Optics
Refraction
Dispersion

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Last time

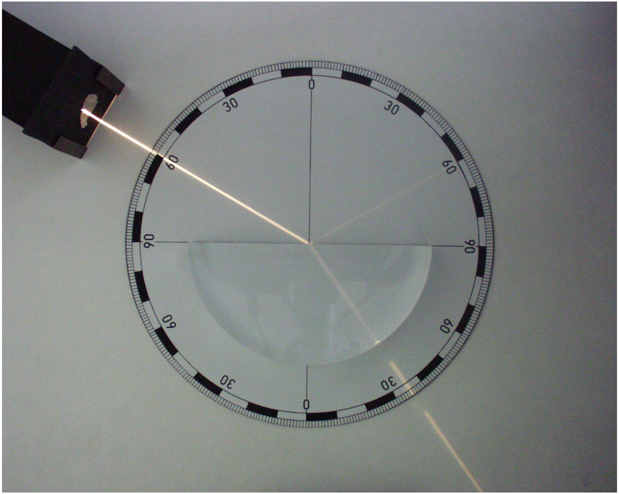
- ray optics
- reflection

Overview

- refraction
- dispersion

Refraction

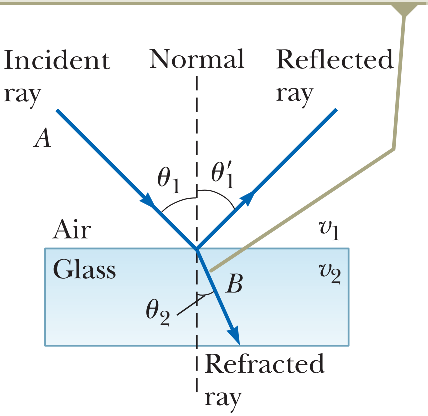
When light rays pass from one medium into another, they are often observed to bend.



[1] Image from Wikipedia, by Zátonyi Sándor.

Refraction

All rays and the normal lie in the same plane, and the refracted ray is bent toward the normal because $v_2 < v_1$.



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Both found visible light had a **slower speed** in water than in air. This agreed with the **wave model** of light.

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Both found visible light had a **slower speed** in water than in air. This agreed with the **wave model** of light.

However, Fizeau could not explain the magnitude of the speed change that occurred for light in *moving water*...

Refractive Index

Light *at a particular frequency* moves at different speeds in different media.

Light interacts with the charges that constitute the medium, and the net effect is a wave that moves more slowly.

Refractive index of a medium, n

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

where $v = \frac{\omega}{k}$ is the phase velocity of light with angular frequency ω in that medium.

Materials with a higher n are said to be more **optically dense**.

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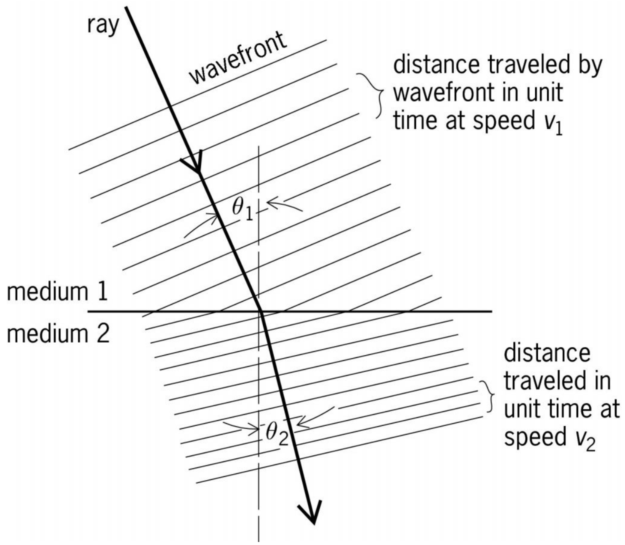
2. the wavelength changes ($v = f\lambda$)

When the wavefronts slow, they bend.

Refraction



[1]McGraw-Hill Concise Encyclopedia of Physics. © 2002 by The McGraw-Hill Companies, Inc.

Refractive Index

The index of refraction also relates to the ratio of the wavelength of light at a particular frequency in the medium, λ_n, to that same light's wavelength in a vacuum, λ.

$$n = \frac{c}{v} = \frac{f\lambda}{f\lambda_n}$$

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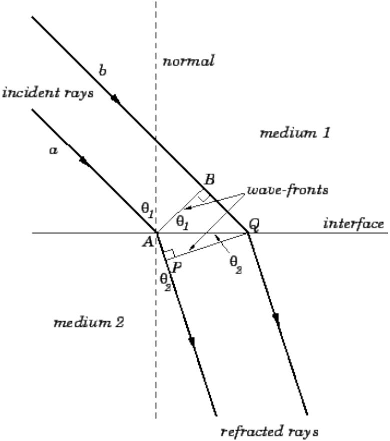
If the light passes from one medium with refractive index n_1 to another with index n_2:

$$\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1}$$

Snell's Law: Angle relationship in Refraction

How do the refractive indices relate to the angles of incidence and refraction?



