Directional Density of Gases Under FitzGerald-Lorentz Contraction: Predictions for Optical Interferometry

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Abstract

We show that the directional density of an ideal gas remains isotropic under FitzGerald-Lorentz contraction of its container, while that of a bound solid becomes anisotropic. Combined with the invariance of the optical phase delay per molecule, this yields parameter-free predictions for gas-filled interferometers under Lorentzian Relativity. For a single gas-filled arm measured against a direction-independent reference, the signal on rotation is $\Delta N = k(L/\lambda)(n-1)(v/c)^2$, where k depends on the interferometric configuration. The signal arises from the orientation-dependent molecule count in the contracted gas path. We predict null results for solid-dielectric interferometers regardless of refractive index.

1 Directional Density

We define directional density $\rho_d(\hat{n})$ as the number of atoms per unit length along direction $\hat{n}$. For a homogeneous medium with number density n, this is simply proportional to n and independent of direction when n is isotropic.

Bound systems. In a crystal moving at velocity v, FitzGerald-Lorentz contraction compresses lattice spacings along $\mathbf{v}$ by a factor $1/\gamma$ while leaving perpendicular spacings unchanged. The directional density along $\mathbf{v}$ increases by γ; perpendicular directions are unaffected. Atoms cannot redistribute — they are held by binding forces. The anisotropy is $\Delta\rho_d/\rho_d \approx \beta^2/2$.

Unbound systems. For an ideal gas, the spatial distribution remains uniform regardless of container shape or velocity distribution anisotropy. Consider a particle bouncing between walls separated by L_x at speed $|v_x|$. The time spent in any interval dx is $dx/|v_x|$; the oscillation period is $2L_x/|v_x|$. The ratio — the time-averaged density — is $1/(2L_x)$, independent of speed. A faster particle crosses each interval more quickly but returns proportionally sooner. For N non-interacting particles, $n(\mathbf{r}) = N/V = \text{const}$ throughout the volume.

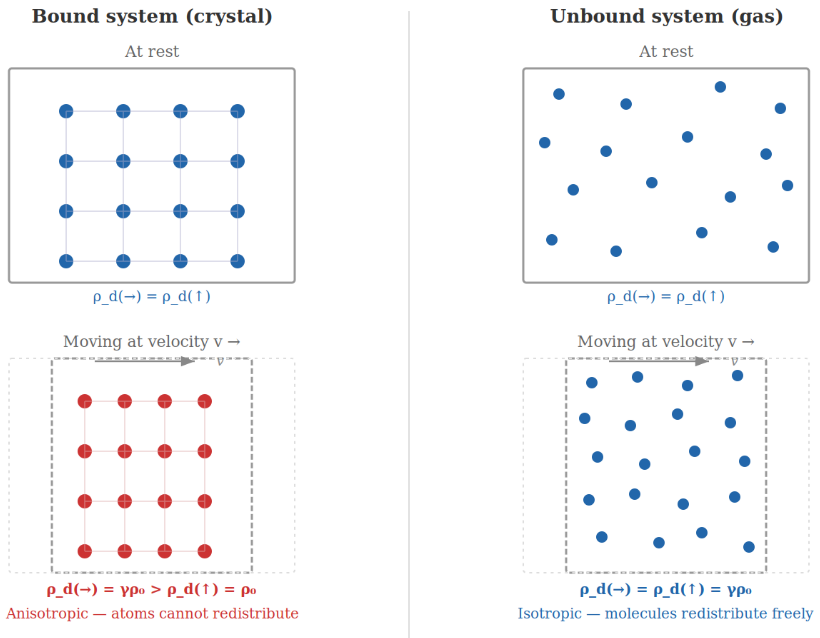
This holds even with anisotropic velocities. In the canonical ensemble, the Hamiltonian $H = \sum p_i^2/(2m)$ yields $P(\mathbf{r}, \mathbf{p}) \propto \exp(-p^2/2mkT) \times \Theta(\mathbf{r} \in V)$, where position and momentum are statistically independent. The spatial distribution is uniform for any momentum distribution.

