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Relationship Between the Electron Magnetic Moment, and the Magnetic Flux Density Around Electrical Conductors

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Abstract: Electrons have intrinsic properties of electrostatic charge and magnetic moment. Is the magnetic field around an electrical conductor due to the electrostatic charge or the magnetic moment? Contemporary mathematics states that the field is due to the electrostatic charge. This paper proposes that the field is due instead to the magnetic moment. The distinction provides a significant new understanding of magnetism. In this paper the magnetic flux density around a single free electron is equated to the electron's intrinsic magnetic moment. The flux density around an electrical conductor is then calculated by multiplying the number of free electrons comprising the electrical current by the flux density around the individual electron. The paper provides a Gaussian relationship between the electron's intrinsic magnetic moment and the electron's surrounding magnetic flux density. Force fields and forces of nature are discussed.

Keywords: magnetism; magnetic moment; magnetic flux density; Gauss; force fields

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1. Introduction

In this paper the magnetic flux density (B) surrounding an electrical conductor is calculated by multiplying the magnetic flux density surrounding an individual free electron (b) by the number of free electrons comprising the electrical current. The calculation relates the magnetic flux density of the individual electron b to the individual electron's intrinsic magnetic moment (μ_e). The paper provides a Gaussian relationship between the electron's intrinsic magnetic moment μ_e and the magnetic flux density surrounding the individual free electron b. Force fields and forces of nature are discussed.

2. Relationship Between the Electrostatic Charge q_e and the Magnetic Moment μ_e

The electron's electrostatic charge q_e and magnetic moment μ_e are both intrinsic properties of the electron, and have the following constant values (National Institute of Standards and Technology):

Electrostatic charge	q_e	$= -1.602{,}176{,}634 \times 10^{-19}$	Units:	C	(1)
Magnetic moment	μ_e	$= -9.284{,}764{,}692 \times 10^{-24}$	Units:	Nm/T	(2)
Mass	m_e	$= 9.109{,}383{,}714 \times 10^{-31}$	Units:	kg	(3)

Therefore, there is a fixed ratio of q_e/μ_e, where,

$$q_e/\mu_e = -1.602{,}176{,}634 \times 10^{-19}/-9.284{,}764{,}692 \times 10^{-24} \quad (4a)$$

$$q_e/\mu_e = 17{,}255.974{,}569 \quad \text{Units: } s/m^2 \quad (4b)$$

And then q_e equals,

$$q_e = \mu_e(17{,}255.974{,}569) \quad \text{Units: } (m^2C/s)(\ s/m^2) = C \quad (5)$$

The electrostatic charge q_e is proportional to the magnetic moment μ_e. The two properties are different, but if we know the value of one, we know the value of the other because of their fixed ratio.

Therefore, the electrostatic charge q_e can be a proxy for the magnetic moment μ_e. The reciprocal of Equation 4 is,

$$\mu_e/q_e = 0.000,057,950,943 \quad \text{Units: } m^2/s \quad (6)$$

3. Existing Equations Unchanged

According to Equation 4, the ratio of q_e/μ_e is constant. We can therefore always express the traditional magnetic and electromagnetic equations in terms of q_e (as is currently done) or in terms of μ_e. Therefore, the existing magnetic and electromagnetic equations remain intact and unchanged by the mathematics presented in this paper.

4. Magnetic Field Surrounding an Electrical Conductor

The existence of circular magnetic fields surrounding electrical conductors was discovered by Hans Christian Oersted in 1820. According to Ampere's Law, the magnetic flux density (B) around an electrical conductor is equal to,

$$B = \mu_o I/2\pi R \quad \text{Units: } T \quad (7)$$

$$\mu_o = 4\pi \times 10^{-7} \quad \text{Units: } Tm/A \quad (8)$$

where μ_o is the permeability of free space, I is the electron current, and R is the radial distance from the electrical conductor. Electron current I is equal to,

$$I = Q/t = n_e q_e/t \quad \text{Units: } C/s \quad (9)$$

where the overall charge in motion (Q) is equal to electron charge q_e times the number of free electrons traveling lengthwise through the wire (n_e). Substituting Equation 9 for electrical current into Equation 7 we have,

$$B = \mu_o n_e q_e/t2\pi R \quad \text{Units: } T \quad (10)$$

And substituting Equation 5 for q_e into Equation 10 we have,

$$B = \mu_o n_e \mu_e(17{,}255.974{,}569)/t2\pi R \quad \text{Units: } T \quad (11)$$

This paper proposes that in Equation 10, q_e is not producing the magnetic field B. q_e is simply a proxy for the actual source of the magnetic field, μ_e(17,255.974,569), as shown in Equation 11.

