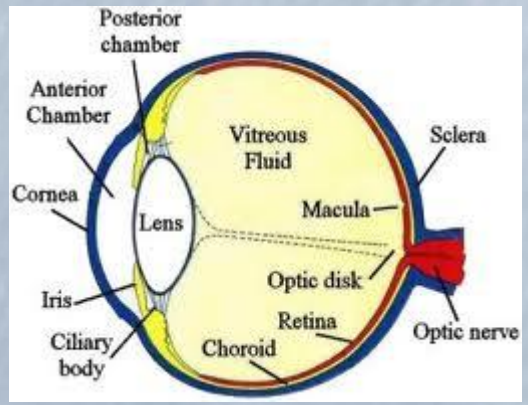
Ray Optics

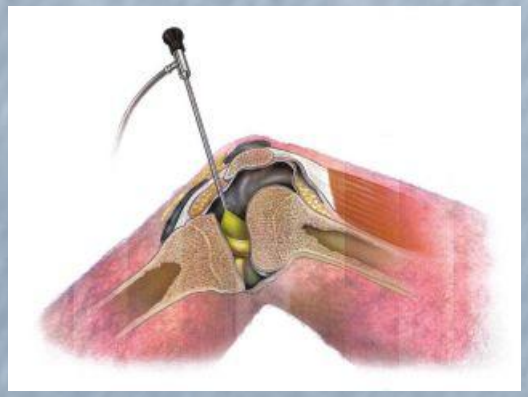
- Ray model
- Reflection
- Refraction, total internal reflection
- Color dispersion
- Lenses
- Image formation
- Magnification
- Spherical mirrors

Ray optics

Optical imaging and color in medicine

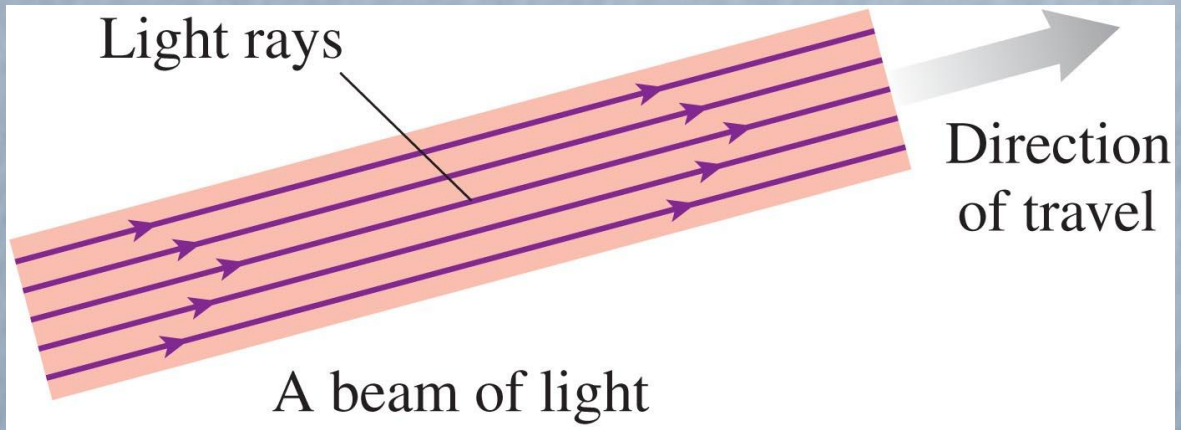
Integral part of diagnosis





Ray model

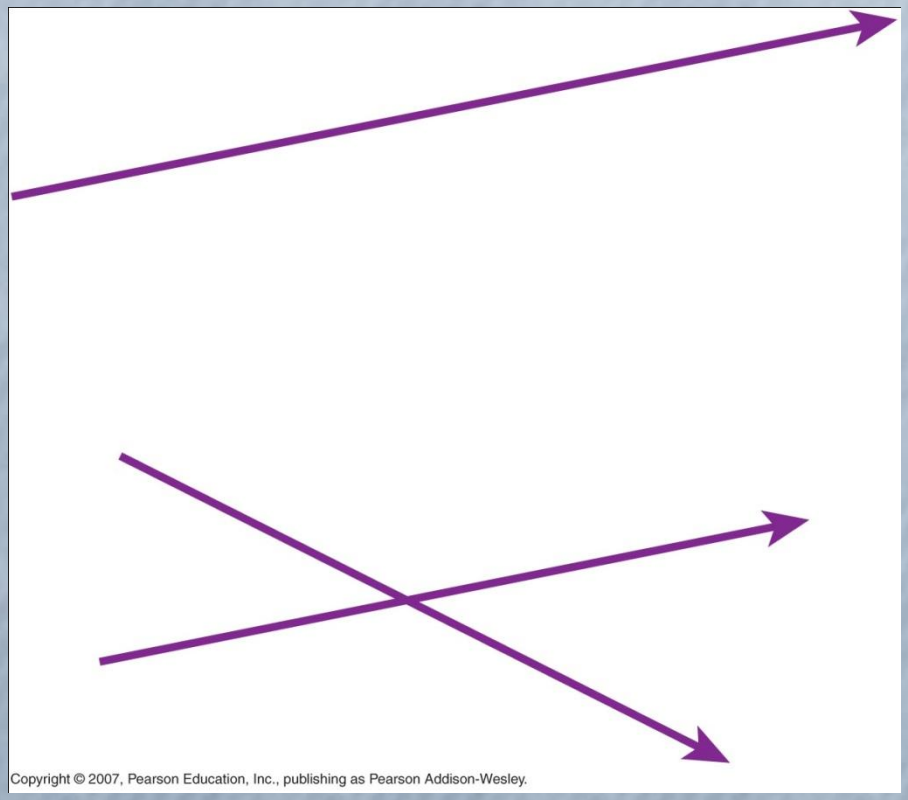
- Ray model is composed of **light rays** – abstract idea to show the direction along which light energy flows
- Works for systems where the objects are much larger than the wavelength of light



Ray model rules

Light travels in straight lines

Light rays can cross

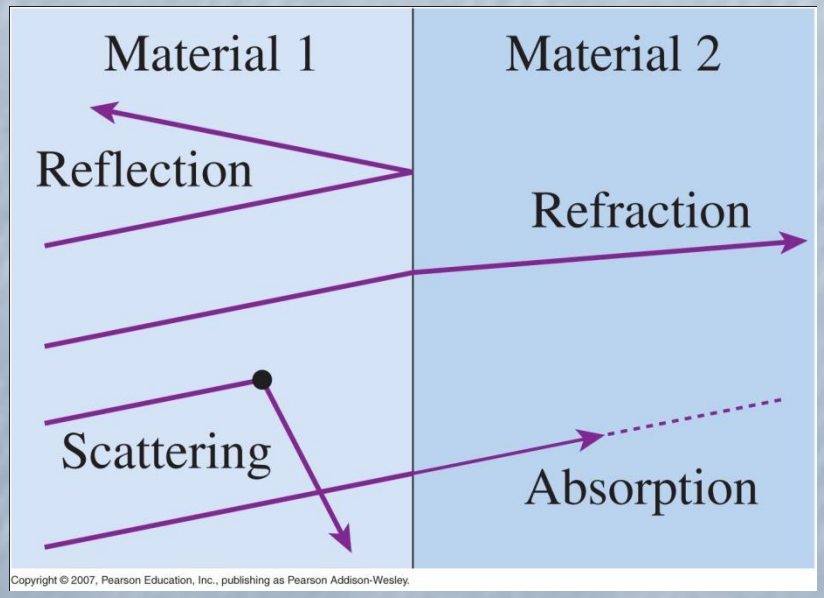


Ray model rules

Light rays travel though materials with a speed c/n, where n is the refractive index.