Therefore, when a gas container contracts along $\mathbf{v}$, the gas redistributes uniformly in the new volume. FitzGerald-Lorentz contraction is a linear transformation with Jacobian $1/\gamma$: the volume of any container, regardless of shape or orientation, decreases to V/γ. Crucially, when the container is rotated, the contracted volume remains V/γ — only the shape changes, not the volume. A container aligned with $\mathbf{v}$ is shorter and wider; rotated 90°, it is longer and narrower; but in both cases the enclosed volume is the same. Gas, having no shear modulus and no shape memory, is insensitive to container shape — it fills whatever volume is available, uniformly. The 3D density is therefore $N/(V/\gamma) = \gamma n_0$, isotropic and independent of container orientation. The directional density remains the same in all directions (Fig. 1).

A solid, by contrast, deforms with the container: its atoms are bound to lattice sites and follow the shape change. The directional density of a crystal becomes anisotropic under contraction.

In a rotating interferometer, gas redistribution is further ensured by molecular collisions with the container walls. One might ask whether molecular trajectories in a static container could retain some directional “memory” imposed by the contracted geometry — for example, if the velocity distribution acquired a subtle anisotropy that persisted over time. In a rotating apparatus, this concern is eliminated: as the container turns, the walls continuously change orientation in space, and each molecular reflection randomizes the trajectory relative to the new geometry. The rotation acts as a physical mixer. At thermal velocities (~500 m/s in air), molecules undergo hundreds of wall collisions per second in a meter-scale container — far faster than any plausible rotation rate. The gas is therefore fully re-thermalized at every instantaneous orientation, with the spatial density uniform throughout the volume at all times.

Fig. 1. Directional density under Lorentz-FitzGerald contraction



Dashed outline: contracted container. Grey outline: rest-frame dimensions.

Figure 1: Directional density under FitzGerald-Lorentz contraction. Left: crystal (bound) — atoms follow lattice deformation, directional density becomes anisotropic. Right: gas (unbound) — molecules redistribute uniformly in the contracted volume, directional density remains isotropic. Dashed outline: contracted container. Grey outline: rest-frame dimensions.

2 Optical Phase in a Gas Path

The phase delay contributed by each gas molecule to a traversing photon is a Lorentz scalar $\delta\phi$ — it results from the electromagnetic interaction within a bound system (the molecule) and is frame-independent [note 1]. The total gas-induced phase along a path of length L is:

$$\Phi_{\text{gas}} = N_{\text{path}} \times \delta\phi \tag{1}$$

where N_{path} is the number of molecules in the beam path.

A vacuum path, or a path through a solid medium (optical fiber, glass rod), serves as a reference. Being a bound system, it contracts with the apparatus, and its optical phase is direction-independent — this is the standard null result of vacuum interferometry.

3 Interferometric Signal

Consider two parallel channels of length L_0 in a single rigid block: one evacuated, the other filled with gas. The block is mounted on a rotating platform. As the platform completes a full turn, the block sweeps all directions in the horizontal plane.

The vacuum channel provides a direction-independent phase reference — its round-trip optical phase is the standard null result of bound-system interferometry.

The gas channel, oriented at angle θ to $\mathbf{v}$, has contracted length $L(\theta) = L_0(1 - \beta^2 \cos^2\theta/2)$. Since the gas density is isotropic and constant (Section 1), the molecule count in the beam path is simply proportional to the path length:

$$N(\theta) = N_0\left(1 - \frac{\beta^2 \cos^2\theta}{2}\right) \tag{2}$$

where N_0 is the rest-frame molecule count. The path contracts — fewer molecules fit along it. The formula is the same as for length contraction, applied directly to molecule count.

