

Optical Density, Light Speed, and the Index of Refraction

Lesson Notes

Learning Outcomes

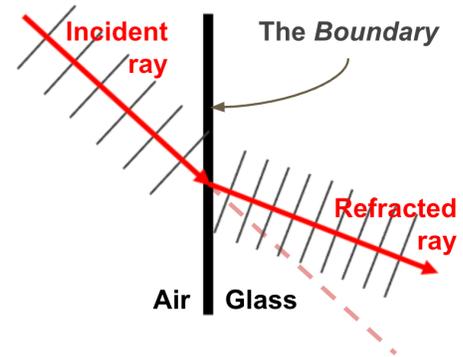
- How are the optical density of a material, the index of refraction of a material, and the speed of light in the material related?

REVIEW: Refraction at a Boundary

When a light wave crosses the boundary between two transparent materials, ...

- the **speed changes**
- the **wavelength changes**
- the **direction changes**

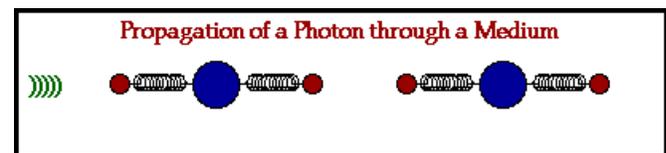
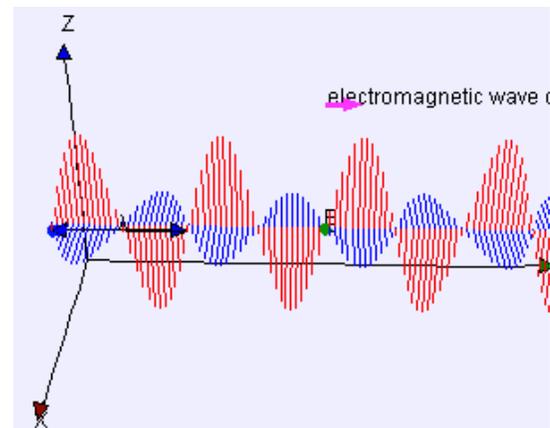
The change in direction of a light wave is known as **refraction**.



How can one predict whether the speed will increase or decrease when crossing the boundary?

Light Propagation Through a Medium

- Light waves are created by a vibrating charge, resulting in a rapidly fluctuating electric and magnetic field (an *EM wave*).
Image Source: <https://commons.wikimedia.org/wiki/File:Electromagneticwave3Dfromside.gif>
- An EM wave travel through empty space at **3.00×10^8 m/s**, a value known as **c**.
- It's passage through a transparent material requires the absorption and re-emission of the electromagnetic energy.
- While the particle-to-particle speed is *c*, the absorptions and re-emissions results in a time delay and the overall speed at which light travels through a material is less than *c*.



Optical Density and Light Speed

- Every material has its own unique **optical density**.
- The optical density describes the general sluggishness of the atoms in absorbing, maintaining, and re-emitting the EM energy as light passes through it.
- The more optically dense that a material is, the slower that light will travel through that material.

Air	Water	Glass	Diamond
<i>Least Dense</i>			<i>Most Dense</i>
<i>Fastest light speed</i>			<i>Slowest light speed</i>

The Index of Refraction

The **index of refraction** (n) describes how many times slower light travels in a material relative to its speed in a vacuum.

$$n = \frac{c}{v}$$

c = speed of light in vacuum (3.00×10^8 m/s)

v = speed of light in a material

Light travels slowest in materials with the highest index of refraction values.

Material	n	v (m/s)
Air	1.00	3.00×10^8 ← Fastest
Water	1.33	2.25×10^8
Glass	1.52	1.97×10^8
Diamond	2.42	1.24×10^8 ← Slowest

Optical Density, n , and Light Speed

- As the optical density increases, the speed of light decreases.
- As the n value increases, the speed of light decreases.
- Most dense materials \Rightarrow Largest n values \Rightarrow Slowest light speeds
- Least dense materials \Rightarrow Smallest n values \Rightarrow Fastest light speeds

The direction that light refracts and the amount that it refracts at a boundary is dependent upon the relative density, n values, and light speed of the two materials.