At a boundary, light can be reflected or refracted (or both)

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

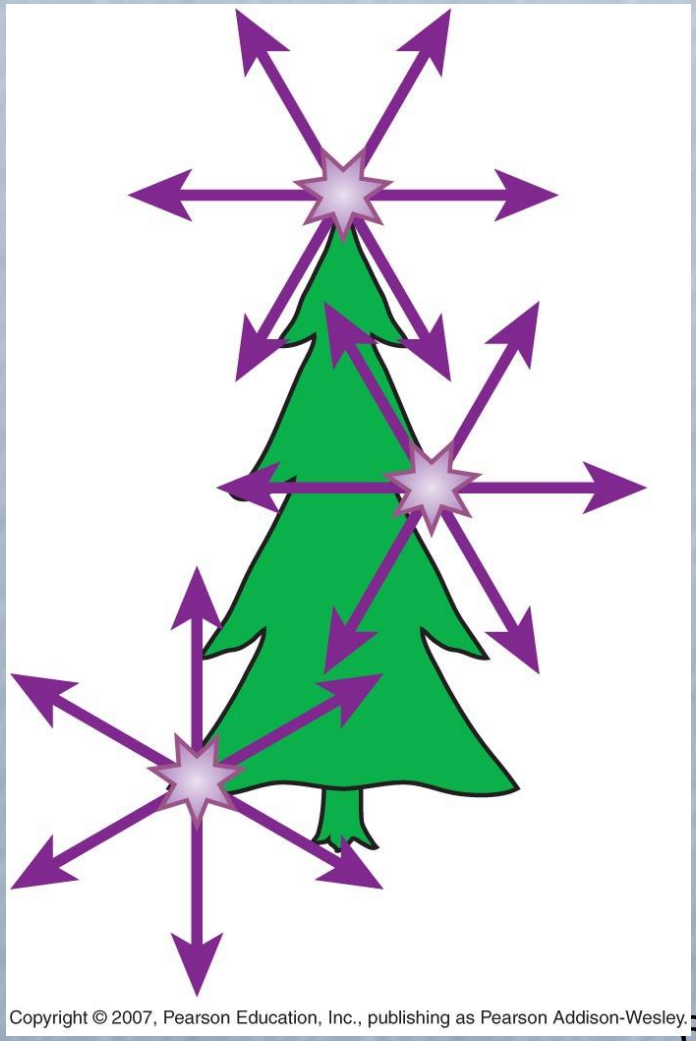


Ray model rules

Light rays originate from **objects**.

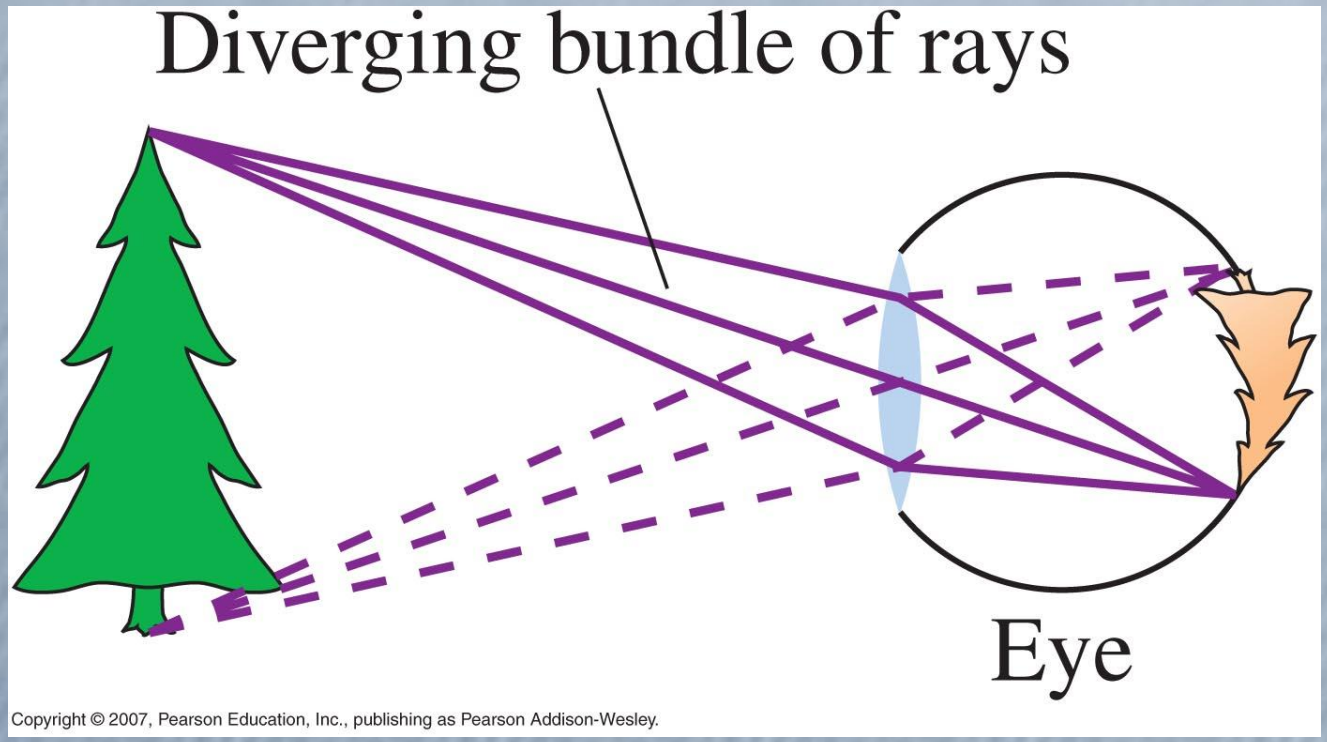
The object radiates in all directions

The light may be from the object (self-luminous objects – light bulbs), or the light may be reflected.



