Method for Measuring Magnetic Field Velocity Using an Electron Gun and Magnetometer

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Abstract

“The principle of the constancy of the speed of light” is the most important postulate of special relativity. According to Einstein’s scientific principle, all theories must conform to empirical facts; therefore, finding an experimental method that can accurately measure the speed of electromagnetic fields or electromagnetic waves is a major research topic in the physics community. This paper proposes an experimental method for measuring the speed of magnetic fields using electron beams of different energies and magnetometers placed along different orientations, with the core idea being to identify the temporal correspondence between the electrons that excite the magnetic field and the resulting magnetic field excitation. If the measured differences in propagation speed are all extremely small, this proves that the propagation speed of electromagnetic fields is indeed independent of the motion speeds of the source charges and currents, thereby validating “the principle of the constancy of the speed of light”; otherwise, it proves that “the principle of the constancy of the speed of light cannot be established.”

Full Text

A Method for Measuring Magnetic Field Speed Using Electron Guns and Magnetometers

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The principle of the constancy of light speed is the most fundamental postulate of special relativity. According to Einstein’s scientific principle, all theories must conform to empirical facts. Therefore, devising an accurate experimental method to measure the speed of electromagnetic fields or electromagnetic waves represents a major challenge in physics. This paper proposes an experimental

method to measure magnetic field speed using electron beams of different energies and magnetometers positioned at various orientations. The core concept is to identify the precise time correspondence between the exciting electrons and the resulting excited magnetic field. If the measured propagation speeds show minimal variation, this would demonstrate that electromagnetic field propagation velocity is indeed independent of the motion velocity of source charges and currents, thereby validating the principle of the constancy of light speed. Conversely, any significant variation would invalidate this principle.

Keywords: electron gun, electron beam, magnetometer, turning point, magnetic field speed, principle of the constancy of light speed

1. The Need for Definitive Verification of the Principle of Constancy of Light Speed

The principle of the constancy of light speed constitutes the most important foundation of special relativity [1]. Nevertheless, it remains a controversial hypothesis to this day. Einstein explicitly stated that special relativity originated from electrodynamics and optics, and should be attributed to Maxwell's electromagnetic theory. However, Maxwell's electromagnetic theory employs Galilean-Newtonian spacetime, which differs substantially from the Minkowski spacetime used in special relativity. According to Einstein's scientific principle, all mature theories must conform to empirical facts and established logical principles [1]. To provide a definitive judgment on the "principle of constancy of light speed," a genuine experiment capable of measuring the propagation speed of electromagnetic fields or waves is essential. This paper proposes that electron guns and magnetometers can be used to implement measurements of magnetic field propagation speed.

2. Basic Concept for Measuring Magnetic Field Speed Excited by Electron Beams

In a sufficiently large, flat laboratory, an electron gun is placed horizontally on the ground. The direction of electron beam flight is defined as the positive X-axis direction. Along this positive X-axis direction, three detection plates (P, A, Q) are positioned at appropriate distances from the electron gun exit, and a magnetometer (M) is placed at a point within the field. Both the detection plates and magnetometer are equipped with time signals provided by cesium atomic clocks, as shown in [Figure 1: see original paper].

The overall approach is as follows: the detection plates measure the arrival times of the electron beam, while the magnetometer measures the corresponding arrival times of the magnetic field excited by the electron beam, thereby enabling calculation of the magnetic field speed. The core idea is to establish the temporal correspondence between the electrons that excite the magnetic field and the resulting magnetic field itself.

According to the Biot-Savart law, a magnetic field is produced around a current element:

$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{Id\mathbf{l} \times \mathbf{r}}{r^3} \tag{2.1}$$

The magnetic field direction follows a circular path perpendicular to the electron beam and centered on the beam's cross-section, i.e., along the basis vector $\mathbf{e}_\varphi$ direction.

