

Velocity of electromagnetic waves emitted by a moving source charge

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Abstract

We have proven that the d'Alembert wave equation in vacuum is derived under the condition of source-observer relative rest; therefore, “source-observer relative rest” constitutes a necessary condition for the “invariance of electromagnetic wave speed.” One may naturally ask: If a relative velocity exists between source and observer, what should the propagation speed of electromagnetic waves be? According to the Liénard-Wiechert retarded potential theory, when relative motion occurs between source and observer, the retarded potential becomes dependent upon this relative velocity. This paper points out that this is equivalent to a change in the permittivity and permeability of vacuum, resulting in effective permittivity and effective permeability. Calculations demonstrate that in a vacuum with source-observer relative motion, both the effective permittivity and effective permeability are anisotropic. The result derived in this paper shows that the propagation speed of electromagnetic waves equals the algebraic sum of the electromagnetic wave speed under source-observer relative rest and the velocity component of the source-observer relative motion along the direction of electromagnetic wave propagation. This result is consistent with empirical observations, conforms to established logical principles, and is natural and reasonable.

Full Text

The Speed of Electromagnetic Waves Emitted by a Moving Source Charge

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We have proved that the D'Alembert wave equation in vacuum is derived under the condition that the source and observer are relatively stationary. There-

fore, “source-observer relative rest” is a necessary condition for the “principle of constancy of electromagnetic wave speed.” It is natural to ask: if there exists relative velocity between source and observer, what should the propagation speed of electromagnetic waves be? According to the Liénard-Wiechert retarded potential theory, when there is relative motion between source and observer, the retarded potentials will be related to this relative velocity. This paper points out that this is equivalent to changes in the dielectric constant and permeability in vacuum, becoming effective permittivity and effective permeability. Calculations show that in a vacuum with source-observer relative motion, both the effective permittivity and effective permeability are anisotropic. The result derived in this paper is that the propagation speed of electromagnetic waves equals the algebraic sum of the electromagnetic wave velocity under source-observer relative rest and the component of the relative motion along the electromagnetic wave propagation direction. This result accords with human empirical facts and accepted logical principles, and is natural and reasonable.

Keywords: speed of electromagnetic wave, relative speed between source and observer, retarded potential, equivalent permittivity, equivalent permeability, anisotropy

1. D’Alembert Wave Equation under Source-Observer Relative Rest

We have proved that in vacuum, under the condition of source-observer relative rest, the D’Alembert wave equation is

$$\begin{aligned}\nabla^2\varphi - \frac{1}{c_0^2}\frac{\partial^2\varphi}{\partial t^2} &= -\frac{\rho}{\varepsilon_0} \\ \nabla^2\mathbf{A} - \frac{1}{c_0^2}\frac{\partial^2\mathbf{A}}{\partial t^2} &= -\mu_0\mathbf{j}\end{aligned}$$

In the above D’Alembert wave equations, we denote

$$c_0 \equiv \frac{1}{\sqrt{\varepsilon_0\mu_0}} \quad (1.1)$$

as the electromagnetic wave propagation speed, or speed of light, in vacuum under source-observer relative rest. This “electromagnetic wave speed” or “speed of light” depends entirely on the permittivity and permeability in vacuum under source-observer relative rest. We emphasize that under source-observer relative rest in vacuum, both permittivity and permeability are constant; the propagation space of electromagnetic fields or waves is uniform and isotropic. Therefore, under such conditions, regardless of the distance and geometric orientation between observer and source charge or current, regardless of the absolute motion

of the laboratory where the source charge, source current, and observer are located, and regardless of whether the laboratory is on Earth, the propagation speed should be the same. This is a reasonable conclusion that accords with human empirical facts.