5. Relationship Between the Magnetic Moment μ_e and Magnetic Flux Densities b and B

Let's revisit Equation 7 for the magnetic flux density B surrounding an electrical conductor. The electron current for a single electron (ie) is equal to,

$$i_e = q_e/t \quad \text{For } n_e = 1 \quad \text{Units: } C/s \quad (12)$$

The magnetic flux density attributable to the single electron (b) is then equal to,

$$b = \mu_o i_e/2\pi R = \mu_o q_e/t2\pi R \quad \text{For } n_e = 1 \quad \text{Units: } T \quad (13)$$

And then the overall magnetic flux density around an electrical conductor is equal to,

$$B = b n_e = \mu_o n_e q_e/t2\pi R \quad \text{Units: } T \quad (14)$$

We may also rearrange Equation 13 to solve for the electron current i_e of a single electron,

$$i_e = b2\pi R/\mu_o \quad \text{Units: } C/s \quad (15)$$

Let's introduce a new term: **Electron characteristic magnetic moment area (A_b)**. Magnetic moment μ_e for a single electron is equal to the electrical current of the single electron i_e times the electron characteristic magnetic moment area A_b for the single electron, where,

$$\mu_e = A_b i_e \quad \text{Units: } m^2(C/s) \quad (16)$$

Rearranging terms in Equation 16 to solve for electron characteristic magnetic moment area A_b we have,

$$A_b = \mu_e/i_e = \mu_e/(q_e/t) \quad \text{Units: } (m^2C/s)/(C/s) = m^2 \quad (17)$$

$$t = 1 \text{ second}$$

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And solving for electron characteristic magnetic moment area A_b for a time period t of one second we have,

$$A_b = \mu_e/(q_e/t) = -9.284{,}764 \times 10^{-24}/-1.602{,}177 \times 10^{-19} \quad (18a)$$

$$A_b = 0.000{,}057{,}950{,}943 \quad \text{Units: } (m^2C/s)/(C/s) = m^2 \quad (18b)$$

It can be seen that the term $\mu_e/(q_e/t)$ in Equations 17 and 18 are equal to Equation 6 times the time period of one second (t = 1), where,

$$(\mu_e/q_e)t = (0.000{,}057{,}950{,}943)t = A_b \quad \text{Units: } (m^2/s)s = m^2 \quad (19)$$

$$t = 1 \text{ second}$$

Rearranging terms in Equation 16 to solve for single electron current i_e we have,

$$i_e = \mu_e/A_b = q_e/(1 \text{ second}) \quad \text{Units: } C/s \quad (20)$$

Setting Equations 15 and 20 equal to each other we have,

$$b2\pi R/\mu_o = i_e = \mu_e/A_b \quad \text{Units: } C/s \quad (21)$$

Solving for electron flux density b we have,

$$b = \mu_e\mu_o/2\pi RA_b \quad \text{Units: } T \quad (22)$$

We next solve for the overall magnetic flux of an electrical conductor by multiplying Equation 22 by the free electrons in motion n_e:

$$B = bn_e = \mu_e\mu_o n_e/2\pi RA_b \quad \text{Units: } T \quad (23)$$

Let's define in more detail the number of free electrons in motion n_e traveling lengthwise through the wire, where,

$$n_e/(1 \text{ second}) = n_C A_C v_d \quad \text{Units: } (e/m^3)(m^2)(m/s) = e/s \quad (24)$$

where the electrical conductor's cross-sectional area (A_C) is in units of m^2, and electron drift velocity (v_d) is in units of m/s. The number of free electrons in a cubic meter of copper (n_C) is (Walker, J., 2011),

$$n_C = 8.49 \times 10^{28} \text{ Copper} \quad \text{Units: } e/m^3 \quad (25)$$

In a copper electrical conductors one of the outer valance electrons is free to leave the atom. This free motion of the outer electrons enables the flow of electron current through copper wire.

Replacing n_e in Equation 23 with Equation 24 we have,

$$B = \mu_e\mu_o n_C A_C v_d/2\pi RA_b \quad \text{Units: } T \quad (26)$$

Equations 23 and 26 solve for the magnetic flux density B around the electrical conductor by summing the magnetic moments μ_e of all of the free electrons in the electrical current I.