In this paper, the magnetometer M and the first two detection plates P and A form a fixed triangle, as shown in [Figure 2: see original paper]. Here, W is any point between P and A; PA = AM = l are fixed lengths; and α, β, δ are fixed angles, with only being variable. The magnetic field intensity is:

$$B = \frac{\mu_0}{4\pi}\int \frac{I \sin\theta dl}{r^2} \tag{2.2}$$

In this integral, r is the length from point P to point A. The three variables l, r, and in the integrand can be reduced to a single variable using the sine and cosine laws within triangle WAM:

In triangle WAM, the sine theorem yields the variable r:

$$\frac{\sin\theta}{R} = \frac{\sin\beta}{r} \tag{2.3}$$

Similarly, in triangle WAM, the sine theorem expresses x as a function of :

$$x = \frac{R\sin(\alpha + \beta + \delta - \theta)}{\sin\theta} \tag{2.4}$$

Substituting (2.3) and (2.4) into (2.2) gives:

$$B = \frac{\mu_0 I}{4\pi}\int \frac{\sin^2\theta}{R\sin\beta} \cdot \frac{R\sin(\alpha + \beta + \delta - \theta)}{\sin^2\theta} d\theta = \frac{\mu_0 I}{4\pi\sin\beta}\int \sin(\alpha + \beta + \delta - \theta) d\theta \tag{2.5}$$

While calculating magnetic field intensity is not the focus of this paper, the ability to compute the magnetic field intensity excited by the electron gun's electron beam may prove helpful for validating the magnetic field data recorded by the magnetometer.

3. Special Detection Plates and the Turning Point of Electron Flux

In the previous section, we explained that three detection plates (P, A, Q) should be placed at appropriate distances from the electron gun exit, with their collective task being to record the precise arrival times of electrons at each plate. We now clarify the distinct structures and functions of each detection plate, as shown in [Figure 3: see original paper].

1. First detection plate P is positioned at the electron gun exit, featuring a central circular aperture that allows the majority of electrons in the beam to pass through while permitting a small number to be measured for arrival time.

2. Second detection plate A is located at point A, at a distance l from the first plate. This is a half-metal sheet that blocks 50% of the electrons, creating a turning point in electron flux from which an accurate turning point time can be obtained. Additionally, the side adjacent to the magnetometer is missing, ensuring that electrons from this portion of the beam are not blocked throughout the entire process.

3. Third detection plate Q is located at point Q, at a distance d from the second plate. This is a complete metal sheet that blocks all electrons from passing through.

4. Magnetic Field Turning Point Reaching the Magnetometer

Since the second detection plate at point A serves as the turning point for electron flux, the magnetic field waveform excited by electrons at this location and propagating to the magnetometer must correspondingly exhibit a turning point. This design ensures that electrons passing through the central aperture of the first detection plate from the electron gun increase in number over time between P and A, and the excited magnetic field strengthens accordingly. When the electron beam encounters the second detection plate, most electrons are blocked, the number of electrons passing through suddenly decreases, and the excited magnetic field abruptly weakens. When the electron beam reaches the third detection plate, all electrons are blocked and the excited magnetic field suddenly disappears.

The variation in electron number over time for different stages is shown in [Figure 4: see original paper]. The sudden reduction in electron number at the second detection plate creates a distinctive turning point. The electron arrival time at detection plate A is t_A.

Correspondingly, due to changes in electron number within the beam, the magnetic field intensity excited by the electron beam also varies. The trend of magnetic field intensity recorded by the magnetometer resembles that shown in [Figure 4: see original paper], as illustrated in [Figure 5: see original paper]. A corresponding turning point appears at time t_M, thereby establishing the connection between source electrons and the excited magnetic field. The magnetic field arriving at the magnetometer at time t_M is excited by electrons that arrived at detection plate A at time t_A.

Thus, we know that on the magnetometer record, the turning point occurs at time t_M, and the magnetic field at this moment is excited by electrons at time t_A. Based on this, the magnetic field propagation speed can be calculated from the time interval for magnetic field propagation from detection plate A to magnetometer M and the distance between them:

$$V_{\text{mag}} = \frac{AH}{t_M - t_A} \tag{4.1}$$

This is the fundamental formula for calculating magnetic field propagation speed and applies to all calculations for electron beams of different energies and magnetometers at different orientations.

