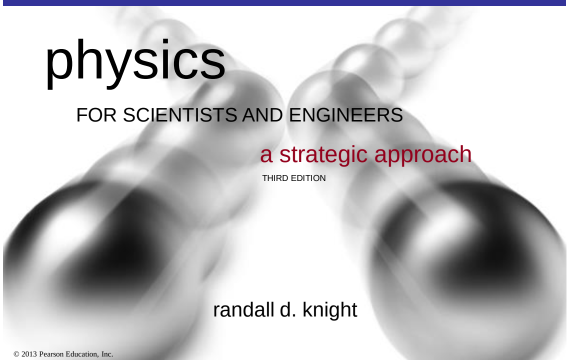
Class 4, Sections 23.1-23.5 Preclass Notes



physics

FOR SCIENTISTS AND ENGINEERS

a strategic approach

THIRD EDITION

randall d. knight

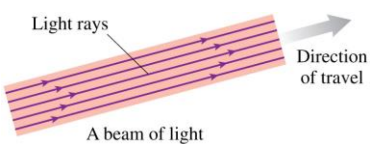
ALWAYS LEARNING PEARSON

Chapter 23 Ray Optics

Chapter Goal: To understand and apply the ray model of light.

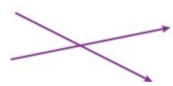
The Ray Model of Light

- Let us define a **light ray** as a line in the direction along which light energy is flowing.
- Any narrow beam of light, such as a laser beam, is actually a bundle of many parallel light rays.
- You can think of a single light ray as the limiting case of a laser beam whose diameter approaches zero.



The Ray Model of Light

- Light travels through a transparent material in straight lines called light rays.
- The speed of light is $v = c/n$, where n is the index of refraction of the material.



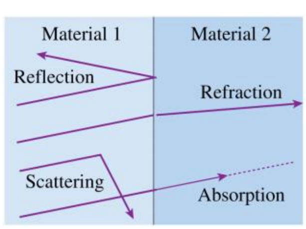
- Light rays do not interact with each other.
- Two rays can cross without either being affected in any way.

The Ray Model of Light

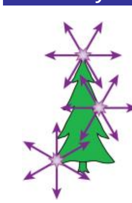
Light interacts with matter in four different ways:

At an interface between two materials, light can be either ***reflected*** or ***refracted****.*

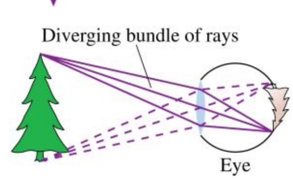
Within a material, light can be either ***scattered*** or ***absorbed****.*



The Ray Model of Light

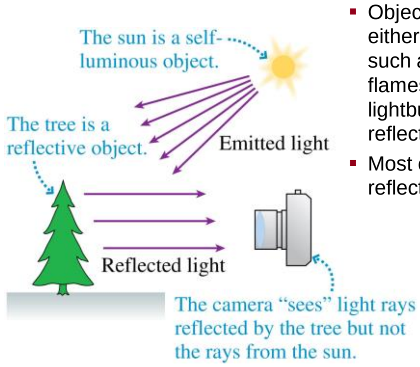


- An **object** is a source of light rays.
- Rays originate from *every* point on the object, and each point sends rays in *all* directions.



- The eye "sees" an object when *diverging* bundles of rays from each point on the object enter the pupil and are focused to an image on the retina.

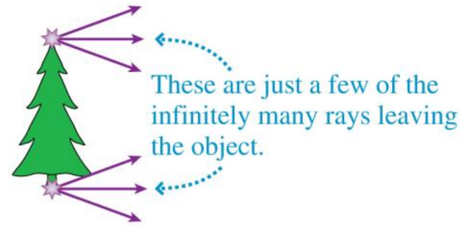
Objects



- Objects can be either self-luminous, such as the sun, flames, and lightbulbs, or reflective.
- Most objects are reflective.

