Optics
Refraction
Dispersion
Image formation from Mirrors

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Last time

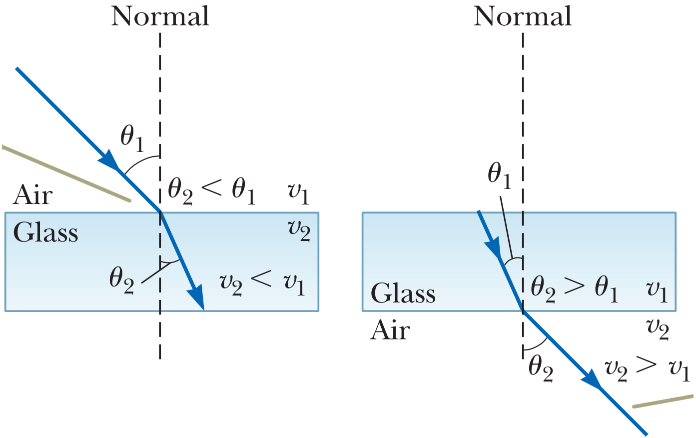
- speed of light
- ray optics
- reflection
- refraction

Overview

- practice with refraction
- dispersion
- image formation from mirrors

Snell's Law and Refraction

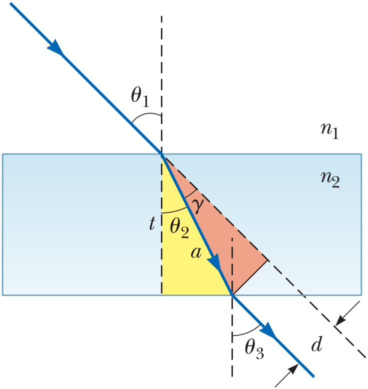
If $n_1 < n_2$ the ray bends towards the normal, if $n_1 > n_2$ the ray bends away from the normal.



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

Example 35.4: Light Passing Through a Slab

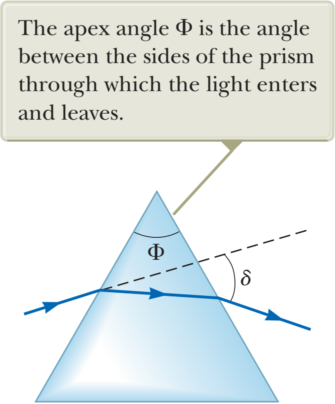
A light beam passes from medium 1 (refractive index n_1) to medium 2, with the latter medium being a thick slab of material whose index of refraction is n_2. Show that the beam emerging into medium 1 from the other side is parallel to the incident beam.



Also, find how d depends on t (and θ_1, θ_2).

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

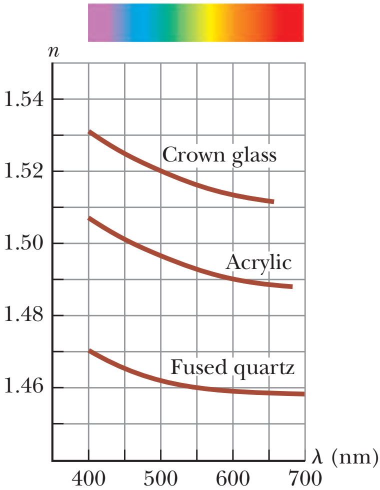
We have already said that the speed of light for a given frequency of light is different in different media.

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, $n(\omega)$.

Dispersion

A plot of refractive index vs. wavelength for some kinds of transparent solids:



Dispersion

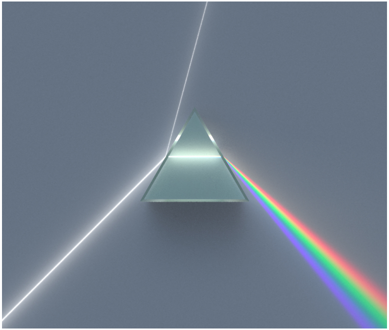
All materials exhibit dispersion, to varying degrees, except the vacuum.

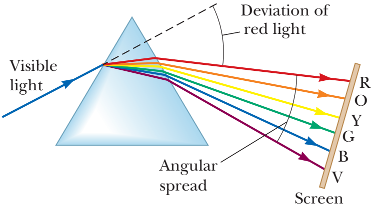
This has important effects: rainbow creation!