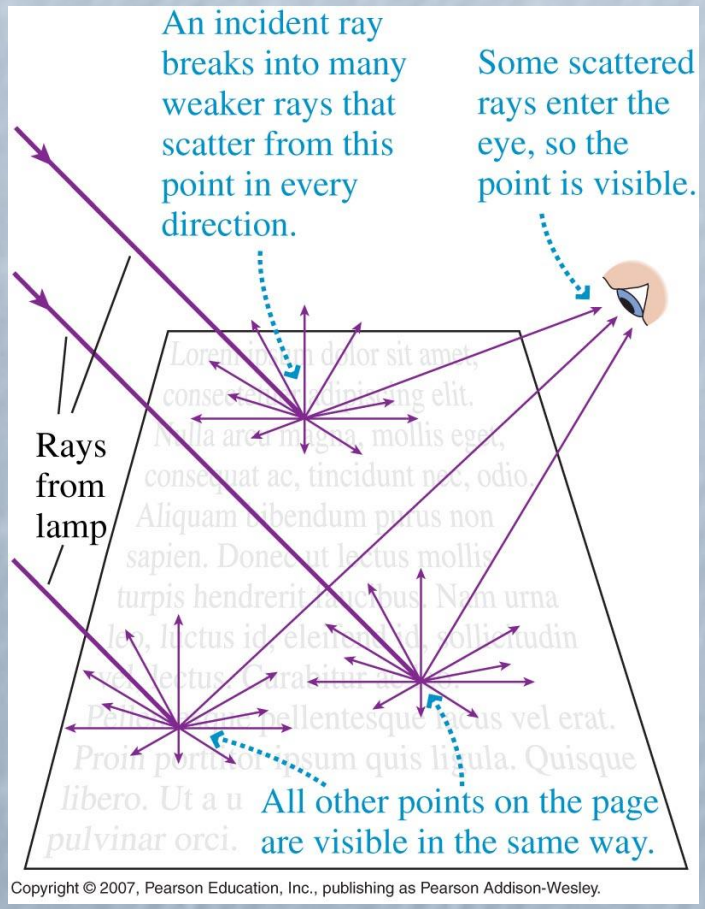
Ray model rules

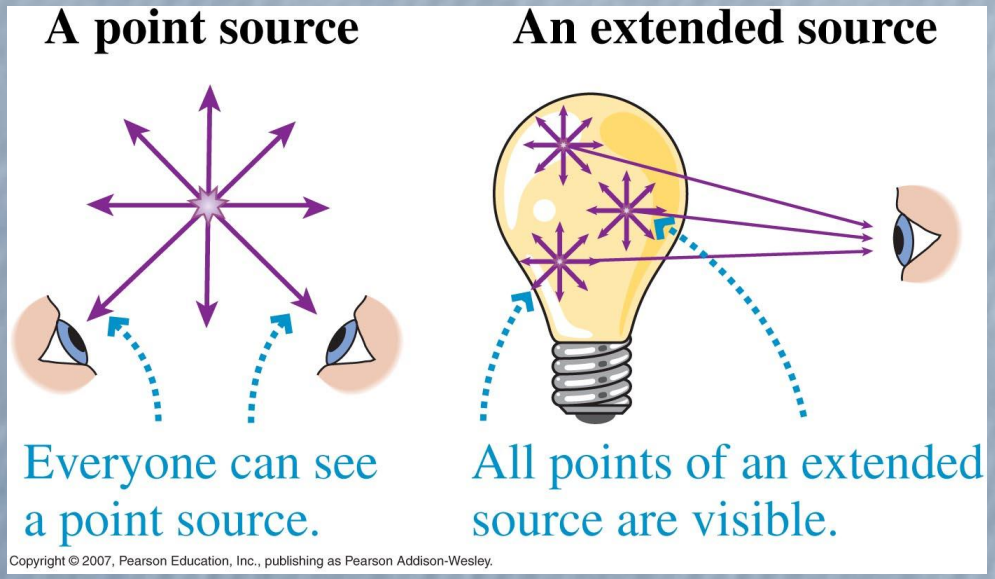
Light rays are detected by the eye if they pass through the pupil, and can be focused onto the retina at the back of the eye.



Seeing Objects

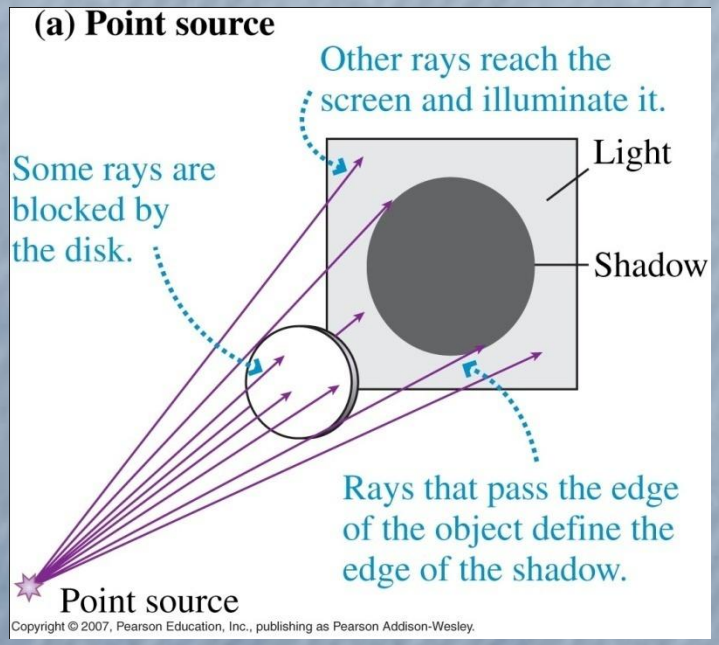
Objects are seen when light (scattered or transmitted) from an object enters the eye.

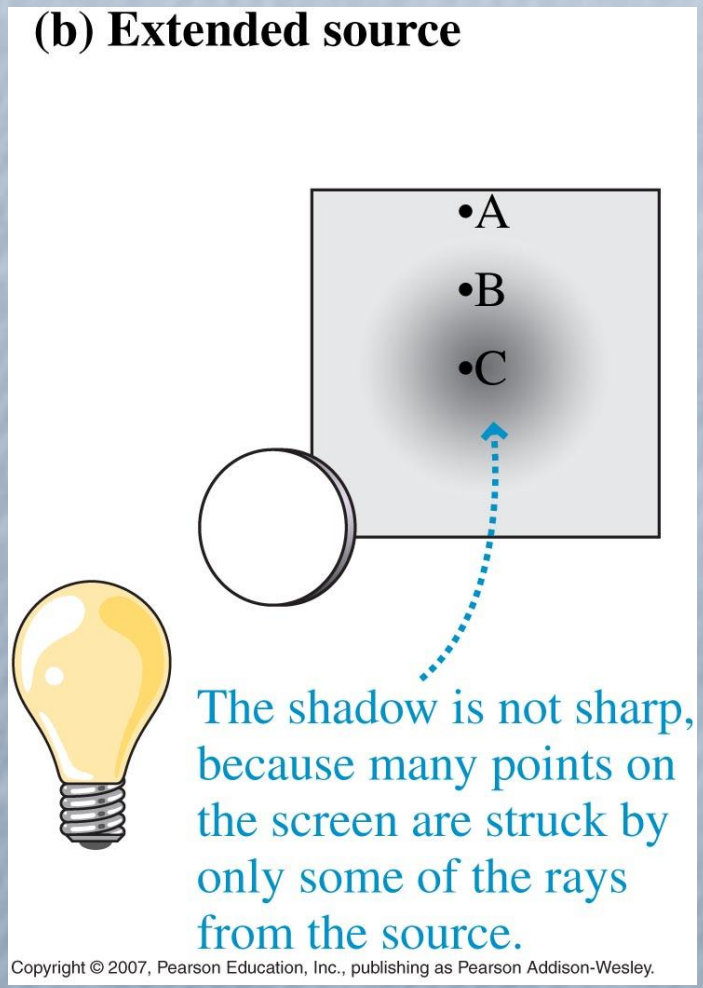




Shadows

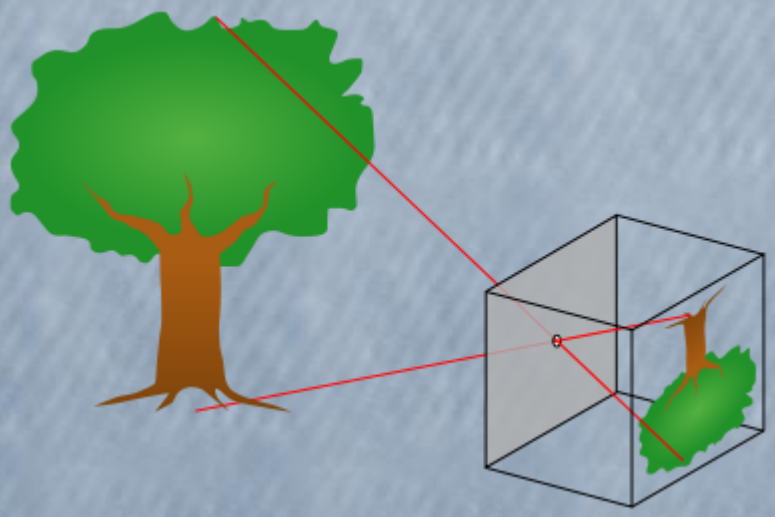
- Light rays can be absorbed by an opaque object.
- For an extended source, shadows can be fuzzy

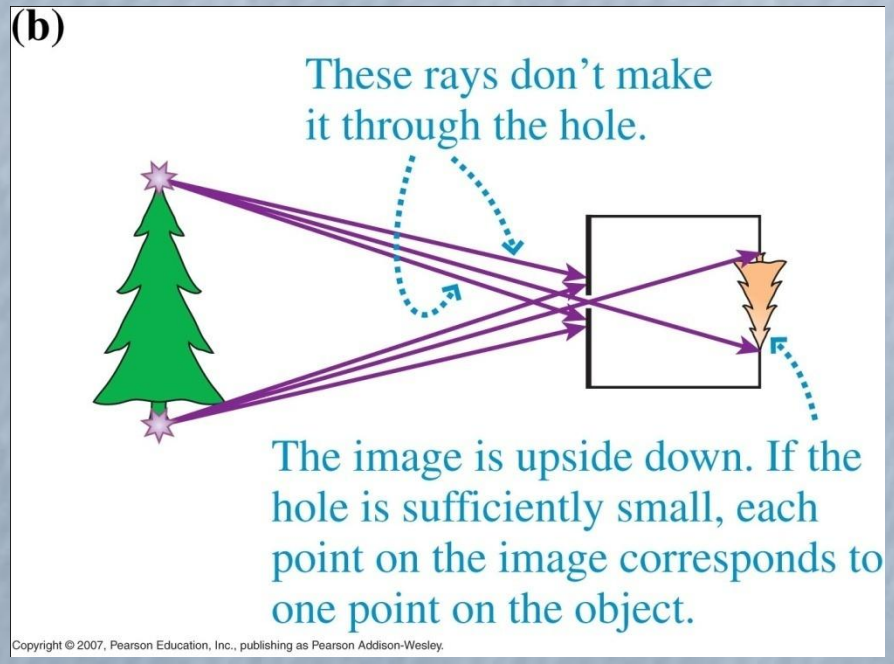




Pin hole camera

The pin hole camera selects rays which will create an inverted image.