Ray Diagrams

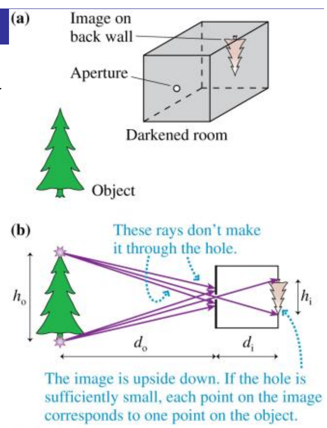
- Rays originate from *every* point on an object and travel outward in *all* directions, but a diagram trying to show all these rays would be messy and confusing.
- To simplify the picture, we use a **ray diagram** showing only a few rays.



Apertures

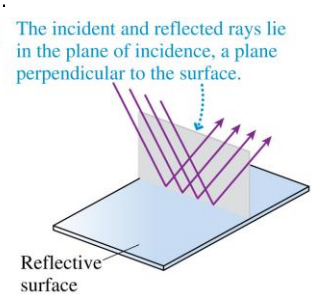
- A **camera obscura** is a darkened room with a single, small hole, called an **aperture.**
- The geometry of the rays causes the image to be upside down.
- The object and image heights are related by:

$$\frac{h_i}{h_o} = \frac{d_i}{d_o}$$



Specular Reflection of Light

Reflection from a flat, smooth surface, such as a mirror or a piece of polished metal, is called **specular reflection**.

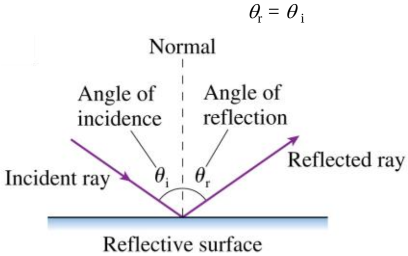


Specular Reflection

The **law of reflection** states that:

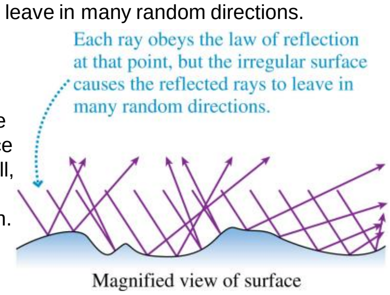
1. The incident ray and the reflected ray are in the same plane normal to the surface, and
2. The angle of reflection equals the angle of incidence:

$$\theta_r = \theta_i$$

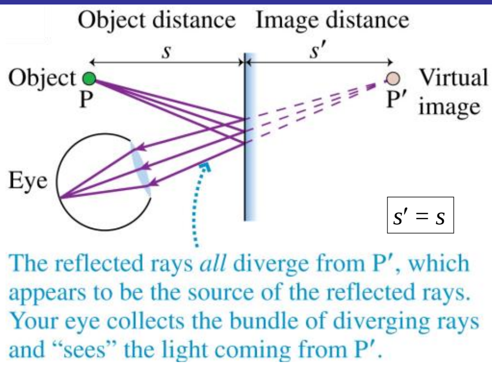


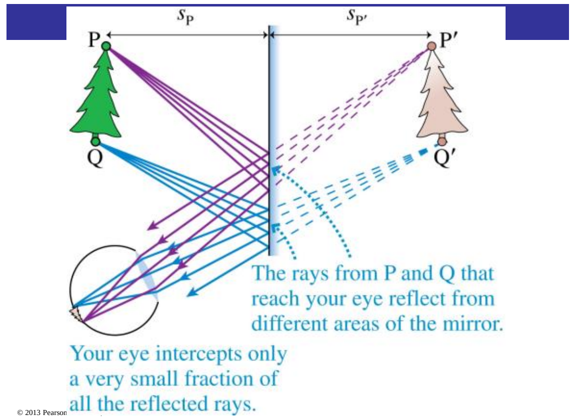
Diffuse Reflection

- Most objects are seen by virtue of their reflected light.
- For a "rough" surface, the law of reflection is obeyed at each point but the irregularities of the surface cause the reflected rays to leave in many random directions.
- This situation is called **diffuse reflection.**
- It is how you see writing on a piece of paper, the wall, your hand, your friend, and so on.



