

Exploring Light's Bend: Gravity's Influence Versus Refraction

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Abstract

This article presents a simple real-world laser experiment designed to make the direction of optical refraction physically visible and to compare that behavior with gravitational deflection. A straight rod and a laser beam are partially submerged in water so that the propagation of light can be observed as the beam crosses the water–air interface. In the water-to-air transition, the laser beam bends away from the normal, as required by Snell's law. Gravitational deflection, by contrast, bends the trajectory of light toward the massive body responsible for the gravitational field. The experiment is not presented as a direct test of General Relativity nor should it be interpreted as such. Its value is pedagogical, not confirmatory. Rather, it provides a clear physical demonstration that ordinary optical refraction and gravitational lensing should not be treated as equivalent mechanisms. The distinction is especially important when considering claims that astronomical light deflection near massive bodies could be attributed entirely to atmospheric or refractive effects.

Keywords: refraction, gravitational deflection, gravitational lensing, Snell's law, laser experiment, light propagation, General Relativity.

1 Introduction

The bending of light near massive bodies is one of the best-known predictions associated with General Relativity [2]. In that framework, light follows null geodesics through curved spacetime, and its trajectory can therefore be deflected when it passes near a sufficiently massive object. The historical eclipse observations of 1919 provided an early astronomical measurement of the deflection of starlight in the gravitational field of the Sun [3].

At times, however, gravitationally observed light deflection has been compared with ordinary optical refraction. Since both phenomena can change the apparent position of a luminous source, it is useful to distinguish them physically and geometrically.

The purpose of the present article is therefore not simply to show that refraction exists. The objective is more specific:

to observe directly how a laser beam changes direction at a water–air interface, and then compare the direction and mechanism of that deflection with gravitational light bending.

The central point is that the experiment concerns not merely whether light bends, but *how* it bends and *in which direction* it bends.

2 Basic Refraction

When light passes from one transparent medium to another, its propagation speed changes. If the ray crosses the interface at a nonzero angle with respect to the normal, its direction generally changes as well. This phenomenon is known as refraction.

For two media with refractive indices n_1 and n_2 , Snell's law is [1]

$$n_1 \sin \theta_1 = n_2 \sin \theta_2, \quad (1)$$

where the angles are measured from the normal to the interface.
For a ray traveling from water into air,

$$n_{\text{water}} > n_{\text{air}},$$

and therefore, for transmission below the critical angle,

$$\theta_{\text{air}} > \theta_{\text{water}}.$$

Thus, when light passes from water into air, it bends **away from the normal**.

Conversely, when light passes from air into water, it bends **toward the normal**. This distinction is important because it prevents an overly general statement such as “refraction always bends light away from the normal.” The direction depends on the refractive indices of the two media and on the direction in which the ray crosses the interface.

3 The Swimming-Pool Laser Experiment

The experiment uses a straight rod approximately three meters long, partially submerged in a swimming pool at an oblique angle. In the original setup, the rod was made of aluminum, although the specific material is not essential for the optical effect.

A laser source is attached to the rod and aligned so that the beam propagates approximately parallel to it. The rod therefore acts as a fixed geometrical reference for observing the path of the light beam.

3.1 The apparent bending of the rod

A familiar optical effect occurs when a straight rod is partially submerged in water: the submerged portion appears displaced relative to the portion in air. The rod itself has not physically bent. The apparent discontinuity is produced by the refraction of rays traveling from water to air before reaching the observer.



Figure 1: A straight rod partially submerged in water appears displaced at the water–air interface because of refraction. The rod itself remains physically straight.

This visual effect is useful, but it is not the principal result of the experiment.

3.2 The actual bending of the laser beam

The essential observation is the physical change in direction of the laser beam as it crosses the water–air boundary.

While traveling through the water, the beam follows a straight path. When it reaches the surface and emerges into air, its direction changes according to Eq. (1). Since the beam is moving from the medium with the larger refractive index to the medium with the smaller refractive index, the emerging ray bends away from the normal.



Figure 2: Experimental arrangement showing the straight reference rod and the laser beam. The apparent position of the rod and the physical direction of the refracted beam must not be confused.