2. Retarded Potentials with Source-Observer Relative Motion

In Section 1, we proved that in vacuum with source-observer relative rest, the electromagnetic wave propagation space is isotropic, and the retarded scalar potential and vector potential are independent of the electromagnetic wave propagation direction. According to Liénard-Wiechert retarded potential theory, when the source charge moves relative to the observer with relative velocity \mathbf{u} , the retarded scalar potential and vector potential become

$$\varphi = \frac{1}{4\pi\epsilon_0} \frac{q}{(1 - \mathbf{e}_r \cdot \mathbf{u}/c_0)R} \quad (1.2)$$

$$\mathbf{A} = \frac{\mu_0}{4\pi} \frac{q\mathbf{u}}{(1 - \mathbf{e}_r \cdot \mathbf{u}/c_0)R} \quad (1.3)$$

where q is the source charge, ϵ_0 and μ_0 are the permittivity and permeability in vacuum under source-observer relative rest, c_0 is the electromagnetic wave speed in vacuum under source-observer relative rest, \mathbf{R} is the vector from the retarded position of the source charge to the observer position, t_r is the retarded time, \mathbf{e}_r is the unit vector along the electromagnetic wave propagation direction, and θ is the angle between the source-observer relative velocity direction and the electromagnetic wave propagation direction.

Thus, when there exists relative velocity between source and observer, two changes occur: first, the retarded scalar and vector potentials depend on the magnitude of the relative velocity u ; second, they depend on the electromagnetic wave propagation direction, and the propagation space is no longer isotropic but varies with the angle θ .

3. Electromagnetic Wave Speed under Source-Observer Relative Motion

From (1.2) and (1.3), we see that with source-observer relative motion, the electromagnetic wave propagation space is no longer isotropic. We denote $\epsilon^* = K\epsilon_0$ as the effective permittivity and $\mu^* = K\mu_0$ as the effective permeability, where

$$K \equiv \frac{1}{1 - \mathbf{e}_r \cdot \mathbf{u}/c_0} = \frac{1}{1 - (u/c_0) \cos \theta} \quad (1.4)$$

We emphasize that the motion direction of the source charge relative to the observer becomes a special direction; the electromagnetic wave propagation space is no longer isotropic, and the propagation speed is no longer invariant in all directions but depends on the velocity of the source charge. The vacuum D'Alembert wave equation no longer holds, and the electromagnetic wave propagation speed cannot be determined from it.

We therefore approach the problem from the physical picture of electromagnetic wave propagation to solve for the propagation speed. Consider first the electromagnetic wave speed along the direction of source charge motion, as shown in Figure 1 [Figure 1: see original paper]. In the figure, the observer at point D (marked by a circle) is stationary in the laboratory, while the source charge at point S (marked by an arrow) moves uniformly relative to the laboratory with relative velocity \mathbf{u} . The source charge motion direction is the same as the electromagnetic wave propagation direction.

First, imagine if the source charge in the laboratory remains stationary at point S while the observer is at point D, with distance L between them. The electromagnetic wave emitted from the source charge propagates in all directions with speed c_0 , and the time interval required to reach the observer at point D is

$$\Delta t_0 = \frac{L}{c_0} \quad (1.5)$$

Now consider the motion of the source charge. On the one hand, the electromagnetic wave propagates from the source charge toward the observer D; on the other hand, the source charge itself moves toward the observer D with velocity u . During the time interval Δt , the source charge also moves toward the observer D a distance $\Delta L = u\Delta t$. Therefore, the actual distance the electromagnetic wave travels relative to the observer is $L - \Delta L$, and the time interval from when the wave leaves the source charge to when it reaches the observer D is

$$\Delta t = \frac{L - u\Delta t}{c_0} \quad (1.6)$$

Solving for Δt gives:

$$\Delta t = \frac{L}{c_0 + u} \quad (1.7)$$

Thus, the propagation speed of the electromagnetic wave emitted by the moving charge toward observer D is

$$c = \frac{L}{\Delta t} = c_0 + u \quad (1.8)$$

This is the case where the source charge moves toward the observer. If the charge moves away from the observer, the sign before u in (1.8) should be changed to negative:

$$c = c_0 - u \quad (1.9)$$

In summary, for cases where the source charge moves toward or away from the observer, the electromagnetic wave speed propagating from the source charge to the observer is

$$c = c_0 \pm u \quad (1.10)$$

where the “+” sign corresponds to toward motion and the “-” sign to away motion.