The Plane Mirror



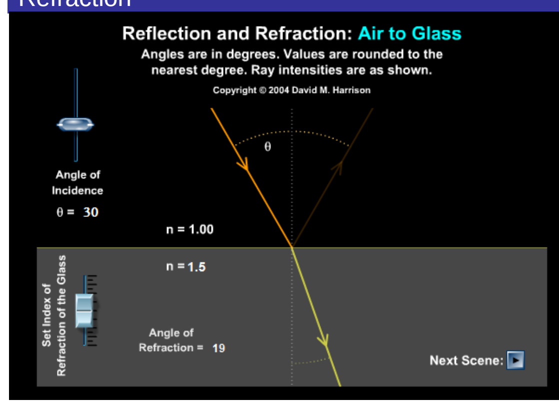


Refraction

Two things happen when a light ray is incident on a smooth boundary between two transparent materials:

1. Part of the light *reflects* from the boundary, obeying the law of reflection.
2. Part of the light continues into the second medium. The transmission of light from one medium to another, but with a change in direction, is called **refraction**.

Refraction



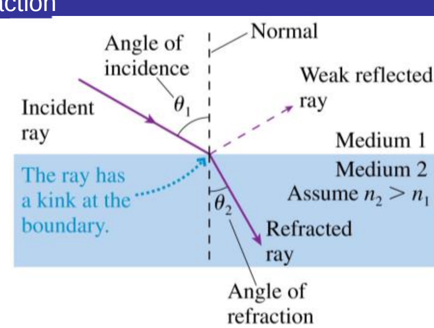
Indices of Refraction

TABLE 23.1 Indices of refraction

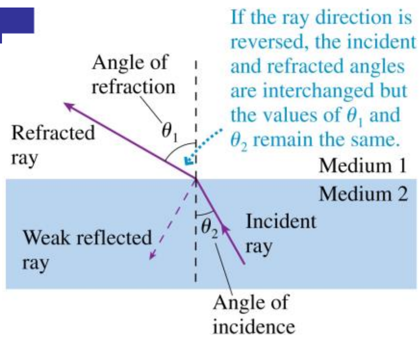
Medium	n
Vacuum	1.00 exactly
Air (actual)	1.0003
Air (accepted)	1.00
Water	1.33
Ethyl alcohol	1.36
Oil	1.46
Glass (typical)	1.50
Polystyrene plastic	1.59
Cubic zirconia	2.18
Diamond	2.41
Silicon (infrared)	3.50

$$n = \frac{c}{v_{\text{medium}}}$$

Refraction



$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \text{(Snell's law of refraction)}$$

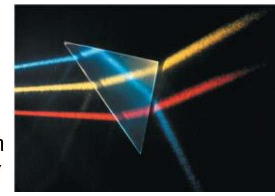


$n_1 \sin\theta_1 = n_2 \sin\theta_2$ (Snell's law of refraction)

Total Internal Reflection

- When a ray crosses a boundary into a material with a lower index of refraction, it bends *away* from the normal.
- The critical angle of incidence occurs when $\theta_2 = 90°$:

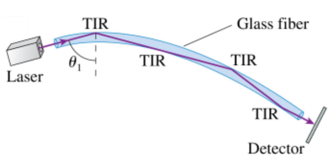
$$\theta_c = \sin^{-1}\frac{n_2}{n_1}$$



- The refracted light vanishes at the critical angle and the reflection becomes 100% for any angle $\theta_1 > \theta_c$.

Fiber Optics

- The most important modern application of **total internal reflection** (TIR) is optical fibers.
- Light rays enter the glass fiber, then impinge on the inside wall of the glass at an angle above the critical angle, so they undergo TIR and remain inside the glass.
- The light continues to "bounce" its way down the tube as if it were inside a pipe.



