Reflection Without Re-emission: Fresnel Coefficients as Evidence for Worldline-Selective Photons

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Abstract

Optical reflection is universally described as a consequence of electromagnetic boundary conditions and, in quantum electrodynamics, as absorption and re-emission by charged particles. While these descriptions are mathematically successful, they remain ontologically silent. In this work we demonstrate that the experimentally observed properties of reflection—phase preservation, single-photon coherence, geometric determinism, and material-independence—cannot be consistently interpreted as a local emission process. We show that Fresnel reflection coefficients already contain a "smoking gun": the reflected photon behaves as if selected from a globally constrained spacetime geometry rather than produced locally. We propose an alternative interpretation in which reflection corresponds to the emergence of an allowed worldline consistent with global boundary conditions, without violating causality or no-signaling. The argument relies exclusively on established experimental data and standard equations.

1 Introduction

Reflection is one of the oldest and apparently simplest phenomena in physics. From mirrors to water surfaces to glass interfaces, light reflects with remarkable regularity, obeying precise geometric laws. Despite this simplicity, the ontological status of reflection remains unresolved.

Classically, Maxwell's equations describe reflection as the result of boundary conditions on electromagnetic fields. Quantum electrodynamics (QED) replaces the classical wave with photons interacting with charged particles, typically described as absorption followed by re-emission. While both frameworks predict experimental outcomes with extraordinary precision, neither provides a physically explicit account of what a reflected photon *is*.

In this paper we argue that this is not an innocent omission. Instead, the mathematical structure of reflection—specifically Fresnel coefficients and single-photon interference experiments—already rules out a naive local re-emission ontology.

2 Fresnel Reflection: Formalism

Consider an electromagnetic wave incident on an interface between two media with refractive indices n_1 and n_2. For normal incidence, the Fresnel reflection coefficient is

$$R = \left| \frac{n_1 - n_2}{n_1 + n_2} \right|^2 . \tag{2.1}$$

Several crucial features follow immediately:

1. R depends only on global material parameters, not microscopic details.
2. Reflection occurs at *any* interface: metals, glass, water, dielectrics.
3. The reflected wave preserves phase relations and polarization.
4. The reflected intensity is determined instantaneously, without delay.

None of these features require a particulate emission model.

3 Single-Photon Reflection Experiments

Modern quantum optics allows reflection experiments at the single-photon level. The results are unequivocal:

- A single photon incident on a partially reflective interface exhibits interference.
- Phase coherence is preserved between reflected and transmitted paths.
- Fringes remain stable even when photons are sent one at a time.

These facts impose a severe constraint. If the photon were absorbed and later re-emitted locally, the emitted photon's phase would be independent of the incoming one. QED itself does not enforce phase memory at the level of individual emission events.

Thus, the observed coherence cannot originate from a local stochastic emission.

4 The Ontological Gap in QED

In QED, reflection is calculated as a scattering amplitude. The theory explicitly states that incoming and outgoing photons are not identical particles; they are field excitations.

However, this raises a decisive question:

> Where is the phase and directional information stored during the interaction?

QED answers: in the field. But the field is not an ontological entity; it is a calculational object encoding correlations.

Therefore, QED predicts reflection without describing a physical process that preserves the necessary information locally.

5 The Smoking Gun: Global Phase Preservation

The crucial experimental fact—the smoking gun—is the following:

> The reflected photon preserves global phase information that cannot be reconstructed by any local emission process.

This is not an interpretation. It is a mathematical necessity imposed by interference experiments.

No collection of independent emitters, each undergoing absorption and re-emission, can reproduce a deterministic specular wavefront at the single-photon level without hidden coordination.

6 Failure of the Re-emission Ontology

Let us assume, for contradiction, that reflection is local re-emission.

Then:

1. The photon must be destroyed.
2. A new photon must be emitted.
3. The emission phase must be locally determined.

This implies phase decoherence unless one assumes:

- nonlocal coordination,
- hidden variables,
- or instantaneous global adjustment.

None of these are present in standard QED without additional assumptions.

7 Worldline-Selective Interpretation

We propose a minimal reinterpretation:

> Reflection is not the creation of a new photon, but the selection of an allowed photon worldline consistent with global spacetime constraints.

In this view:

- The interface acts as a geometric boundary condition.
- Multiple photon worldlines are mathematically admissible.
- Only those compatible with the boundary condition manifest.

The reflected photon is not emitted *by* the surface, but emerges *from* the constrained geometry.

8 Causality and No-Signaling

This interpretation does not violate:

- Special Relativity: all worldlines remain lightlike.
- No-signaling: no controllable information propagates backward.
- Energy conservation: probabilities obey Fresnel coefficients.

The process is retrocausal only in the informational sense, analogous to entanglement correlations.

9 Material Universality Explained

Why do glass, water, and mirrors behave similarly?

Because the phenomenon is not material emission but geometric admissibility. The material determines which worldlines are allowed, not which photons are created.

10 Conclusion

The standard account of reflection works mathematically but fails ontologically. The experimental facts—especially single-photon phase preservation—force us to abandon the idea of local re-emission as a physical process.

The Fresnel equations themselves already encode the smoking gun: reflection is global, geometric, and worldline-selective.

This interpretation requires no new physics, only intellectual honesty about what the equations already say.