5. Measuring Magnetic Field Propagation Speed with Two Magnetometers at Different Orientations

As shown in [Figure 3: see original paper], two identical magnetometers M_1 and M_2 are positioned at locations with equal distance AH from point A and at angles φ_1 and φ_2 relative to the X-axis, both equipped with time signals from cesium atomic clocks. The relationship between the electron gun and the two magnetometers is shown in [Figure 6: see original paper].

In [Figure 6: see original paper], G is the electron gun. Along the electron beam's direction of motion, three position-specific detection plates are installed, each capable of accurately recording electron arrival times. The specific structures of these plates are detailed in the next section. Two identical magnetometers M_1 and M_2 are placed at equal distances from the electron gun, oriented at angles φ_1 and φ_2 relative to the electron beam, with both receiving time signals from the same cesium atomic clock.

The overall direction of electron beam motion along the positive X-axis remains constant. For magnetometers at different orientations, magnetic field propagation speeds can be calculated separately. If the calculated magnetic field speeds from the two magnetometers show minimal difference, this proves that magnetic field propagation is isotropic. Otherwise, the electron beam's direction of motion would constitute a special direction, and the principle of constancy of light speed would not hold.

6. Repeating Experiments with Different Electron Beam Energies

Select a specific energy E_n to excite the electron beam and emit it along the positive X-axis direction. The electron beam's velocity is:

$$v_n = \sqrt{\frac{2E_n}{m}} \tag{6.1}$$

Changing the electron beam energy alters its velocity. By repeating the above experiments, if the measured magnetic field propagation speeds show minimal variation for different electron beam velocities, this proves that magnetic field propagation speed is independent of source charge velocity, thereby validating the principle of constancy of light speed. Otherwise, the principle does not hold.

Shortly after proposing special and general relativity, Einstein stated with certainty in *Relativity: The Special and General Theory* that special relativity developed from electrodynamics and optics, and that while special relativity did not modify theoretical predictions much in these fields, it greatly simplified theoretical structure. He also clearly pointed out that the origin of special relativity should be attributed to Maxwell's electromagnetic theory. However, Maxwell's equations in vacuum consist of four equations:

$$\begin{aligned} \nabla \cdot \mathbf{E} &= \frac{\rho}{\varepsilon_0}, \\ \nabla \times \mathbf{B} - \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t} &= \mu_0 \mathbf{j}, \\ \nabla \cdot \mathbf{B} &= 0, \\ \nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} &= 0, \end{aligned} \tag{7.1}$$

These are Gauss's law, Ampère's law, the divergence-free equation indicating no magnetic monopoles, and Faraday's law of electromagnetic induction, respectively—all derived from extensive experimental results under the condition that source and observer are relatively stationary.

The constant 'c' in Maxwell's equations is understood as the speed of the electromagnetic field in vacuum. We emphasize that since Maxwell's equations are derived under source-observer stationary conditions, the electromagnetic field speed here can only be understood as the speed under such source-observer stationary conditions.

According to Maxwell's electromagnetic theory, which Einstein strongly advocated, a comprehensive, correct, and reasonable understanding of the "principle of constancy of light speed" should be: "In any vacuum laboratory, as long as source and observer remain relatively stationary, regardless of which celestial body the laboratory is on and regardless of the laboratory's absolute motion velocity, the propagation speed of the electromagnetic field is identical." This complete and accurate understanding of Maxwell's equations and the d'Alembert wave equation is natural, realistic, and conforms to established logical principles, requiring no introduction of any strange or incomprehensible assumptions.

Based on this understanding, we can anticipate that only under source-observer stationary conditions will the result of "isotropic electromagnetic field propagation speed" appear.

According to the experimental protocol in this paper, the electron beam should have relative velocity with respect to the magnetometer. We anticipate that measured magnetic field propagation speeds will show differences related to the electron beam's velocity.

Regardless of whether measurement results are consistent or inconsistent with contemporary textbooks, this would constitute a major scientific practice that would greatly stimulate thought and questioning in the scientific community. In any case, through relentless experimentation, reflection, and inquiry, identifying the true, natural, and reasonable electromagnetic field propagation speed represents a great scientific goal for the physics community.

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Note: Figure translations are in progress. See original paper for figures.