Fiber Optics

- In a practical optical fiber, a small-diameter glass core is surrounded by a layer of glass cladding.
- The glasses used for the core and the cladding have:

$$n_{core} > n_{cladding}$$

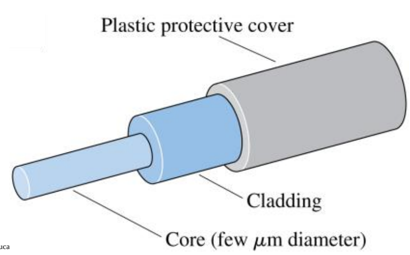


Image Formation by Refraction

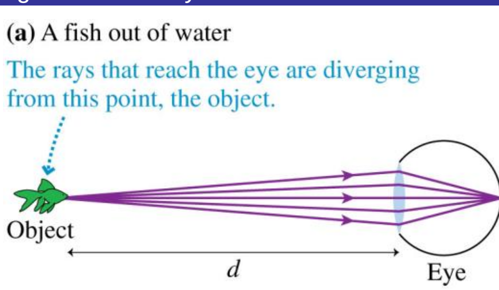


Image Formation by Refraction

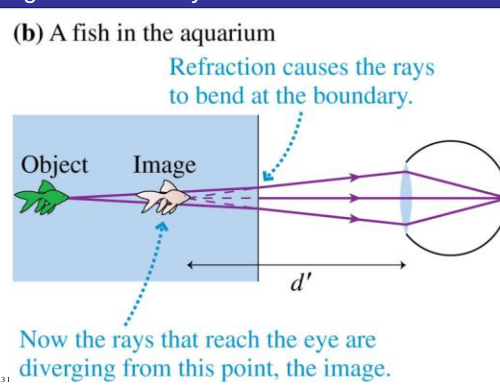
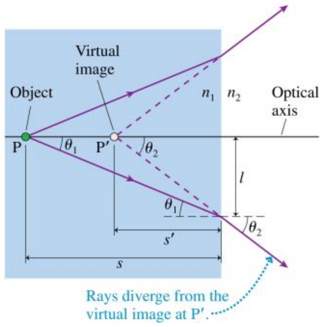


Image Formation by Refraction

- Rays emerge from a material with $n_1 > n_2$.
- Consider only **paraxial rays**, for which θ_1 and θ_2 are quite small.
- In this case:

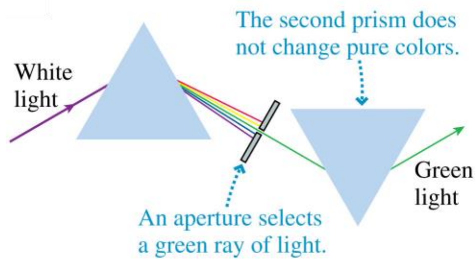
$$s' = \frac{n_2}{n_1} s$$

where s is the **object distance** and s' is the **image distance.**



Color and Dispersion

- A prism *disperses* white light into various colors.
- When a particular color of light enters a prism, its color does not change.



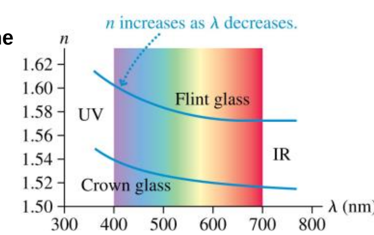
Color

- Different colors are associated with light of different wavelengths.
- The longest wavelengths are perceived as red light and the shortest as violet light.
- What we perceive as white light is a mixture of all colors.