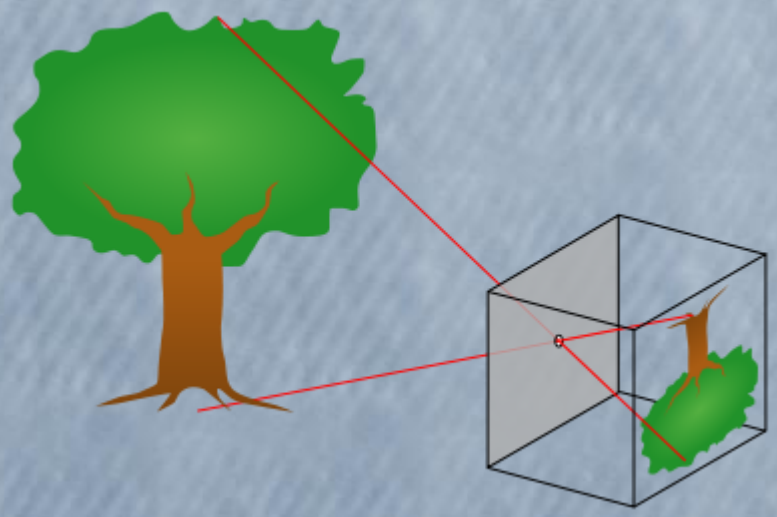




Pin hole camera

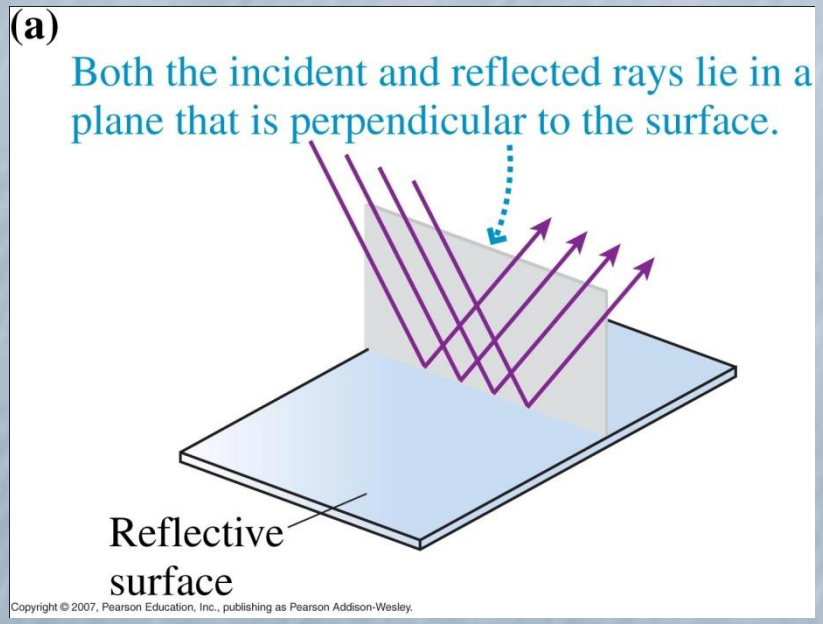
Advantages – no focusing required, (infinite field of depth), no color dispersion

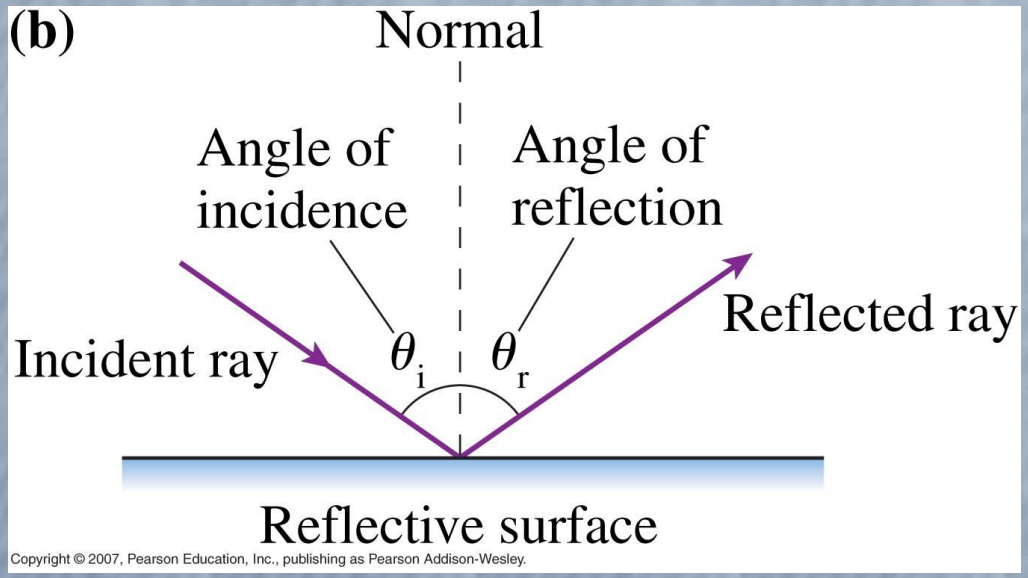
Disadvantage – requires long exposure time



Reflection

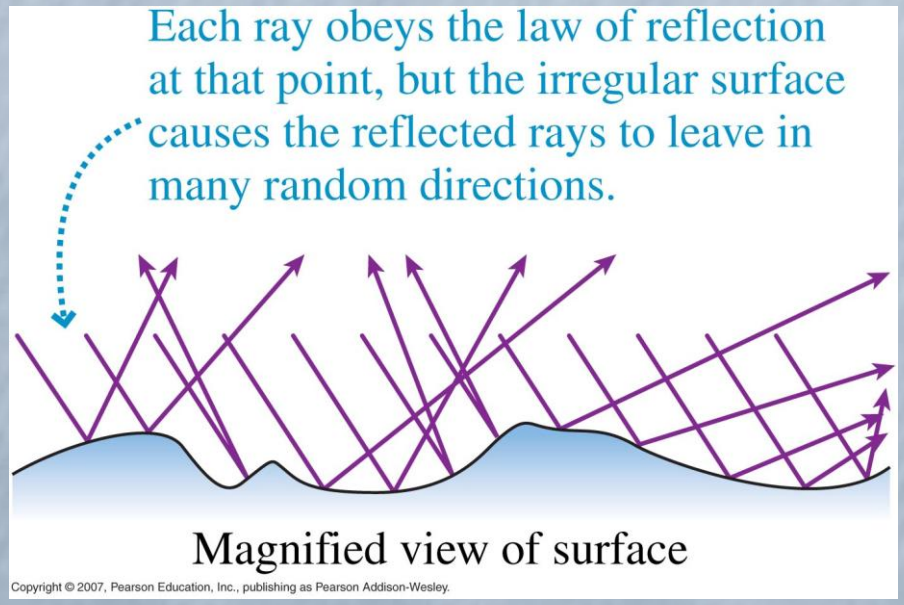
specular reflection is the reflection from a flat surface.