On rotation through 360°, the phase difference between the gas and vacuum channels varies as $\cos 2\theta$ (second harmonic) with peak-to-peak amplitude:

$$\Delta N = \frac{L}{\lambda}(n-1)\beta^2 \tag{3}$$

for a two-pass (reflected) configuration, or half this for a single pass. This is a parameter-free prediction: L and λ are apparatus constants, n is the measured refractive index, and v (hence β) is the velocity to be determined.

Numerical examples for $v = 220$ km/s ($\beta = 7.3 \times 10^{-4}$), $L = 1$ m, $\lambda = 532$ nm, two-pass:

Gas	$n-1$	ΔN
Air, 1 atm	2.73×10^{-4}	$2.7 \times 10^{-4}\ \lambda$
He, 1 atm	3.3×10^{-5}	$3.3 \times 10^{-5}\ \lambda$
CO_2, 1 atm	4.5×10^{-4}	$4.5 \times 10^{-4}\ \lambda$
Air, 10 atm	2.73×10^{-3}	$2.7 \times 10^{-3}\ \lambda$

The signal scales linearly with pressure (through $n-1$) and with path length, offering direct routes to better sensitivity.

Harmonic content. If the velocity vector $\mathbf{v}$ makes angle ψ with the horizontal plane, the horizontal projection of the contraction is reduced by $\cos^2\psi$. The signal on rotation remains a pure second harmonic:

$$\Delta N(\theta) \propto \cos^2\psi \times \cos 2(\theta - \varphi) \tag{4}$$

where φ is the azimuthal direction of $\mathbf{v}$ projected onto the horizontal. The elevation ψ modulates the amplitude but does not change the harmonic order. A first-harmonic ($\cos\theta$) component in a horizontal interferometer therefore cannot arise from directional density — its presence indicates systematic effects (gravity, thermal gradients).

However, if the block is tilted at angle h relative to the rotation plane — for example, to sample a wider range of sky directions — the contraction factor $\cos^2\theta$ in Eq. (2) is evaluated along the tilted beam axis rather than in the horizontal plane. Decomposing $(\hat{n}\cdot\hat{v})^2$ for a beam tilted at angle h and velocity elevation ψ gives both a second-harmonic component (amplitude $\propto \cos^2 h \cos^2\psi$) and a first-harmonic component (amplitude $\propto \sin 2h \sin 2\psi$). Their ratio is $4\tan h \tan\psi$. This has two consequences: (i) the first harmonic vanishes when either $h = 0$ (no tilt) or $\psi = 0$ (velocity in horizontal plane), and (ii) even a moderate tilt can produce a large first harmonic when ψ is large — for example, at $h = 10°$ and $\psi = 48°$ (Cygnus from mid-latitudes) the ratio is already ~0.8. Data taken at different tilt angles must be analyzed separately, and the harmonic content itself becomes a diagnostic of the geometry.

4 Predictions Across States of Matter

The analysis yields clean predictions for two limiting cases:

Ideal gas (fully unbound). Molecules redistribute freely; directional density isotropic. Full signal: $\Delta N = (L/\lambda)(n-1)\beta^2$.

Ideal crystal (fully bound). Atoms locked in lattice positions; directional density anisotropic, but optical response per unit cell transforms correspondingly. This is the FitzGerald-Lorentz "conspiracy": length contraction, time dilation, and the electromagnetic response of bound matter combine to render the optical phase direction-independent. Signal: zero.

Medium	$n-1$	Binding	Predicted signal
Air, 1 atm	2.73×10^{-4}	Unbound	$(L/\lambda)(n-1)\beta^2$
CO_2, 1 atm	4.5×10^{-4}	Unbound	$(L/\lambda)(n-1)\beta^2$
Fused silica	0.458	Bound	0
Diamond	1.417	Bound	0

Liquids (intermediate case). Real liquids are neither ideal gases nor ideal crystals. Molecules are mobile but interact strongly, with short-range order and characteristic relaxation times. The degree to which directional density remains isotropic under contraction depends on the balance between intermolecular forces (which resist redistribution, as in solids) and molecular mobility (which enables it, as in gases). A small residual signal, intermediate between the gas and solid limits, cannot be excluded on theoretical grounds, but quantitative predictions for liquids require detailed molecular dynamics beyond the scope of this work.