Dispersion can also have detrimental effects. In camera lenses, dispersion causes a blurring of the image.

[1]Image from http://imaging.nikon.com

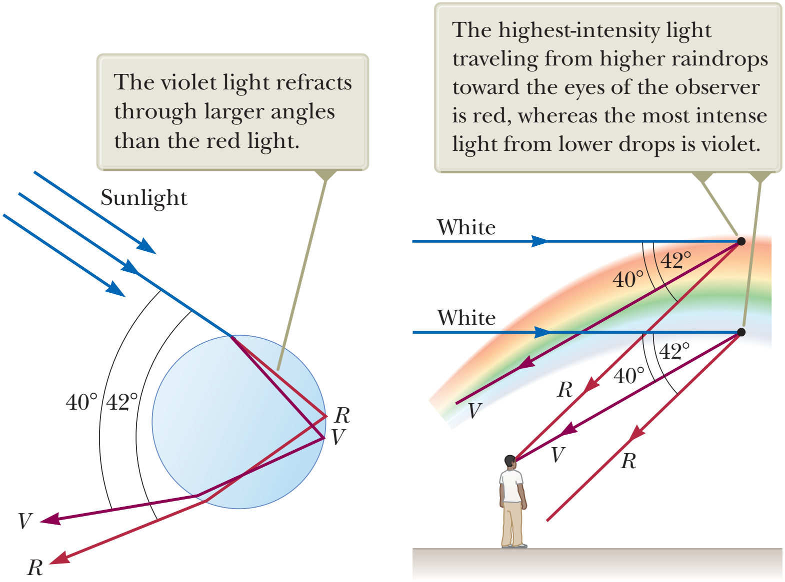
Prism Dispersion





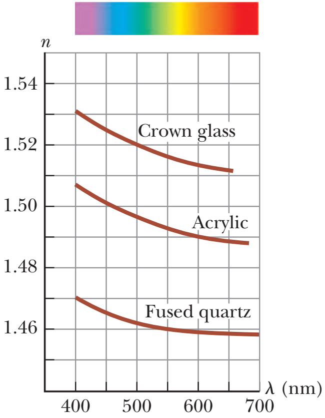
[1] Left, Wikipedia by Spigget; right, Serway & Jewett, page 1083.

Dispersion in Rainbows



Dispersion Question

Quick Quiz 35.4[1] In photography, lenses in a camera use refraction to form an image on a light-sensitive surface. Ideally, you want all the colors in the light from the object being photographed to be refracted by the same amount. Of the materials shown, which would you choose for a single-element camera lens?



(A) crown glass

(B) acrylic

(C) fused quartz

(D) impossible to determine

[1] Serway & Jewett, page1074.

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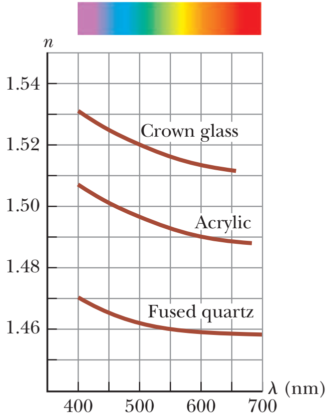

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Question

A water resistant flashlight is switched on under water in a pool. The ray from the flashlight strikes the top surface of the water, and makes an angle of 30° with the water's surface. What is the angle of refraction?

The refractive index of water is $n = 1.333$.

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What's happening?

Total Internal Reflection

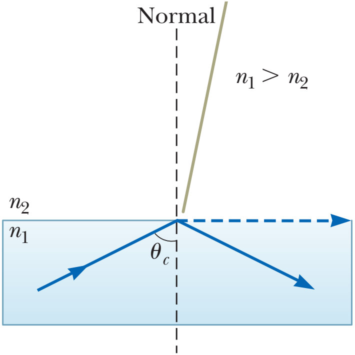
When a light ray travels from a medium with a higher refractive index to one with a lower refractive index, and it strikes the interface at a sufficiently large incident angle, there is no valid solution for the refracted ray.

In fact, in this case we don't see one! All of the light is reflected at the boundary.

This is called **total internal reflection**.

Total Internal Reflection

The **critical angle**, θ_c, is the maximum angle of incidence such that there could be a refracted ray. The ray would just skim along the surface between the media.