If the source charge moves at low speed in the laboratory, then

$$c \approx c_0 \left(1 \pm \frac{u}{c_0} \right) \quad (1.11)$$

This result accords extremely well with human empirical facts over thousands of years, and also conforms to accepted logical principles—it is natural and reasonable!

4. Electromagnetic Wave Speed along Arbitrary Directions

For cases where the source charge moves toward or away from the observer, we have already obtained a clear understanding. If the direction of source charge motion relative to the observer is not aligned with the electromagnetic wave propagation direction, forming a certain angle between them, what is the geometry of the wave propagation speed?

In Sections 2 and 3, we have seen that what affects the retarded scalar and vector potentials, and thus the electromagnetic wave propagation speed, is the parallel component of the source-observer relative velocity—that is, the velocity component parallel to the electromagnetic wave propagation direction. Therefore, we need only modify the source charge velocity u in (1.10) to the velocity component of the source charge along the electromagnetic wave propagation direction, u_r :

$$c = c_0 \pm u_r \quad (1.12)$$

where

$$u_r = u \cos \theta \quad (1.13)$$

is the velocity component of the source charge along the electromagnetic wave propagation direction, as shown in Figure 2 [Figure 2: see original paper]. In the figure, S is the source charge and D is the observer (field point). For clarity and simplicity, we assume the observer is always stationary in the laboratory, with only the source charge moving relative to it.

If the source charge moves at low speed in the laboratory, then (1.12) simplifies to

$$c \approx c_0 \pm u \cos \theta \quad (1.14)$$

Equation (1.14) equals the algebraic sum of the electromagnetic wave speed under source-observer relative rest and the component of the source-observer relative velocity along the electromagnetic wave propagation direction. This result also accords extremely well with human empirical facts and conforms to accepted logical principles—it is natural and reasonable!

Discussion

1. On Einstein's Scientific Criterion

In his book *Relativity: The Special and General Theory*, Einstein provides a “scientific judgment criterion,” stating that a correct theory must conform to accepted logical principles and must accord with public empirical facts. In the special relativity chapter of *Electromagnetism and Electrodynamics, Volume 2*, Hu Youqiu and Cheng Fuzhen point out that the spacetime view of special relativity is incompatible with people's daily life experience. The explanation in special relativity textbooks is that the spacetime view of special relativity is profound and correct, while people's daily life experience is not entirely correct. This paper argues that the answer from nature may be the opposite: given that the principle of the constancy of the speed of light only holds for the special case of source-observer relative rest and cannot be generalized to cases of source-observer relative motion, the spacetime view of special relativity has no practical significance. Instead, the Galilean-Newtonian spacetime view is fundamentally correct.

2. On Michelson Interferometer Experiments

The physics community has performed two major categories of experiments using Michelson interferometers: one to test for the existence of the ether, and the other to explore gravitational waves. The first category yielded null interference results, while the second category completed in recent years showed interference fringe shifts. The physics community has used two different theories to explain these results: the null interference in the first category proves that Galilean transformation is incorrect and that ether does not exist; the fringe shifts in the second category occur because gravitational waves act asynchronously on the

two arms of the interferometer, causing inconsistent arm length changes and resulting in optical path differences.

Based on the arguments in this paper, both categories of experimental results can be explained by a single theory: when source and observer are relatively stationary, the electromagnetic wave propagation space is isotropic and the electromagnetic wave propagation speed is identical, producing no optical path difference. In a Michelson interferometer, the light source is stationary relative to the final interference screen, so there is no optical path difference; while a black hole eruption, on the one hand produces gravitational waves, and on the other hand, the matter source has a velocity component toward Earth, making the gravitational wave propagation space anisotropic and thus producing an optical path difference. This explanation is more natural and reasonable than the theory that interference arms undergo different deformations under gravitational wave action.

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

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