The experimental arrangement therefore displays two distinct optical phenomena at the same time:

1. the **apparent displacement** of the submerged rod; and
2. the **actual change in direction** of the laser beam at the interface.

This distinction is important because an apparent displacement of an object is not identical to the physical path followed by the light itself.

4 Geometrical Description of Refraction

Figure 3 illustrates the water-to-air transition that is central to the experiment.

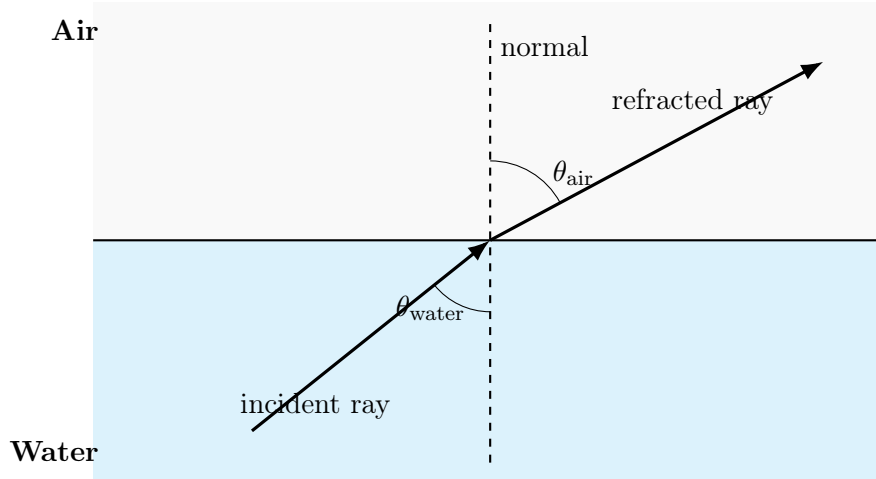


Figure 3: Water-to-air refraction. Because $n_{\text{water}} > n_{\text{air}}$, the emerging ray bends away from the normal, so that $\theta_{\text{air}} > \theta_{\text{water}}$.

The converse case is shown in Figure 4. A ray entering water from air bends toward the normal.

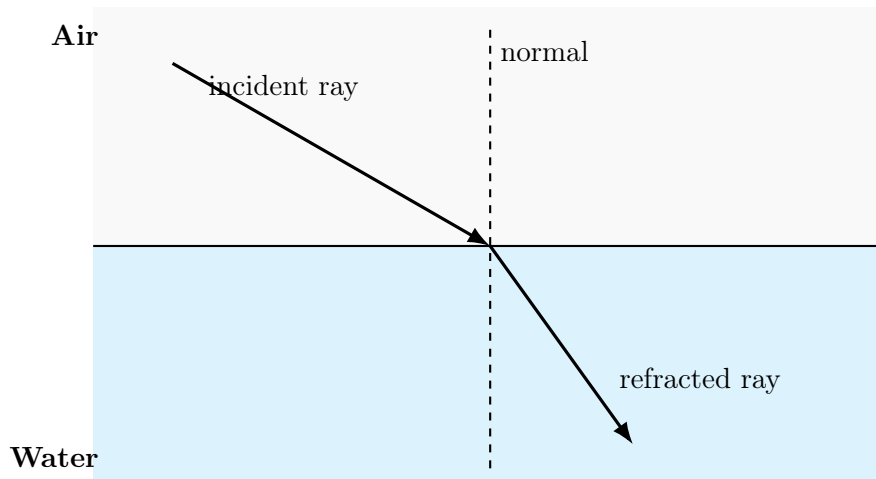


Figure 4: Air-to-water refraction. In this direction the ray bends toward the normal because it enters a medium of higher refractive index.

Figures 3 and 4 together clarify why the direction of refraction cannot be described without specifying the media and the direction of propagation.

5 A Parallel-Sided Medium

Another useful case is a ray passing through a slab with parallel interfaces. At the first boundary the ray refracts; at the second boundary it refracts again. If the external medium is the same on both sides, the outgoing ray becomes parallel to the original incoming ray, although it is laterally displaced.