The most unambiguous experimental test is the comparison of a gas-filled interferometer (where the full signal is predicted) with a vacuum or solid-reference interferometer (where a null is predicted). The gas-versus-vacuum comparison involves no intermediate states and no modeling assumptions beyond ideal gas statistics.

5 Discussion

The signal in gas-filled interferometers arises from a counting asymmetry: a contracted arm contains fewer gas molecules than an uncontracted one, because gas redistributes isotropically while the arm does not. No vacuum condensate or ether drag model is invoked — only FitzGerald-Lorentz contraction and ideal gas statistics.

The prediction $\Delta N = (L/\lambda)(n-1)\beta^2$ coincides with the formula obtained by Consoli and Pluchino [1] through an independent analysis based on the non-trivial vacuum structure of quantum field theory. That two different approaches — one from statistical mechanics, one from vacuum condensate physics — yield the same functional dependence on $(n-1)$ and β^2 supports the validity of both results.

Manley [2,3] developed a Mach-Zehnder interferometer comparing light propagation in gas and vacuum in parallel adjacent paths — a design well suited for testing these predictions. In his analysis [4], the instrument is treated as having first-order sensitivity ($\Delta N \propto v/c$), yielding an inferred velocity of $\sim$0.17 km/s. However, the effect described here is second order ($\Delta N \propto v^2/c^2$). Reinterpreting the same signal amplitude under the second-order formula gives $v = \sqrt{0.17 \times 3.0 \times 10^5} \approx 220$ km/s — close to the solar orbital velocity about the Galactic center. The preferred direction reported in [3] is also broadly consistent with the apex of solar motion toward Cygnus (RA $\approx$ 21 h, Dec $\approx +48°$). Both the amplitude and the direction of the signal may thus be consistent with the directional density prediction when the correct order of the effect is used.

We note that the historical Fresnel drag coefficient $f = 1 - 1/n^2$, being a first-order approximation, is not valid for second-order (β^2) calculations. The exact expression — the relativistic velocity addition applied to the phase velocity c/n — must be used at this order [5]. Care must be taken to distinguish kinematic effects (which are compensated by the exact Fresnel drag) from the directional density effect (which is not).

The decisive experimental test is a comparison of interferometric signals in gas versus vacuum (or solid) reference paths, where the prediction is unambiguous. We note that modern rotating optical cavity experiments — which compare resonance frequencies of fused silica resonators on precision turntables — have reached sensitivities of $\Delta c/c \sim 10^{-17}$ and report null results [6,7]. Since these experiments use solid dielectrics, a null is exactly what the present analysis predicts (Section 4). The same apparatus, modified to include a gas-filled optical path, would have more than sufficient sensitivity to detect the predicted signal of order $(n-1)\beta^2 \sim 10^{-10}$ for air at atmospheric pressure — a margin of seven orders of magnitude. Increasing the gas pressure to 10 atm raises the signal to $\sim 10^{-9}$, further simplifying detection. Pressure variation provides a built-in calibration: the signal should scale linearly with gas pressure through $n-1$. Experiments with liquids, while potentially informative, involve an intermediate state of matter where the degree of molecular redistribution is material-dependent and difficult to model from first principles.

Acknowledgments

The author thanks Victor O. de Haan for years of discussions on ether theories and optical interferometry, and for sharing his experimental insights that have shaped the ideas presented here.

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Note 1

The phase delay per molecule can be derived by decomposing the photon transit into free propagation (at speed c) and interaction with the bound molecular system (Lorentz-transformed from the molecule's rest frame). The exact Fresnel drag coefficient emerges naturally from this decomposition, confirming its validity as a calculational tool without requiring a specific physical model of ether drag.