Color	Approximate wavelength
Deepest red	700 nm
Red	650 nm
Green	550 nm
Blue	450 nm
Deepest violet	400 nm

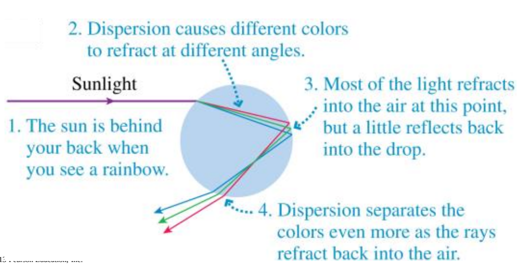
Dispersion

- The slight variation of index of refraction with wavelength is known as **dispersion.**
- Shown is the dispersion curves of two common glasses.
- Notice that ***n*** **is *larger* when the wavelength is *shorter***, thus violet light refracts more than red light.

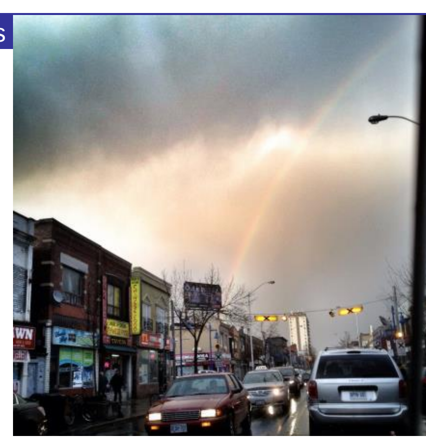


Rainbows

- One of the most interesting sources of color in nature is the rainbow.
- The basic cause of the rainbow is a combination of refraction, reflection, and dispersion.

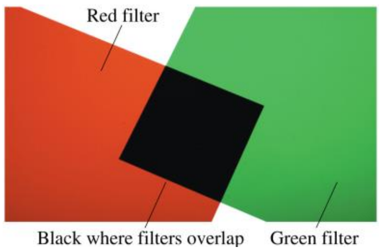


Rainbows



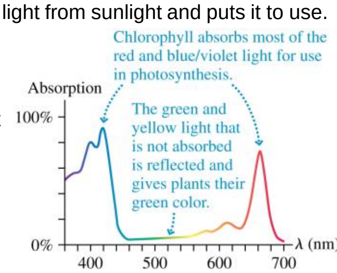
Colored Filters and Colored Objects

- Green glass is green because it absorbs any light that is "not green."
- If a green filter and a red filter are overlapped, no light gets through.
- The green filter transmits only green light, which is then absorbed by the red filter because it is "not red."



Colored Filters and Colored Objects

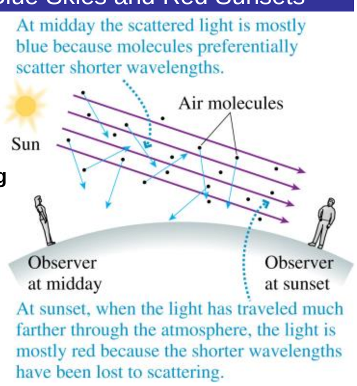
- The figure below shows the absorption curve of *chlorophyll*, which is essential for photosynthesis in green plants.
- The chemical reactions of photosynthesis absorb red light and blue/violet light from sunlight and puts it to use.
- When you look at the green leaves on a tree, you're seeing the light that was reflected because it *wasn't* needed for photosynthesis.



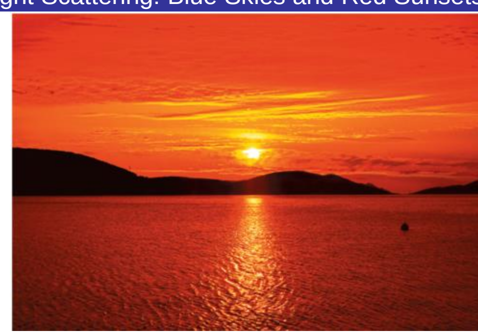
Light Scattering: Blue Skies and Red Sunsets

- Light can scatter from small particles that are suspended in a medium.
- **Rayleigh scattering** from atoms and molecules depends inversely on the fourth power of the wavelength:

$$I_{\text{scattered}} \propto \lambda^{-4}$$



Light Scattering: Blue Skies and Red Sunsets



Sunsets are red because all the blue light has scattered as the sunlight passes through the atmosphere.