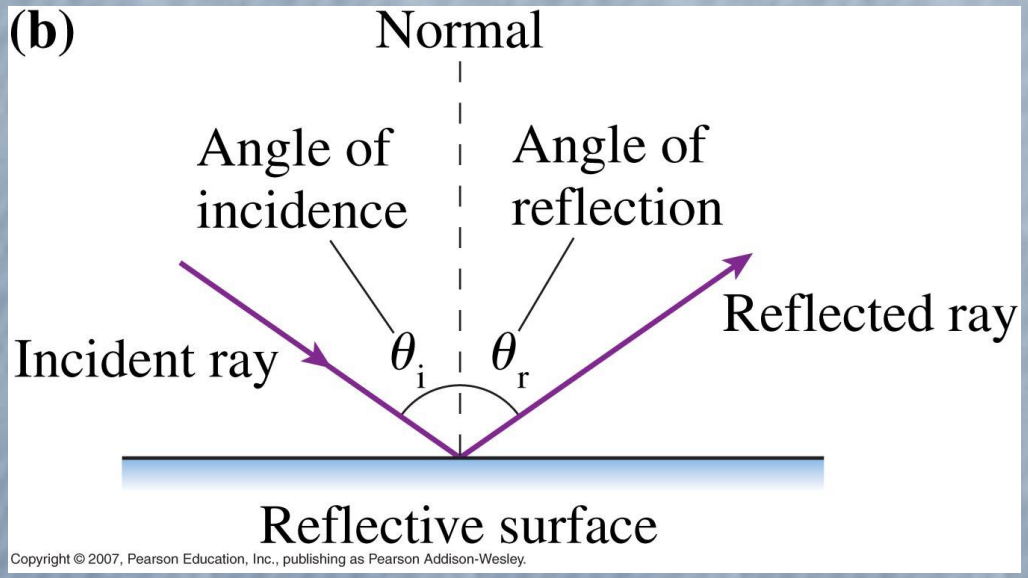




Reflection

diffuse reflection is the reflection from a flat surface.

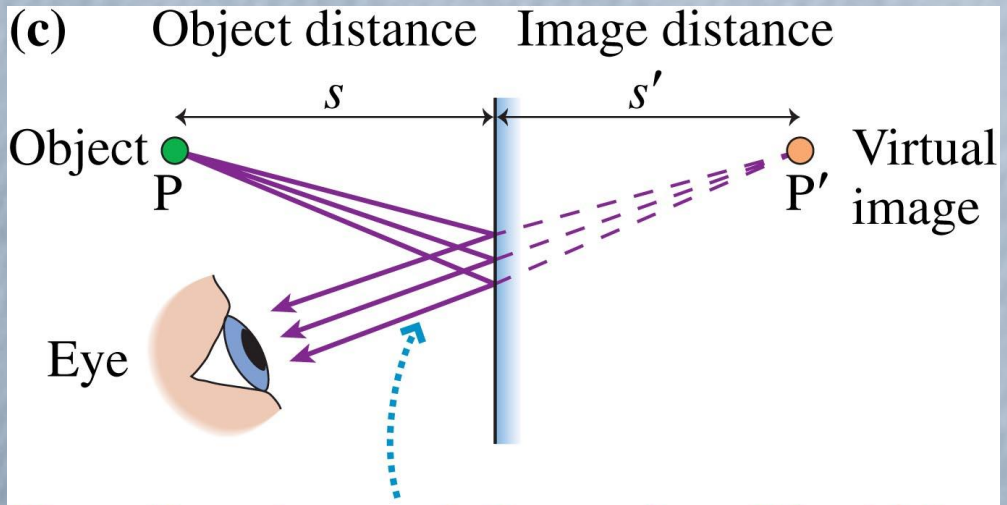




Plane Mirror Images

The reflected image in a mirror is **virtual.**

A screen placed there would not show an image.



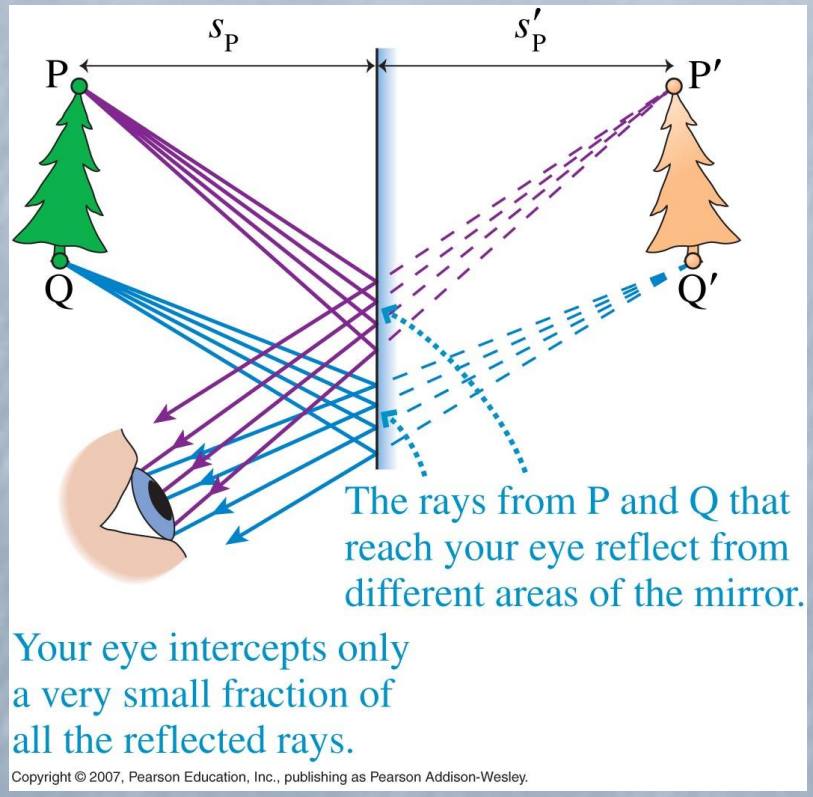
The reflected rays *all* diverge from P′, which appears to be the source of the reflected rays. Your eye collects the bundle of diverging rays and "sees" the light coming from P′.

Plane Mirror Images

The reflected image in a mirror is **not inverted.**

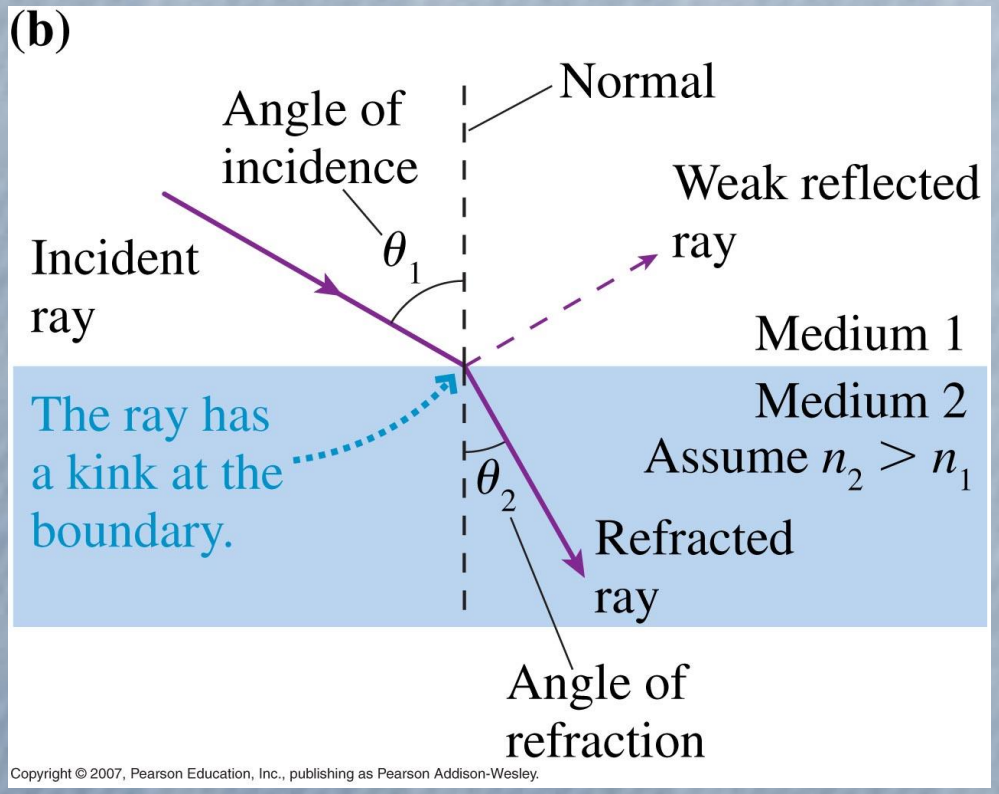
•The correct terminology for a reflected image is to say it **reverses front and back.**