In this case, the angle of refraction $\theta_2 = 90°$.

Total Internal Reflection (TIR) Question

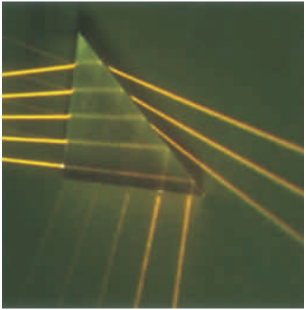
Quick Quiz 35.5[2] In the picture, five light rays enter a glass prism from the left. (i) How many of these rays undergo total internal reflection at the slanted surface of the prism?

(A) one

(B) two

(C) three

(D) four



Courtesy of Henry Leap and Jim Lehman

[2]Serway & Jewett, page1075.

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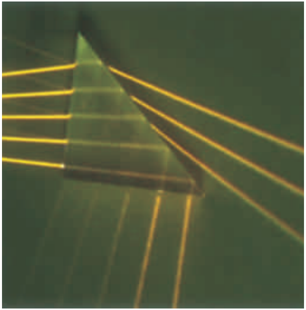

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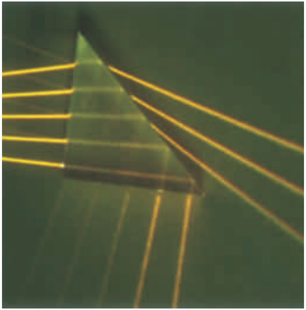
Total Internal Reflection (TIR) Question

Quick Quiz 35.5[3] In the picture, five light rays enter a glass prism from the left. (ii) Suppose the prism can be rotated in the plane of the paper. For all five rays to experience total internal reflection from the slanted surface, the prism should be rotated

(A) clockwise

(B) counterclockwise



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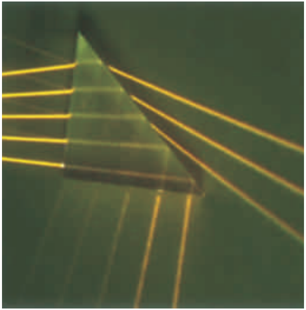

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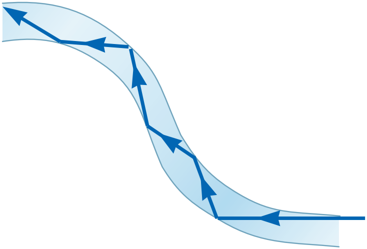
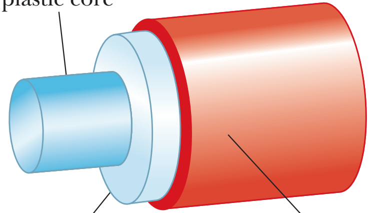
Application of TIR: Optical Fibers





Optical fibers are mainly used for telecommunications: much more information can be carried by an optical fiber than an electrical one in a given amount of time.

Optical fibers are also used in medicine.

Ray Optics and Image Formation

Simple geometric ray optics can be used to understand how images are formed by simple optical devices: mirrors and lenses.

[1] Wikipedia user Heptagon.

Images Formed by Flat Mirrors

When we see an object "in the mirror", we are not actually seeing something that is behind the mirror.

We are seeing an **image** of an **object** that is placed in front of the mirror.

The image seems to be the same distance behind the mirror as the object is in front of it.

The image seems to be the same size as the object.

This is not true for all optical devices, but we can work out things about how the image will form for many different optical devices.

Image Formation Terminology

object distance, p

The perpendicular (shortest) distance from the object to the device.

image distance, q

The perpendicular (shortest) distance from where the image appears to be to the device.

(lateral) magnification, M

The factor by which the image size exceeds the object's size

$$M = \frac{\text{image height}}{\text{object height}}$$

For mirrors and lenses

$$M = -\frac{q}{p}$$

Image Formation Terminology

real image

An image that can be displayed on a screen formed when the light rays pass through and diverge from the image point.

virtual image

An image that cannot be displayed on a screen, but can be seen "in the device" because the light rays appear to diverge from the image point.

The image in a flat mirror is virtual.

Image Formation Terminology

upright image

An image that appears to be right-side-up with respect to the object.

inverted image

An image that appears to be upside-down with respect to the object.

