frac{h}{m_e c}$$

To investigate how mass relates to electromagnetic theory we can look at Equation 5 for the Compton wavelength of the electron. Then we can then substitute and rearrange Equation 4 to get the second term of Equation 6. And since the spin quantum equals ***h/4π*** we can further simplify it as shown, eliminating Planck's constant and the spin quantum altogether.

Equation 6

$$\mu_S = -g\frac{e\lambda_e c}{2h}S = -g\frac{e\lambda_e c}{8\pi}$$

Note that the mass-energy of the electron is equivalent to the mass-energy of a Compton wavelength sized spherical shell. This can be shown by using the equation for the energy density (***ρ***) of the quantum field shown in Equation 8 in terms of circular frequency (***ω***) of the quantum fluctuations. And then computing the energy of a Compton wavelength diameter spherical shell with a thickness based on quantum uncertainty.[6] Note that this approach is similar to a hypothesis originated by Dirac that the electron mass-energy may be due to the energy required for it to push against the Dirac Sea, his early model of the quantum field.

Equation 8

$$\rho = \frac{\hbar(\omega_2^4 - \omega_1^4)}{8\pi^2 c^3}$$

In this way we can see that both the electron's magnetic field and mass-energy are consistent with something spherical that displaces quantum fluctuations the size of the electron's Compton wavelength. Per Gauss's law, electric charge can be thought of as the distributed quantum dipole polarization over a spherical surface. This allows us to consider an electron consisting partially of a spherical shell composed of quantum dipoles with a diameter equal to the Compton wavelength.

In this way the electron appears to be a very small, polarizer, perhaps approximating a point in some respects, that is surround by a quantum field. We can think of it as a bare electron. The quantum field around the bare electron gives it its properties of electric charge, spin, magnetic moment, and mass. Explaining how an electron comes to cause scattering like it has a spherical formation of quantum dipoles the diameter of the Compton wavelength is a question that still must be dealt with in the future.

8. Proton Spin and Magnetic Moment

We can consider the quantum field around protons in a similar way. A bare proton is a positive polarizer polarizing the quantum field around it. As with an electron it is more useful to think of the proton's effective wavelength rather than its mass ($\boldsymbol{m_p}$) when attempting to derive the proton's magnetic moment. The proton's magnetic moment is usually put in terms of the nuclear magneton ($\boldsymbol{\mu_N}$) shown in Equation 9.

Equation 9

$$\mu_N = \frac{e\hbar}{2m_p}$$

For consistency with the electron mathematics we can express the proton's magnetic moment ($\boldsymbol{\mu_{sp}}$) in terms equivalent to Equation 4 as shown in Equation 10, where $\boldsymbol{g_p}$ is the g-factor for the proton in equivalent terms to the electron g-factor.

Equation 10

$$\mu_{sp} = g_p \frac{e}{2m_p} S = g_p \mu_N \frac{S}{\hbar}$$

Now we can put it in terms of wavelength rather than mass, since it is easier to understand how the proton's physical size relates to its magnetic moment. The current CODATA value for the proton's Compton wavelength is 1.321409853 x 10^{-15} meters, so we could use that. The problem is that the proton's Compton wavelength does not match up with the known physical dimensions of a proton.

If we want to consider physical reality with respect to a proton's spin and magnetic moment, we must use the proton's charge radius. The current CODATA value for the charge radius is 0.8751×10^{-15} meters. That gives us a value for the diameter of the proton of 1.7502×10^{-15} meters, which is 1.3245 times larger than the proton's Compton wavelength.

If we then consider the energy density equation for the quantum field (Equation 8) and compute the energy displaced by a spherical shell of 1.7502×10^{-15} meters diameter with a thickness due to quantum uncertainty, we can derive the mass-energy of the proton.[6] In physical reality, the mass of the proton should not be considered as a relationship with the proton's Compton wavelength as the true relationship is with the proton's actual diameter.

We can define the proton diameter as being equivalent to a wavelength we can denote as $\boldsymbol{\lambda_p}$ and enter that into an equation equivalent to Equation 6 to get Equation 11.

Equation 11

$$\mu_{sp} = g_p \frac{e\lambda_p c}{2h} S = g_p \frac{e\lambda_p c}{8\pi}$$

By using the proton diameter based on the charge radius instead of the proton mass or Compton wavelength and including the basic proton g-factor of 2, we compute a value for the proton's magnetic moment that is 2.649 times the nuclear magneton. This is much closer to the true magnetic moment which has a CODATA value of 2.7928473508 times the nuclear magneton.

So instead of using a g-factor of ~2.79285 we instead have a g-factor of ~2.1086 when we use the proton radius magneton that we can symbolize $\boldsymbol{\mu_{Pr}}$. This opens up the possibility that like the electron, the correction to the g-factor for the proton may be due to similar quantum field and self-energy corrections. We might even expect that the proton's g-factor correction terms would be proportionally greater than those of the electron due to the much smaller wavelength, smaller magnetic moment, and higher mass-energy of the proton. Since the computation of the correction to the proton g-factor with respect to this model is an involved process, it is being left for a future paper.

The large difference between the standard proton g-factor and the electron g-factor has been pointed to as evidence for a structural difference between electrons and protons. If, however, we consider the proton's real physical diameter and the related proton radius magneton, it opens up the possibility that the electron and proton have the same structure. And that structure is due to the polarization of the quantum field surrounding a bare electron or proton.