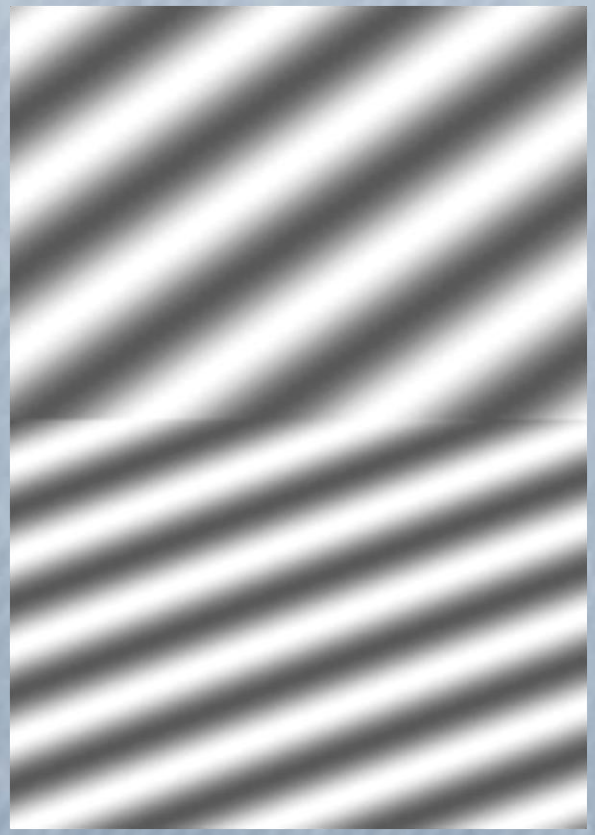
•Or say the image is **reflected**



Refraction

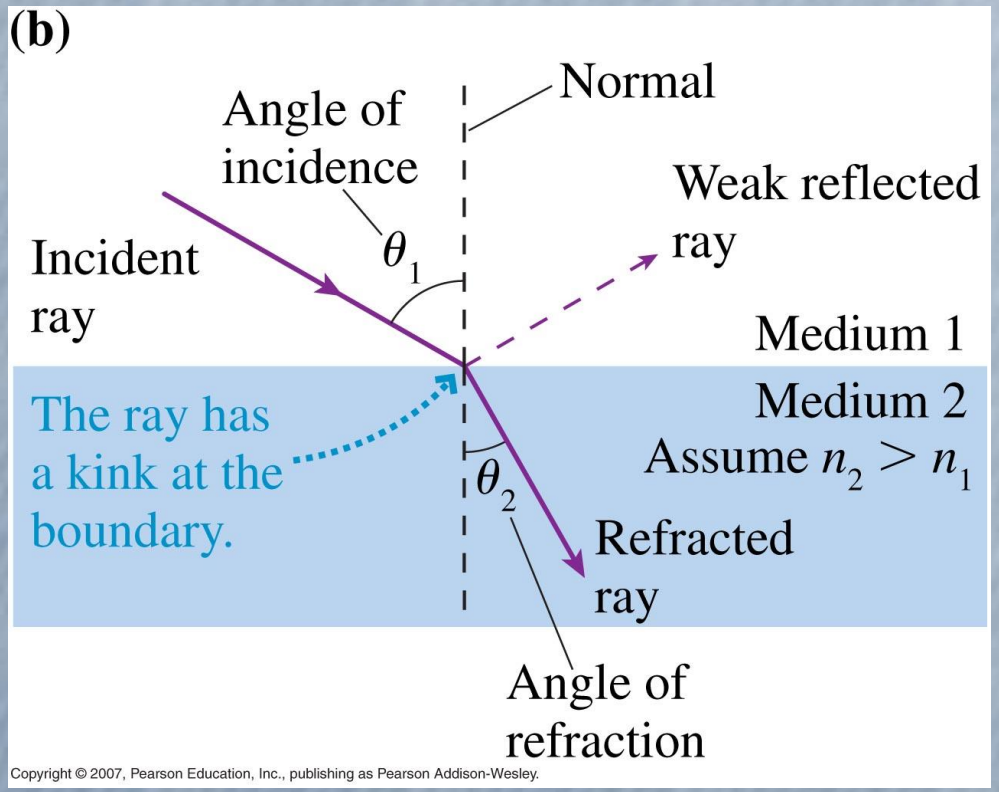
Light rays get bent going through a medium boundary:





Snell's law

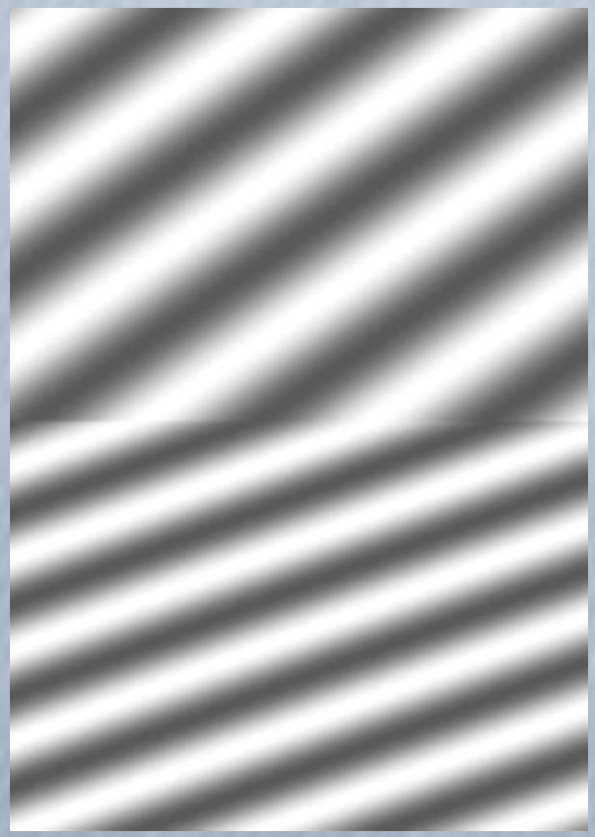
Snell's law relates the angle of refraction to the index of refraction.



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

Snell's Law

- The frequency of the light must be a constant.
- The length of the wave-front at the boundary must be a constant



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

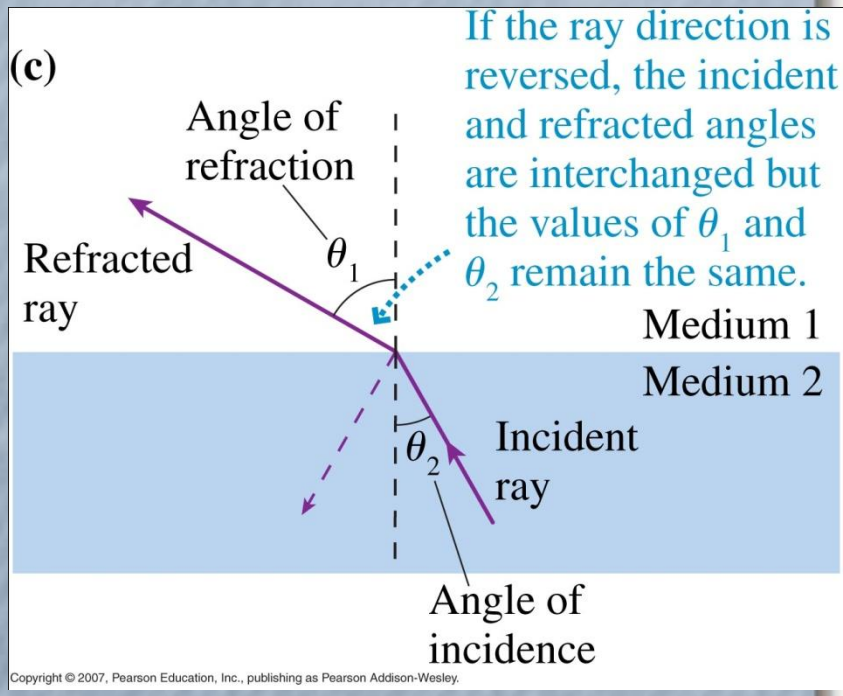
$$\lambda = \frac{v}{f} = \frac{c}{nf}$$

$$l = \frac{c}{n_1 f \sin\theta_1} = \frac{c}{n_2 f \sin\theta_2}$$

Snell's law

- Snell's law is a consequence of light slowing down in a medium.
- Works in either direction
- Independent of reflections

