Refraction Basics

Basic Optics, Chapter 16
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Specifically, we will look more closely at why rays change direction when encountering optically active substances.
Overview

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  - Specifically, we will look more closely at why rays change direction when encountering optically active substances

- In upcoming chapters we will explore the rules governing the passage of rays through lenses—rules that determine:
  - the location of images
  - the orientation of images
  - the status (i.e., real vs virtual) of images (and objects!)
  - the magnification of images
Overview

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● But first, a very brief review…
The term *vergence* describes what light rays are doing in relation to each other.

With respect to a given point, light rays can:

- Spread out (**diverge**)
- Come together (**converge**)
- Run parallel (**vergence = zero**)

**Review: Vergence**

- Divergent
- Convergent
- Zero vergence
Review: Vergence

- Two basic types of spherical lenses
Review: Vergence

- Two basic types of spherical lenses
  - Plus
  - Minus
Review: Vergence

- *Plus* lens: induces convergence
Review: Vergence

- *Minus* lens: induces divergence
Why does light change directions when it passes through a lens?
Why does light change directions when it passes through a lens? Because light slows down when it encounters a substance that is optically ‘more viscous’

(Note: Viscous, not ‘vicious’)

Refraction
Why does light change directions when it passes through a lens? Because light slows down when it encounters a substance that is optically ‘more viscous’

- Just as you can walk through air faster than you can through water, so light can pass more quickly through some substances than it can others.
- How much the light slows down depends on how optically ‘thick’ the substance is.
Refraction

- Why does light change directions when it passes through a lens? Because light slows down when it encounters a substance that is optically ‘more viscous’

  - The reverse is true as well—light speeds up when passing from an optically more-viscous substance into an optically less-viscous substance!

- How much the light slows down depends on how optically ‘thick’ the substance is
The ability of a material to slow the passage of light (i.e., its optical viscosity) is expressed as a ratio—the **Refractive Index** \((n)\)

\[
\frac{\text{Speed of light in vacuum}}{\text{Speed of light in material}} = \text{The refractive index} \ (n) \ \text{of the material}
\]
The ability of a material to slow the passage of light (i.e., its optical viscosity) is expressed as a ratio—the Refractive Index \( (n) \)

\[
\text{Speed of light in vacuum} \times \frac{\text{Speed of light in material}}{\text{Speed of light in vacuum}} = \text{refractive index} \ (n)
\]

Note: Refractive index is a function also of the wavelength of light. This is the source of the phenomenon known as chromatic aberration. This will be important later when we discuss the duochrome test.
Refraction

- Because the speed of light in a vacuum is its highest possible speed, \( n \) cannot be \( < 1.0 \)
- For practical purposes, \( n_{\text{air}} = 1.0 \)

\[
\frac{\text{Speed of light in vacuum}}{\text{Speed of light in material}} = \text{The refractive index (}n\text{) of the material}
\]
Refraction

- Some \( n \) of note:
  - Water: 1.33
  - Aqueous/vitreous: 1.34
  - Spectacle (crown) glass: 1.52
  - High-\( n \) plastics: up to \( \sim 1.9 \)
  - Cornea: 1.376

\[
\text{Speed of light in vacuum} = \text{Speed of light in material} \times \text{refractive index (} n \text{)}
\]
Some $n$ of note:

- Water: 1.33
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- High-$n$ plastics: up to ∼1.9
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Huh? I thought the $n$ of the cornea was 1.3375?

**Speed of light in vacuum** = The refractive index ($n$) of the material

**Speed of light in material**
Some $n$ of note:

- Water: 1.33
- Aqueous/vitreous: 1.34
- Spectacle (crown) glass: 1.52
- High-$n$ plastics: up to ~1.9
- **Cornea:** 1.376

Speed of light in vacuum / Speed of light in material = The refractive index ($n$) of the material

Huh? I thought the $n$ of the cornea was 1.3375? Yes and no—more on this in the slide-set entitled Corneal Optics in the Refractive Surgery section
Refraction

OK, so light changes speed as it passes from a substance of one $n$ to a substance with a different $n$.

Direction of Light Ray

Light in vacuum
$(n = 1.0)$

Light go Faster!

Glass prism
$(n = 1.5)$

Light go Slower!
Refraction

OK, so light changes speed as it passes from a substance of one $n$ to a substance with a different $n$.

But how does this change in speed lead to a change in direction (and therefore to refraction)?