Next, we convert Equation 26 back to Equation 7. Substituting into Equation 26 the equality of Equation 20, $q_e/(1 \text{ second}) = \mu_e/A_b$, we have,

$$B = \mu_o q_e n_C A_C v_d/2\pi R \quad \text{Units: } T \quad (27)$$

Let's revisit Equations 9 and 24.

$$I = q_e(n_e/t) \quad \textit{Repeated for reading continuity} \quad (9)$$

$$n_e/t = n_C A_C v_d \quad \textit{Repeated for reading continuity} \quad (24)$$

Substituting Equation 24 into Equation 9 we have,

$$I = q_e n_C A_C v_d \quad \text{Units: } C/s \quad (28)$$

Substituting Equation 28 into Equation 27 we then again have Equation 7,

$$B = \mu_o I/2\pi R \quad \text{Units: } T \quad (7)$$

Equations 7, 23, 26 and 27 solve for the magnetic flux density B around an electrical conductor. As stated earlier, Equations 23 and 26 solve for the magnetic flux density B around the electrical conductor by summing the magnetic moments μ_e of all of the free electrons in the electrical current I. It is assumed that the free electrons align with the direction of the electrical current when in free space between the copper atoms.

6. Magnetic Moment and Torque

The terms "torque" and "moment" have similar meanings, with torque generally relating to rotating systems (for example with an internal combustion engine), and "moment" generally relates to stationary systems (for example the structural engineering of a cantilevered porch deck). In both cases a force is applied at a radial distance from the axis of rotation or a radial distance from a pivot axis. Turning of a nut with a wrench is one example of a force being applied at a radial distance from

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the axis of rotation. We commonly say the individual is providing a torque with the wrench, but may also say the individual is providing a moment.

The electron is known to have an intrinsic magnetic moment μ_e. The term "moment" is used with the electron because the magnetic force field is understood to not actually be spinning. There is a static twisting force. The static twisting force is somewhat like the structural engineering example of the porch, where a moment is present without rotation.

7. Gaussian Relationship Between the Magnetic Moment and Rotational Magnetic Flux

Let's begin by recalling Equations 16 and 22:

$$\mu_e = A_b i_e \qquad \text{Units: } m^2(C/s) \quad (16)$$

$$b = \mu_e \mu_o / 2\pi R A_b \qquad \text{Units: } T \quad (22)$$

The permeability of free space μ_o is equal to:

$$\mu_o = 4\pi(10^{-7}) \qquad \text{Units: } kgm/C^2 \quad (29)$$

Equation 22 is then equal to,

$$b = \mu_e 4\pi(10^{-7})/2\pi R A_b$$

$$b = \mu_e 2(10^{-7})/R A_b \qquad \text{Units: } (m^2C/s)(kgm/C^2)/m^3 = kg/Cs = T \quad (30)$$

We then multiply both sides by electron characteristic magnetic moment area A_b to solve for electron magnetic flux (ϕ_b):

$$\phi_b = bA_b = \mu_e 2(10^{-7})/R \qquad \text{Units: } Tm^2 \quad (31)$$

We then multiply both sides by radial distance R and divide by $2(10^{-7})$ to solve for the magnetic moment μ_e in terms of magnetic flux ϕ_b:

$$\phi_b R/2(10^{-7}) = bA_b R/2(10^{-7}) = \mu_e \quad (32a)$$

$$\phi_b R(5{,}000{,}000) = bA_b R(5{,}000{,}000) = \mu_e \quad (32b)$$

$$\text{Units: } = (kg/sC)m^3(C^2/kgm) = m^2C/s$$

Where,

$$5{,}000{,}000 = 1/2(10^{-7}) \quad (33)$$

The force field on the left side of Equation 32 is equal to the magnetic moment on the right side of Equation 32. The electron magnetic moment μ_e is equal to the electron magnetic flux ϕ_b times radial distance R, times the units conversion factor and scalar 5,000,000.

According to Gauss, the charge creating a force field is equal to the total flux of the force field times a units conversion factor and scalar. In this case the magnetic flux ϕ_b is the force field, R is the radial distance needed to produces the magnetic moment or "magnetic torque", and 5,000,000 is the units conversion factor and scalar. The magnetic field strength $\phi_b R(5{,}000{,}000)$ is equal to the magnetic moment μ_e.

8. Gaussian Relationship Between Force Fields and Their Charges

This paper proposes that the electron magnetic moment μ_e is the source charge producing the electron magnetic field strength $\phi_b R(5{,}000{,}000)$. Accordingly, it is proposed that magnetism meets the definition of a force of nature, where the charge and flux are equated through Gauss's Law.