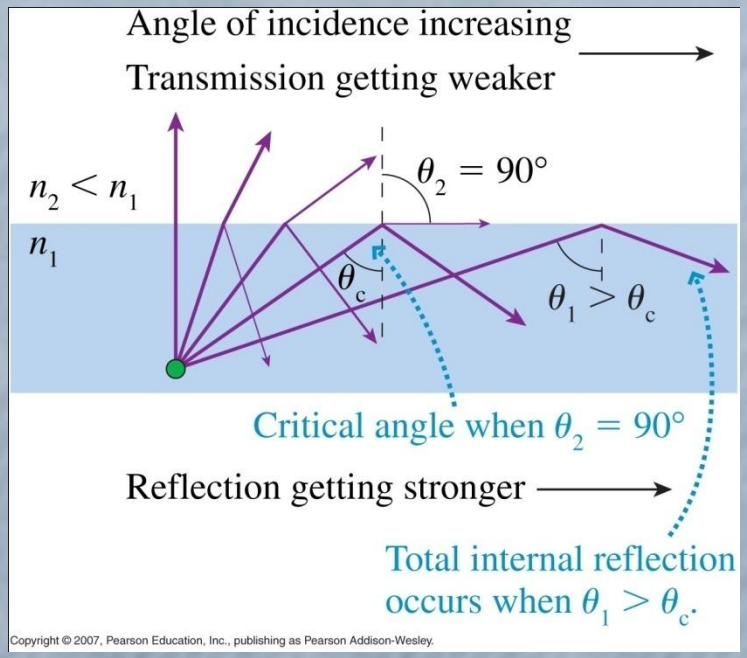
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



Total Internal Reflection

When light is leaving a denser medium to go into a lighter medium, above a certain angle, Snell's law predicts unreal angles (sinθ>1)

- This angle is the **critical angle**
- Above this angle, light will not be refracted, it undergoes **total internal reflection** (TIR)



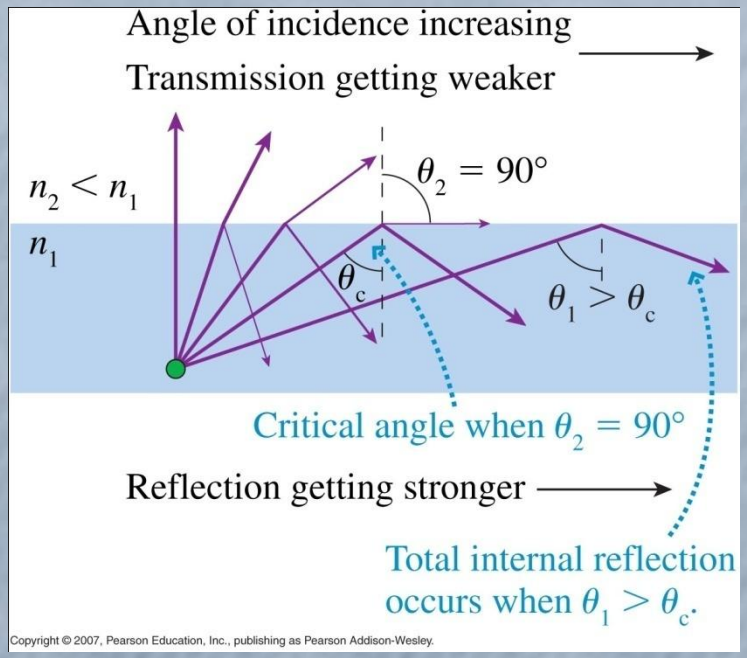
Total Internal Reflection

The critical angle for the boundary between two media can be calculated as

$$n_1 \sin\theta_c = n_2 \sin 90^o$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

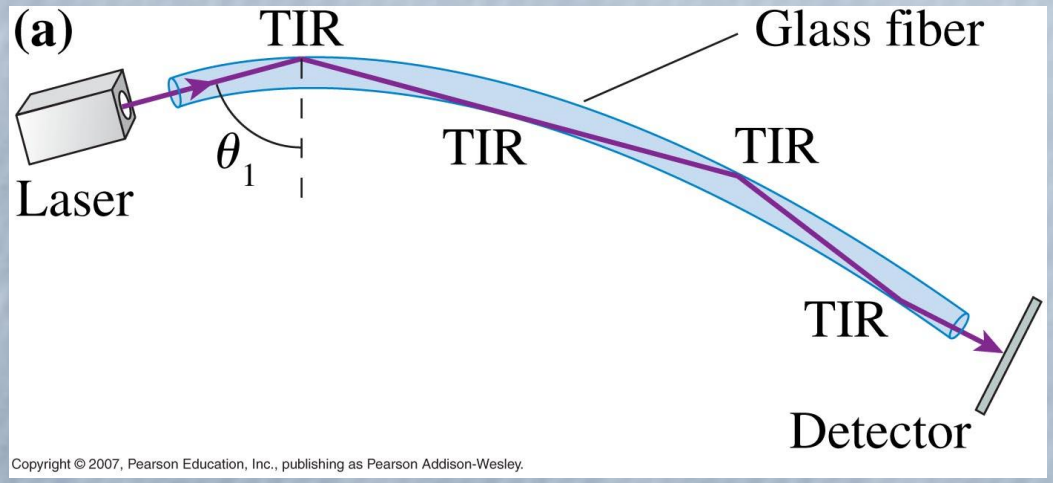
$$n_2 < n_1$$

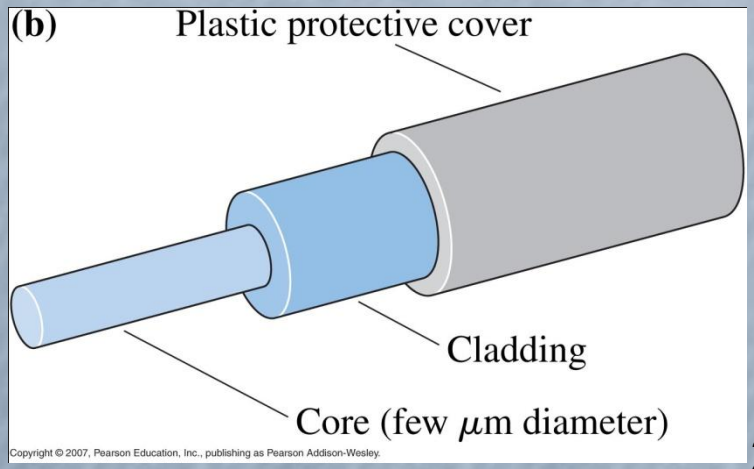


TIR application

Used in fiber optics

The fiber has a core (8μm, or 50/62.5μm) surrounded by cladding (125μm).