9. Neutron Spin and Magnetic Moment

Neutrons are fascinating in that even though they are electrically neutral they still have a magnetic moment. The CODATA value for the neutron magnetic moment happens to be negative and equal to −1.91304272 μ_N. That is equal to -1.44435 μ_{Pr} in terms of the proton charge radius. The ratio between the proton and neutron magnetic moment is 1.45989806. Or, to consider the inverse, the neutron magnetic moment is ~0.68498 smaller than the proton's. This is still much larger than we would expect for an electrically neutral particle, which we might assume to have zero magnetic moment.

A neutron is not, however, electrically neutral in the center as we might naively assume from the transposition of two point-like opposing polarizers. It also does not contain three distinct fractional point-like charges as we might naively assume from the quark model. The predicted neutron magnetic moment due to the quark model is -1.86 μ_N, so the quark model is not very precise in that respect either.

In scattering experiments, protons and neutrons behave like they are composed of a collection of vacuum fluctuations rather than distinct stable particles. This is more in line with Feynman's original parton theory of the proton.[7] And, it is also consistent with the quantum field model suggested in this paper.

The neutron has a negatively charged center, a spherical band of positive charge around that, and is weakly negatively charged outside the positive band of charge.[8] This nonuniformity is not at all unexpected in the quantum field approach given that the neutron is filled with quantum electric dipoles. The nonuniformity dominated by negative electric charge leads to the negative magnetic moment. Since we currently have no idea what bare electrons and protons might look like it is impossible to properly model the bare neutron at this stage.

It is interesting that the square root of the proton g-factor relative to the charge radius 2.1086 is 1.4521 which is 0.5% from the absolute value of the measured neutron g-factor of -1.44435 μ_{Pr}. This equates to -1.9233 μ_N. These results are substantially closer than the commonly cited number from quark theory.

To understand what this means physically we can think of it in terms of combining the magnetic moments of a proton and electron. As part of that we can consider that as an electron combines with a proton, its quantum field collapses around it to the proton charge radius. Something like this is physically necessary since the neutron radius is similar to that of a proton and much smaller than the electron's Compton wavelength. By collapsing in this way an electron's new g-factor, which we can call $-g_{er}$, should become closer to the proton g-factor in μ_{Pr} terms.

We can subtract this electron g-factor from the proton μ_{Pr} g-factor and divide by 2 to account for the neutron being a spin ½ particle rather than spin 1. And then we can take the square root, to get the neutron g-factor in μ_{Pr} terms as shown in Equation 12. There are several different ways to mathematically compute this result so consider Equation 12 a conversation starter.

Equation 12

$$g_{Nr} = -\sqrt{\frac{g_{Pr} - g_{er}}{2}}$$

This equation hints at a physical interpretation where the magnetic moments of the electron and proton combine orthogonally to form a neutron. This also implies that the separate spin of the electron and proton also combine together into the neutron's rotating quantum field—spin. Then half the spin would be spun off into a separate field effect—particle. Further work on the quantum field of the neutron and derivation of a precise form of Equation 12 is left for a future paper.

10. Conclusion

When considering spin and magnetic moment explained as quantum field effects it is necessary to first understand that polarization causes charge rather than charge causing polarization. Under Gauss's Law, the polarized quantum field due to a unit polarizer, such as a bare electron, yields a unit charge.

Then we must recognize that spin arises during quantum field polarization. Polarization is not a spin neutral process as that would require additional energy expenditure. The virtual simultaneity of the dipole rotation even makes it appear like a sphere rotating faster than the speed of light, instead of a whole bunch of dipoles rotating about their own axis without moving much if at all relative to a bare electron or proton. This makes spin a function of the polarizability and van der Waals torque of the quantum field.

Since the bare particle is now surrounded by a quantum field of rotating dipoles, those dipoles produce a magnetic field, which is the magnetic moment of the particle. So magnetic moment is a function of the polarizability and van der Waals torque of the quantum field.

And, since the dipoles have one charge rotating one way and the opposite charge rotating the other way, the magnetic moment is twice as large as we would get from a spherical model with a single charge, thus telling us why the g-factor is approximately two instead of one.

It is also important to note that it does not make much sense to think of the magnetic moment in terms of mass, because we do not usually think of mass as an electromagnetic effect, even though it is. Instead we can write the electron magnetic moment in terms of its Compton wavelength, and since we are no longer converting the wavelength to mass-energy, Planck's constant drops out of the equation.

With protons we find that we have been using the wrong wavelength all along since the proton Compton wavelength is smaller than the proton's real physical dimension. Once we treat the proton's real wavelength as twice its charge radius, we find that the proton's true g-factor is close to two, as we expect if electrons and protons have the same structure.

Combining all that together we can see that the electron and proton charge, spin, magnetic moment, and mass are all properties of the quantum field rather than the particle. And these are ultimately properties of the polarizability and van der Waals torque of the quantum field.

By considering the actual neutron radius it is easy to see that its magnetic moment appears to be the orthogonal combination of the quantum field magnetic moments of a proton and electron. Computing the neutron magnetic moment using the g-factor based on the actual proton radius, yields a more precise computation of the neutron magnetic moment than achieved with the quark model.

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