In nature there are four known forces of nature, each having a charge and a force field. The forces of nature are:

- Gravity
- Electrostatic
- Weak nuclear force
- Strong nuclear force

For these forces of nature we have observed different force field orientations. Protons radiate flux outwardly, and electrons and gravity have flux that radiates inwardly. The week and strong nuclear forces do not obey the inverse square law. We observe that force fields have different

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orientations. Why not then consider other orientations? This paper proposes that the electron magnetic moment μ_e is a rotational magnetic charge having a rotational force field. We may now refer to the electron magnetic moment μ_e as the rotational magnetic charge of the electron (μ_{ec}), where,

$$\mu_{ec} \equiv \mu_e \qquad \text{Units: } m^2C/s \qquad (34)$$

The electron's electrostatic charge q_e has a radial force field, and the electron's magnetic charge μ_{ec} has a rotational force field. This paper proposes that magnetism be considered as the fifth know force of nature, one that presents as a rotational moment. The Gaussian relationship between the rotational magnetic charge μ_{ec} and the magnetic force field of a single electron is:

$$\mu_{ec} = \phi_b R(5{,}000{,}000) \qquad \text{Units: } m^2C/s \qquad (35)$$

The search for magnetic monopoles has been unsuccessful. This is because the magnetic force field is in the form of a closed loop that does not have ends. Closed loops do not have poles.

9. Special Relativity

Einstein describes in his 1905 paper that magnetism is a variance in the electrostatic force field that is found by applying Special Relativity (Einstein, A., 1905, June 30). At the time a reason for the non-existents of magnetic charges (monopoles) was needed for a more complete explanation of the Maxwell equations. According to Einstein's logic, magnetism never existed in the first place, it is simply a manifestation of the electrostatic force field from charged particles in motion.

The traditional mathematical approach for calculation of magnetism due to Special Relativity effects includes calculation of the attraction between two parallel wires with electrical current flowing equally through them in the same direction (Feynman, R., 2010; Purcell, E., & Morin, D., 2013: Griffiths, D., 2017: Schwartz, M., 1972).

Attributing magnetism to Special Relativity effects has two drawbacks. In the first case, the field around the electrical conductor has a rotational orientation. According to Special Relativity, the conductor would experience radial not rotational flux. In the second case, the effect of Special Relativity has been shown to produce only a negligibly small effect in common electrical conductors. This is due to the slow electron drift velocities relative to the speed of light (Mendler, C. April 2025).

Accordingly, Special Relativity does not account for the observed magnetic force field strength, and furthermore, Special Relativity would produce radial and not rotational flux. In this paper the observed magnetic field is attributed to the electron magnetic moment μ_e. The electron magnetic moment μ_e is an intrinsic property of the electron.

10. Conclusion

In this paper the magnetic flux density B surrounding an electrical conductor is calculated by multiplying the magnetic flux density surrounding an individual free electron b by the number of free electrons comprising the electrical current. The calculation relates the magnetic flux density of the individual electron b to the individual electron's intrinsic magnetic moment μ_e. The paper provides a Gaussian relationship between the electron's intrinsic magnetic moment μ_e and the magnetic flux and flux density surrounding the individual free electron.

The electrostatic charge q_e is proportional to the magnetic moment μ_e. The two properties are different, but if we know the value of one, we know the value of the other because of their fixed ratio. Therefore, the electrostatic charge q_e can be a proxy for the magnetic moment μ_e. We can therefore always express the traditional magnetic and electromagnetic equations in terms of q_e (as is currently done) or in terms of μ_e. The existing magnetic and electromagnetic equations remain intact and

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unchanged by the mathematics of this paper, because they can always be expressed in terms of electrostatic charge q_e. However, we gain further understanding of the magnetic and electromagnetic behavior by recognizing that the magnetic field circling electrical conductors is due to the intrinsic magnetic moment μ_e, and not due to q_e.

This paper proposes that the electron magnetic moment μ_e is the source charge producing electron magnetic flux ϕ_b and flux density b. Accordingly, it is proposed that magnetism meets the definition of a force of nature, where the charge and flux are equated through Gauss's Law. The Gaussian relationship between the rotational magnetic charge μ_{ec} and the magnetic force field of a single electron is:

$$\mu_{ec} = \phi_b R(5,000,000) \text{ Units: } m^2C/s$$

The electron magnetic moment μ_e and Bohr Magnetron Number $\overrightarrow{M}_B$ are largely similar. The proposed rotational magnetic charge relates to both terms, where each term has its own detailed considerations.

Further research is recommended for understanding the cause of magnetism, and if there is a gravitational rotational charge that may account for dark matter in the Universe.

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