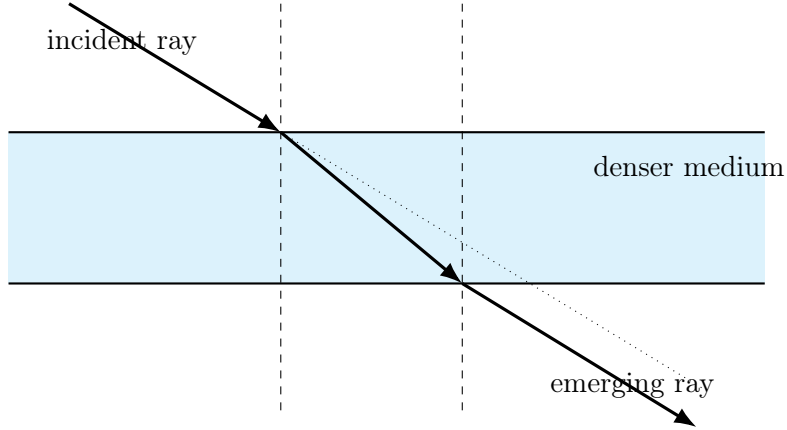


Figure 5: A ray passing through a parallel-sided transparent medium. The outgoing ray is parallel to the incoming ray but laterally displaced.

This case is useful because it shows that ordinary refraction can alter the apparent position of a ray without producing a permanent angular deviation after the refractive medium has been exited symmetrically.

6 Refraction and Apparent Position

Refraction may alter where an observer perceives a luminous source to be located. If light passes through a refracting region before reaching the observer, the observer may extrapolate the arriving ray backward along a straight line and therefore infer an apparent source position different from the true one.

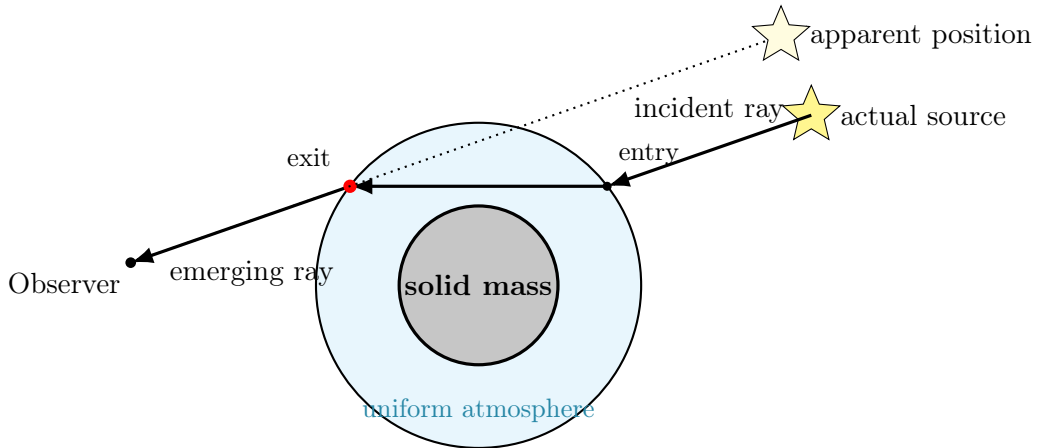


Figure 6: Conceptual illustration of refractive apparent displacement. The observer infers an apparent source position by extending the arriving ray backward.

The important point is that apparent source displacement does not, by itself, identify the physical mechanism responsible for the bending.

7 Gravitational Deflection

Gravitational light deflection is conceptually different from ordinary refraction at a material interface. In General Relativity, a massive body modifies the surrounding spacetime geometry, and light follows the corresponding null geodesics [4].

A ray passing near a massive body is therefore deflected toward the mass.