Light in vacuum
($n = 1.0$)

Glass prism
($n = 1.5$)

*Light go Faster!*

*Light go Slower!*
Think of a light ray as being composed of individual ‘corpuscles’ of light that are linked to one another by a flexible mesh of sorts.

How does a change in light’s speed lead to a change in its direction?

Light in vacuum

\[ n = 1.0 \]

*Light go Faster!*

Glass prism

\[ n = 1.5 \]

*Light go Slower!*
Refraction

How does a change in light’s **speed** lead to a change in its **direction**?

Light in vacuum

\( n = 1.0 \)

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*Light go Slower!*
Refraction

How does a change in light’s *speed* lead to a change in its *direction*?

Light in vacuum

\[ n = 1.0 \]

*Light go Faster!*

Glass prism

\[ n = 1.5 \]

*Light go Slower!*

Because these corpuscles reached the prism first…
Because these corpuscles reached the prism first…

they are now traveling slower than these

Direction of Light Ray

Because these corpuscles reached the prism first.

Glass prism
(\(n = 1.5\))

Light in vacuum
(\(n = 1.0\))

Light go Faster!

Light go Slower!

Refraction

How does a change in light’s speed lead to a change in its direction?
Refraction

How does a change in light’s **speed** lead to a change in its **direction**?

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\[ n = 1.0 \]

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...they are now traveling slower than these

Because these corpuscles reached the prism first...
Refraction

How does a change in light’s speed lead to a change in its direction?

Light in vacuum 
\((n = 1.0)\)

Light go Faster!

Glass prism 
\((n = 1.5)\)

Light go Slower!

...produces a change in direction for the entire ray

Direction of Light Ray
How does a change in light’s speed lead to a change in its direction?

Note that if the refractive medium is hit ‘head on’…

Light in vacuum
\( (n = 1.0) \)

\textit{Light go Faster!}

Glass prism
\( (n = 1.5) \)

\textit{Light go Slower!}
Refraction

How does a change in light’s **speed** lead to a change in its **direction**?

Note that if the refractive medium is hit ‘head on’…

…all the corpuscles slow down at the same time.

Light in vacuum

\[(n = 1.0)\]

*Light go Faster!*

Glass prism

\[(n = 1.5)\]

*Light go Slower!*
Note that if the refractive medium is hit ‘head on’…

So there is no relative slowing, and thus no change in direction.

Direction of Light Ray

Light in vacuum
($n = 1.0$)

Glass prism
($n = 1.5$)

How does a change in light’s speed lead to a change in its direction?

Light go Faster!

Light go Slower!
How does a change in light’s **speed** lead to a change in its **direction**?

So, changing the direction of light via refraction requires two things:
1) The light ray must pass from a substance of one $n$ to a substance of a different $n$; **and**
2) The light ray must encounter the interface between the two substances at an angle (and not just any angle, as we’ll soon see)

<table>
<thead>
<tr>
<th>Light in vacuum</th>
<th>Glass prism</th>
</tr>
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<tbody>
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<td>$n = 1.0$</td>
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*Light go Faster!*  
*Light go Slower!*
Refraction

A light ray is encountering a prism…
A light ray is encountering a prism…Which way will the ray be refracted?
A light ray is encountering a prism…Which way will the ray be refracted? To answer this we have to introduce a concept with a peculiar name: The normal. The normal is simply an imaginary line perpendicular to the refractive interface.
When a ray passes from a material of lower $n$ to one of higher $n$, the ray is deflected toward the normal (how much it deflects is a function of the angle of incidence and the $n$s of the substances—more shortly).
What about when the ray passes from a higher-$n$ substance to a lower $n$?
When a ray passes from a material of higher $n$ to one of lower $n$, the ray is deflected \textit{away} from the normal.
If you think about it, all of this goes along with what you already know about the effect of prisms on light and images.
What if the prism is *rectangular* in shape?
What if the prism is \textit{rectangular} in shape? Snell’s law still rules: When light passes from a substance of lower $n$ into one of higher $n$, the ray is bent toward the normal.
What if the prism is rectangular in shape? Snell’s law still rules: When light passes from a substance of lower $n$ into one of higher $n$, the ray is bent toward the normal. Likewise, when it passes from a substance of higher $n$ into one of lower $n$, the ray is bent away from the normal.
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Why do triangular prisms change the direction of light but rectangular prisms don’t?

Note that rectangular prism has laterally displaced the ray, but unlike the case with its triangular cousin, the direction of travel is unchanged.
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