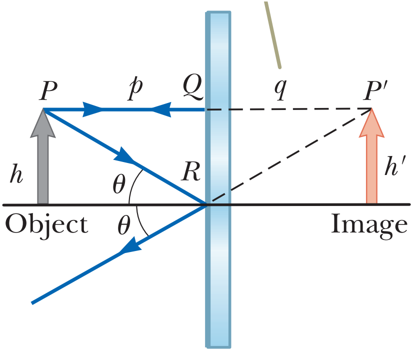
The image in a flat mirror is upright.

focal length, f

The distance from the optical device to where a set parallel rays striking the device head on (perpendicularly) will be focused.

For a flat mirror, the f is infinite.

Ray Diagram for a Flat Mirror

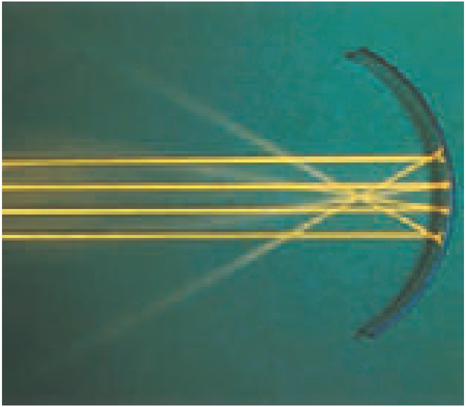


Ray diagrams have the optical device sketched vertically in cross section, the object on the left represented by an arrow pointing up.

The image is also represented by an arrow, but it may be to the left or right, pointing up or down depending on how the image is formed.

We sketch rays with paths we know to find the image.

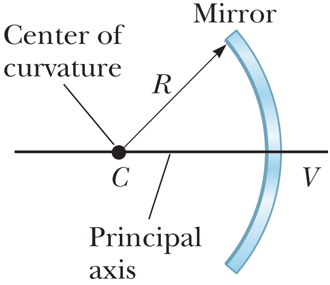
Images formed by Spherical Mirrors: Concave Mirrors

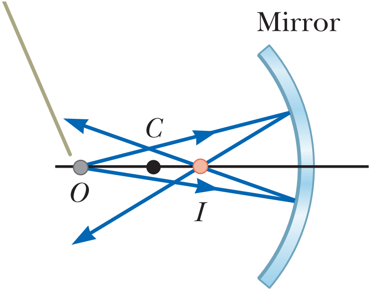


Henry Leap and Jim Lehman

Concave mirrors can focus light.

Images formed by Spherical Mirrors: Concave Mirrors





Assumption: paraxial rays

In studying curved mirrors and thin lenses we assume that all rays are **paraxial rays**.

Paraxial rays are rays close to the principle optical axis of our optical device. (Rays that strike close to the middle.)

For a spherical lens, rays that strike further from the axis are not focused to the same point (spherical aberration).

Mirror Equation and Thin Lens Equation

The same equation can help us to find the location and magnification of the image that will be formed by curved mirrors and thin lenses.

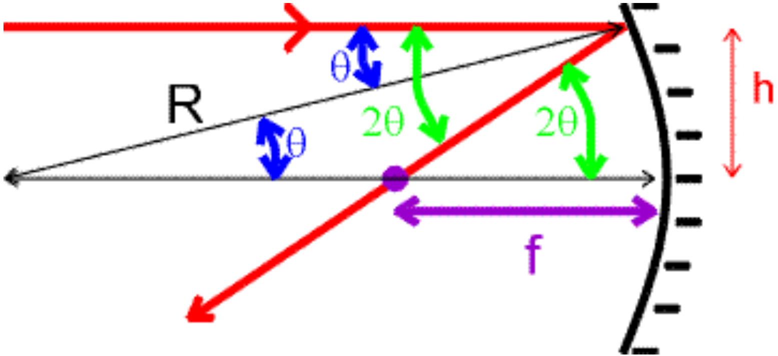
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Spherical Concave Mirrors

The focal point is where the detectors are place on satellite dishes and radio telescopes.

[1]Parkes telescope in Australia.