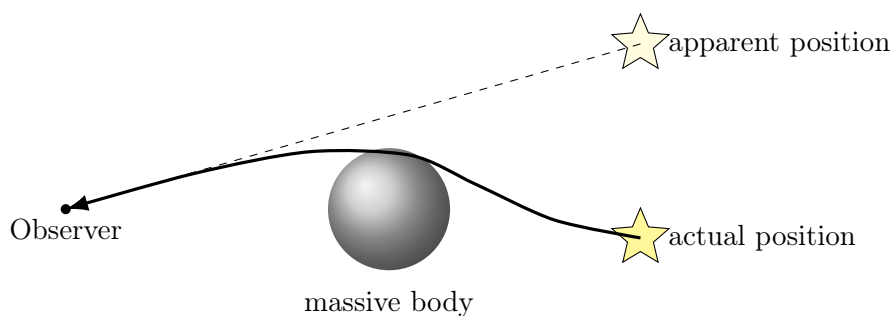


Figure 7: Conceptual gravitational deflection. A light ray passing near a massive body is deflected toward the mass, while backward extrapolation of the arriving ray produces an apparent source position farther from the mass.

The observed apparent position of the source can therefore differ from its true position even though the mechanism is not ordinary material refraction.

It is worth emphasizing, however, that the magnitude of gravitational deflection in the solar system is extremely small. For a ray of light grazing the surface of the Sun, the predicted angular deflection is approximately 1.75 arcseconds — an angle roughly equivalent to the apparent size of a coin viewed from a distance of about 3 kilometers. This minuscule value is far too small to be perceived with the naked eye and can only be detected with precision instruments such as telescopes and photographic plates during a total solar eclipse. By contrast, the refractive deflection observed in the swimming-pool experiment is on the order of several degrees, many millions of times larger. This enormous quantitative difference reinforces the qualitative distinction established in this article: although both phenomena bend light, they do so through entirely different physical mechanisms and at entirely different scales.

8 The Essential Physical Distinction

The experiment and the preceding diagrams allow the comparison to be stated precisely.

For the water-to-air transition used in the experiment,

$$\boxed{\text{water} \rightarrow \text{air} \implies \theta_{\text{air}} > \theta_{\text{water}} \implies \text{light bends away from the normal}} \quad (2)$$

whereas for gravitational deflection,

$$\boxed{\text{gravitational field} \implies \text{light trajectory is deflected toward the massive body}} \quad (3)$$

These statements should not be interpreted as saying that every possible refractive configuration must bend light in a direction opposite to every gravitational configuration. Refraction depends on refractive-index gradients and boundaries, whereas gravitational deflection depends on spacetime geometry.

The more defensible conclusion is therefore that the swimming-pool experiment demonstrates a **specific and observable physical behavior of ordinary refraction**, and that this behavior should not be confused with the mechanism of gravitational lensing.

9 Why the Comparison Matters

Both refraction and gravitational lensing can produce an apparent displacement of a source. This superficial similarity may lead to conceptual confusion if only the apparent image position is

considered.

However, three questions must be distinguished:

1. What physical mechanism changes the ray's direction?
2. In what direction does the ray bend?
3. How does the observer infer the apparent position from the arriving ray?

In the pool experiment, the physical cause is a change in refractive index at a material interface. In gravitational lensing, the physical description is the propagation of light through curved spacetime.

The two phenomena can therefore share an observational consequence—an apparent shift in source position—without being physically identical.

10 Conclusion

The laser-and-rod experiment provides a direct visual demonstration of the behavior of ordinary optical refraction.

Its most important result is not simply that the submerged rod appears bent. Rather, the decisive observation is that the laser beam itself changes direction as it leaves the water. In the water-to-air transition, the ray bends away from the normal in accordance with Snell's law.

This result provides a useful reference when discussing gravitational light deflection. A light ray passing near a massive body is gravitationally deflected toward that body. The gravitational case is therefore not physically equivalent to the water-to-air refraction observed in the experiment.

The experiment should not be interpreted as an independent proof of General Relativity. Its value is more specific: it makes the geometry and direction of ordinary refraction directly observable and thereby helps prevent ordinary refraction from being conflated with gravitational lensing merely because both can alter the apparent position of a light source.

In this sense, the experiment offers a simple but instructive physical distinction:

similar apparent displacement does not imply identical physical mechanism

Author's Note

This revised presentation clarifies the original purpose of the experiment reported by the author in an earlier publication [5]: to distinguish the observable behavior of optical refraction from gravitational light deflection by focusing on the physical direction of the ray itself, rather than only on the apparent position of an object or source.

References

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