Measuring the Speed of Water Waves Using Water: Why Only Differences in the Speed of Light Are Observable in a Maxwell Universe

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Abstract

Observers composed entirely of electromagnetic (EM) fields cannot determine the absolute speed of light c. Clocks count field cycles and rulers register field nodes; both rescale with any local change in the vacuum parameters $\varepsilon(x)$ and $\mu(x)$. Every laboratory therefore self-calibrates to the value $c_0 = 1/\sqrt{\mu_0\,\varepsilon_0}$ even if the underlying light speed $c(x)$ varies from place to place. Using elementary Maxwell theory and a water-wave analogy, we show why present-day cavity experiments can constrain only differences $\Delta c/c$, not the absolute magnitude of c.

One-sentence summary

Because laboratory rulers and clocks are built from electromagnetic fields, Maxwell theory allows detection of only spatial or temporal *variations* in the speed of light—never its absolute value.

Keywords

Maxwell electrodynamics; metrology; speed of light; Lorentz invariance; Fabry–Pérot cavity.

Introduction

Michelson–Morley-type experiments and modern optical cavities show no sign of a preferred frame. While special relativity explains this by postulating a universal c, classical Maxwell theory offers a simpler reading: when measuring tools are built from the very field whose speed is sought, only differences in that speed can ever be observed.

Operational Definition of c in Maxwell Theory

In vacuum the fields satisfy

$$\nabla^2\mathbf{E} = \mu_0\varepsilon_0\,\partial_t^2\mathbf{E},$$

which fixes the characteristic speed

$$c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}.$$

A Fabry–Pérot cavity of fixed length L enforces $n\lambda_n = 2L$. For the fundamental mode ($n = 1$) the wavelength is $\lambda_1 = 2L$. Using $c = \lambda/T$, the same mode provides the period $T_1 = \lambda_1/c$. If the local vacuum parameters shift to new values (μ, ε), both λ_1 and T_1 are multiplied by the same factor $\sqrt{\mu\varepsilon}$; their ratio λ_1/T_1 is unchanged, so any measurement of c still returns c_0.

Blindness of EM-Based Metrology

Water-Wave Analogy

A fish tries to measure the speed v of surface waves. Its rulers (successive crests) and clocks (periods between crests) both stretch if the surface tension varies. Absolute speed is invisible; only relative differences appear. EM observers face the same limitation.

Interferometer logic

Most laboratory searches for anisotropy compare two orthogonal high-Q Fabry–Pérot cavities on a slowly rotating stage. For the m-th longitudinal mode in arm i

$$\nu_i \;=\; \frac{m\, c(x_i)}{2L_i}, \qquad i = x, y,$$

so a directional dependence of $c(x)$ would modulate the beat note $\nu_x - \nu_y$ once per turn. Experiments find no such modulation down to $|\Delta c|/c \leq 10^{-18}$. In our framework the setup samples the vacuum scaling factor *differentially*: it measures $c(x)$ **relative to** $f(p_x)$ versus $f(p_y)$ (see next section for $f(p)$). If f were uniform the two arms would differ only by construction tolerances, and constant-velocity motion would be completely invisible—precisely the conclusion of special relativity. Orthogonal cavities are therefore sensitive only to a gradient $f(p_x) - f(p_y)$; a uniform offset cancels.

Detecting an *absolute* shift in $f(p)$ instead requires a one-arm, time-of-flight technique—e.g. sending a light pulse through a long fiber or free-space delay line and comparing the round-trip time against an independent clock. Such single-path measurements would respond directly to the optical length

$$\mathcal{L}(x) = \int n_{\text{eff}}(x)\, \mathrm{d}x \;=\; \int f(p)\, \mathrm{d}x,$$

and could, in principle, reveal a uniform change in $f(p)$ rather than just a transverse gradient.

Formal Derivation with Variable Vacuum Parameters

Let a scalar background $p(x)$—a proxy for local energy density—multiply both permittivity and permeability by the same positive factor $f(p)$:

$$\varepsilon(x) = \varepsilon_0 f(p), \qquad \mu(x) = \mu_0 f(p).$$

The local wave speed is

$$c(x) = \frac{1}{\sqrt{\mu(x)\varepsilon(x)}} = \frac{c_0}{f(p)}.$$

Constructing a ruler

The cavity's fundamental frequency becomes

$$\nu_{\mathrm{ref}}(x) = \frac{c(x)}{2L} = \frac{c_0}{2L\, f(p)}.$$

The associated wavelength is

$$\lambda_{\mathrm{ref}}(x) = \frac{c(x)}{\nu_{\mathrm{ref}}(x)} = 2L,$$

independent of $p(x)$. A rod made from N such wavelengths has length

$$L_{\mathrm{rod}} = N\lambda_{\mathrm{ref}} = 2NL,$$

also independent of $p(x)$.

Constructing a clock

The period of one oscillation is

$$T_{\mathrm{ref}}(x) = \frac{1}{\nu_{\mathrm{ref}}(x)} = \frac{2L\, f(p)}{c_0}.$$

Combining ruler and clock gives

$$\frac{L_{\mathrm{rod}}}{T_{\mathrm{ref}}(x)} = c_0,$$

showing that absolute variations in $c(x)$ remain hidden; only gradients in $f(p)$ could, in principle, be detected.

Relation to General Relativity

General relativity expresses the same idea geometrically. A perturbed metric

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}(p)$$

gives local null cones identical to those of special relativity, while global geodesics reproduce light-bending through an effective refractive index

$$n_{\text{eff}}(\mathbf{x}) \simeq 1 + \frac{2\Phi(\mathbf{x})}{c_0^2}.$$

The optical-metric formalism is therefore algebraically equivalent to Maxwell with variable (ε, μ).

Conclusion

Maxwell electrodynamics implies that laboratories built from EM fields cannot measure the absolute speed of light. Their rulers and clocks scale together with any local change in ε and μ, leaving only spatial or temporal differences observable. The water-wave analogy captures the point: one cannot determine the speed of water waves using only water.

Note from A. M. Rodriguez

The geometrical argument linking Maxwell theory to general relativity was developed entirely by Anes Palma.

Suggested References

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