Let h be the hypotenuse of the two triangles.

$$h = \frac{\lambda_1}{\sin\theta_1} = \frac{\lambda_2}{\sin\theta_2}$$

[1]Figure by Richard Fitzpatrick, http://farside.ph.utexas.edu/teaching/

Snell's Law

$$\frac{\lambda_1}{\sin\theta_1} = \frac{\lambda_2}{\sin\theta_2}$$

Rearranging,

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{\lambda_2}{\lambda_1} = \frac{n_1}{n_2}$$

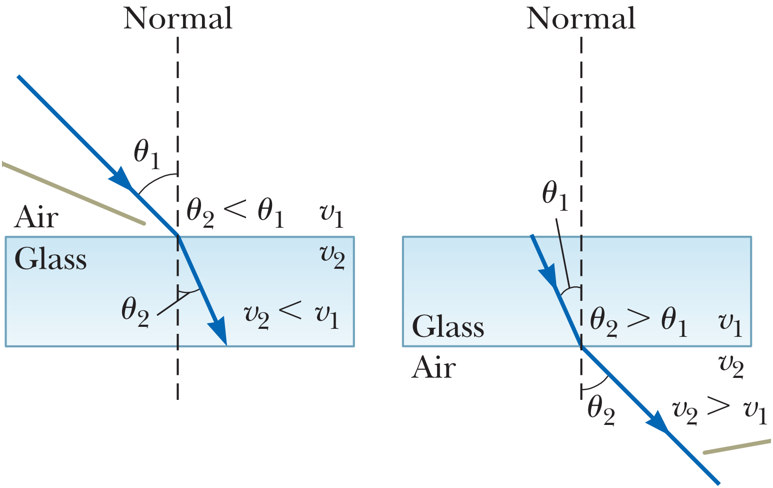
And rearranging again gives **Snell's Law**:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

[1] Willebrord Snell discovered this law experimentally.

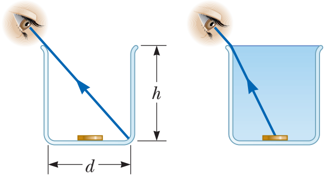
Snell's Law and Refraction

If $n_1 < n_2$ the ray bends towards the normal, if $n_1 > n_2$ the ray bends away from the normal.



Refraction Example, Ch35, #32

A person looking into an empty container is able to see the far edge of the container's bottom as shown. The height of the container is h, and its width is d. When the container is completely filled with a fluid of index of refraction n and viewed from the same angle, the person can see the center of a coin at the middle of the container's bottom.



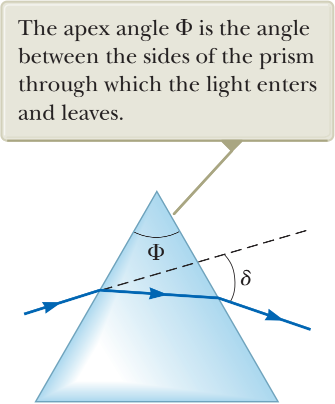
Show that the ratio h/d is given by

$$\frac{h}{d} = \sqrt{\frac{n^2 - 1}{4 - n^2}}$$

For what range of values of n will the center of the coin not be visible for any values of h and d?

Measuring Refractive Index

Another standard way to measure refractive indices of solids is using a prism:



δ is called the **angle of deviation**.

[1]See example 35.5, on page 1070.

Fermat's Principle

Also called the Principle of Least Time.

Fermat's Principle

The path a light ray follows between at starting point S and an end point T is the path between S and T that is travelled in the least time.

This principle correctly predicts the reflection and refraction equations.

This also relates to the calculus of variations, another approach to solving mechanics problems.

[1] Do questions 84 and 85 in the textbook.

Dispersion

We have already said that the speed of light for a given frequency of light is different in different media.

However, the speed of light is also different for different frequencies of light in *the same* medium.

This means the refractive index is a function of frequency, $n(\omega)$.

Summary

- refraction
- dispersion

Waves Full Solution Homework due today.

Homework

- WebAssign for Ch35

Serway & Jewett (recommeded):

- Ch 35, onward from page 1077. OQs: 9, 15; CQs: 7, 9, 13;