Spherical Concave Mirrors Focal Length

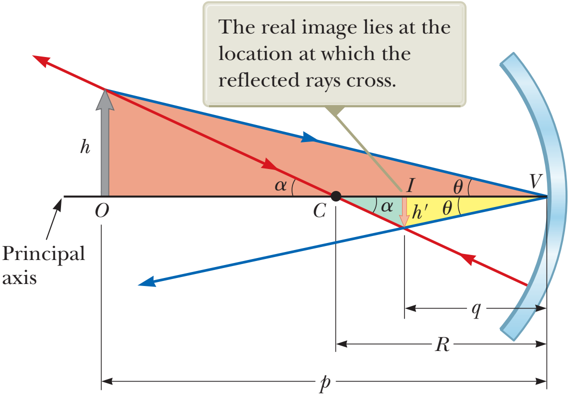


For a spherical concave mirror of radius R

$$f = \frac{R}{2}$$

Concave Mirrors and the Mirror Equation

Simple geometry shows why the mirror equation is true for a concave mirror.



We will use this ray diagram.

Ray Diagrams for Spherical Mirrors

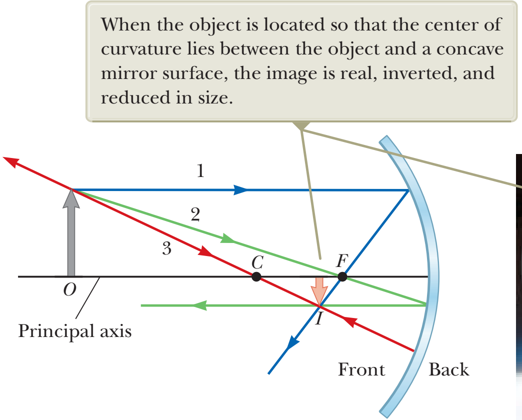
For a ray diagram: draw at least two rays that you know the path of accurately.

For Spherical mirrors:

1. Draw a ray from the top of the object parallel to the principle axis reflected through the focal point F.
2. Draw a ray from the top of the object through the focal point and reflected parallel to the principal axis.
3. Draw a ray from the top of the object through the center of curvature C and reflected back on itself.

Where the lines meet, an image is formed.

Examples of Ray Diagrams



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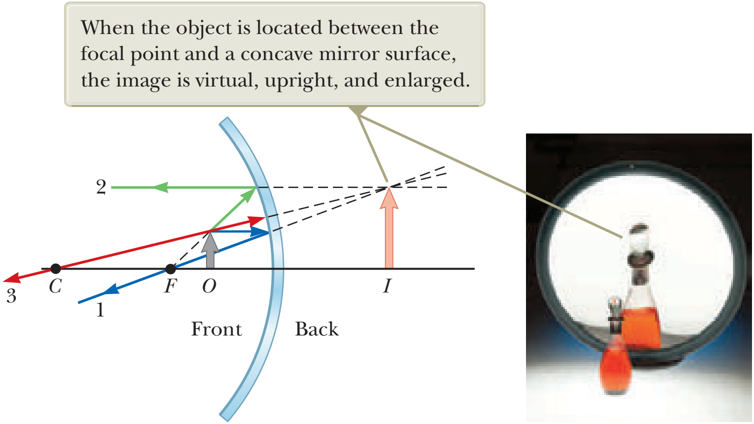
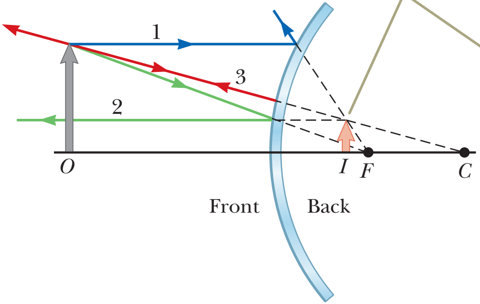


Examples of Ray Diagrams (Convex Mirror)

When the object is in front of a convex mirror, the image is virtual, upright, and reduced in size.



Summary

- refraction
- dispersion
- total internal reflection
- image terminology
- images formed by spherical mirrors

4th Collected Homework due Monday June 18.

Homework Serway & Jewett:

- Ch 35, onward from page 1077. OQs: 9, 15; CQs: 7, 9, 13; Probs: 7, 13, 27, 31 37, 39, 41, 47, 59, 69, 75, 84, 85, 64 (in this problem the description means that one side of the mirror reflects 10% of the light and transmits the other 90%, the other side reflects 90%)
- Carefully read *all* of Chapter 36.