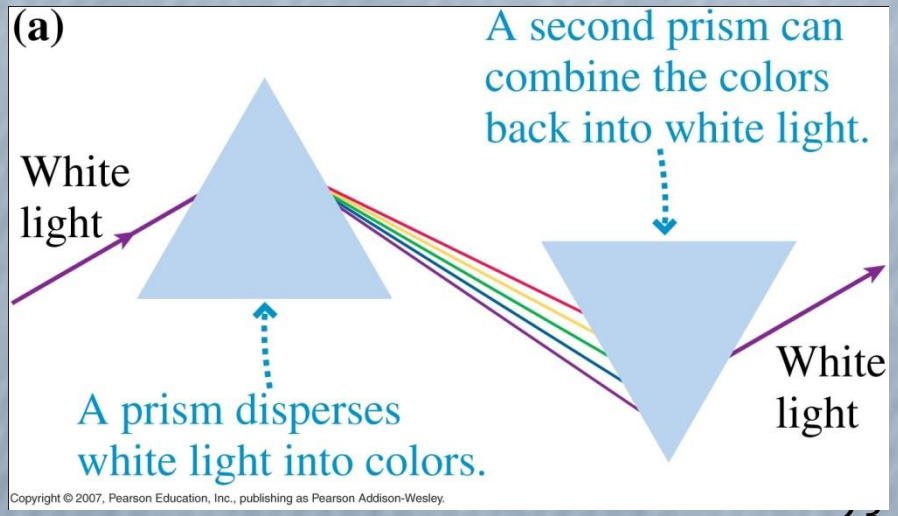




$$n_{core} > n_{cladding}$$

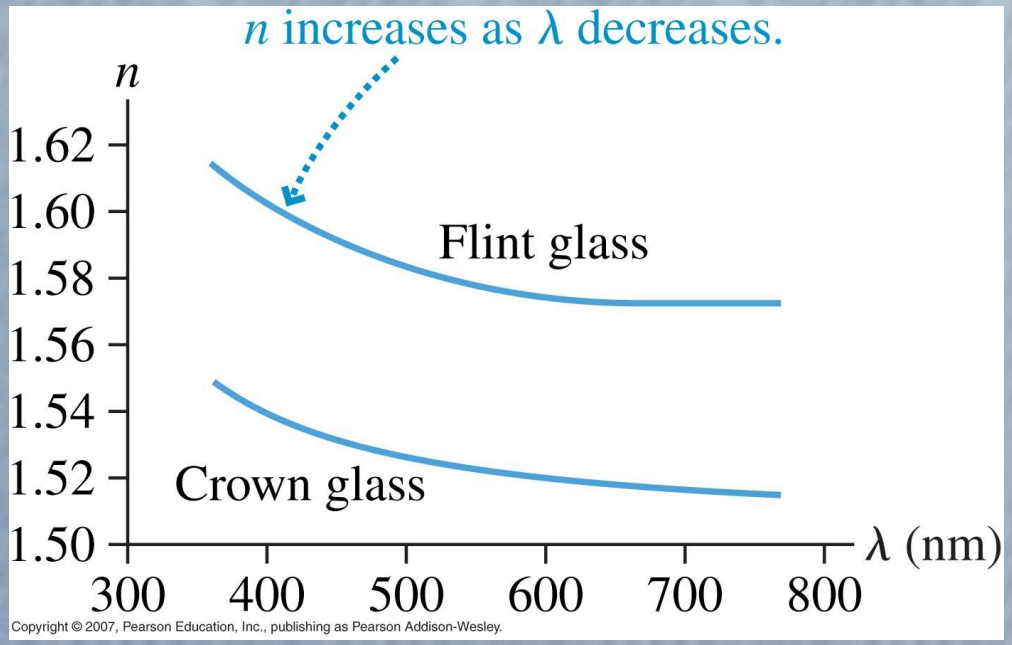
Color

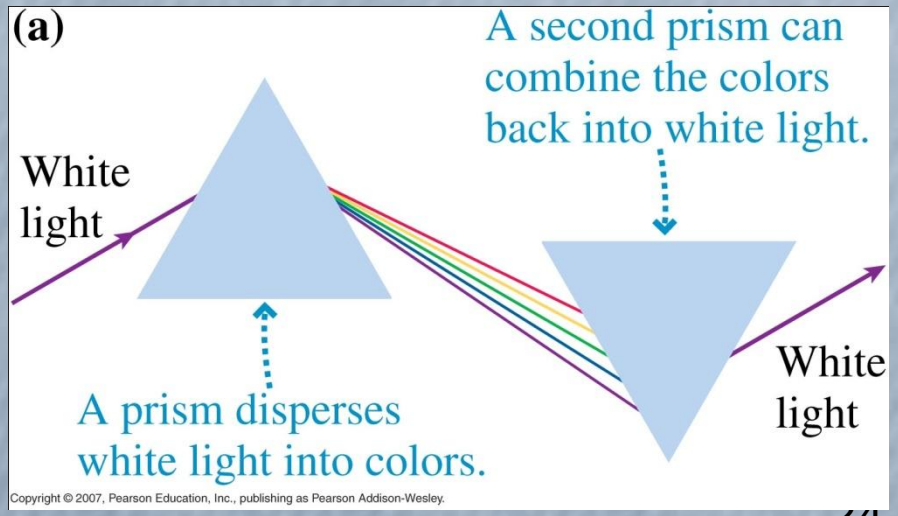
- Color is a property of the human eye. The eye detects different wavelengths as different photo-chemical reactions
- White light is a mixture of all colors
- The refractive index of materials changes slightly with color.



Color Dispersion

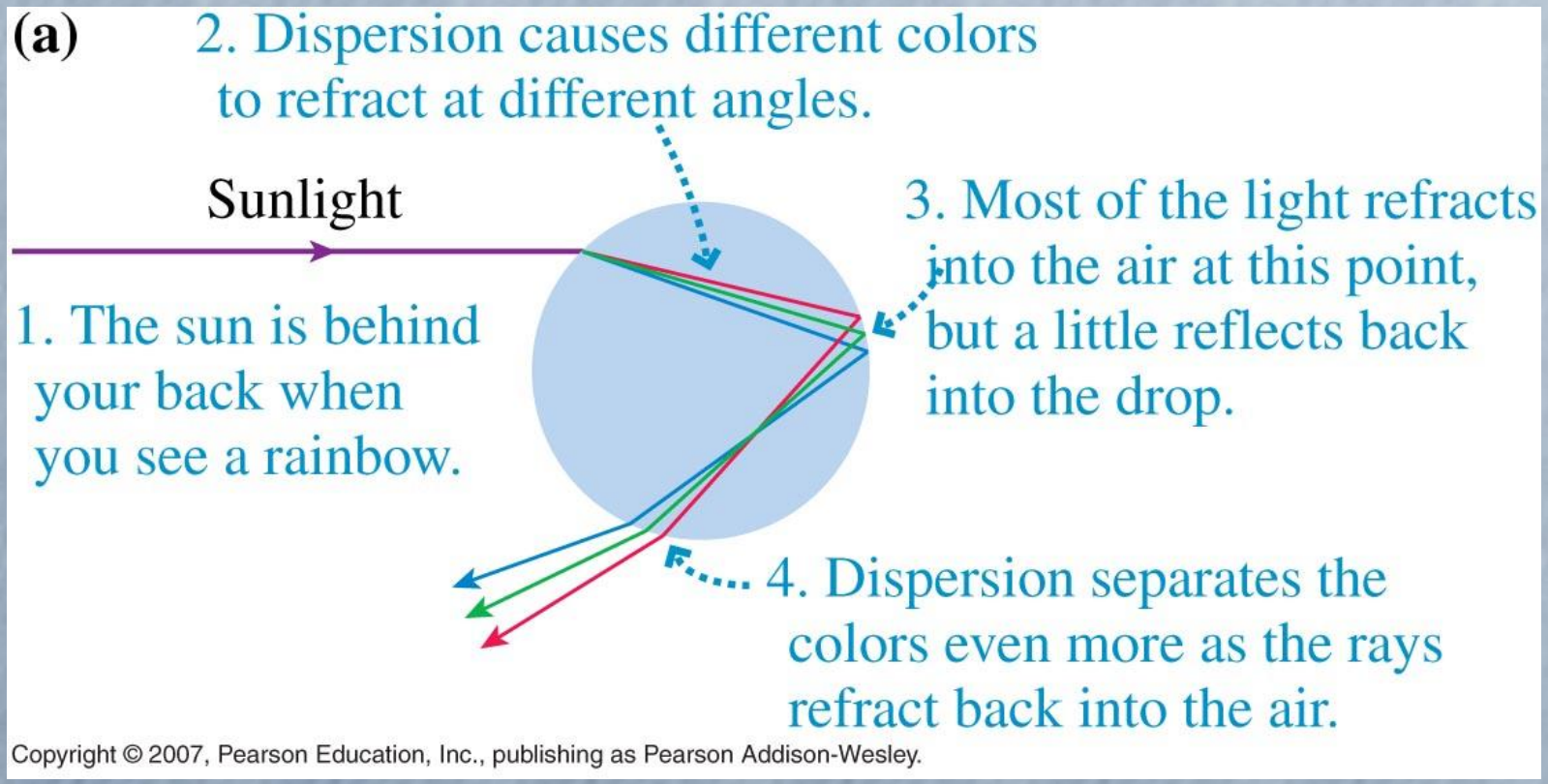
- The refractive index of materials changes slightly with color, and a prism can be used to split up and recombine the different colors in white light.





Color Dispersion

Rainbows are created by color dispersion in water droplets in the sky.



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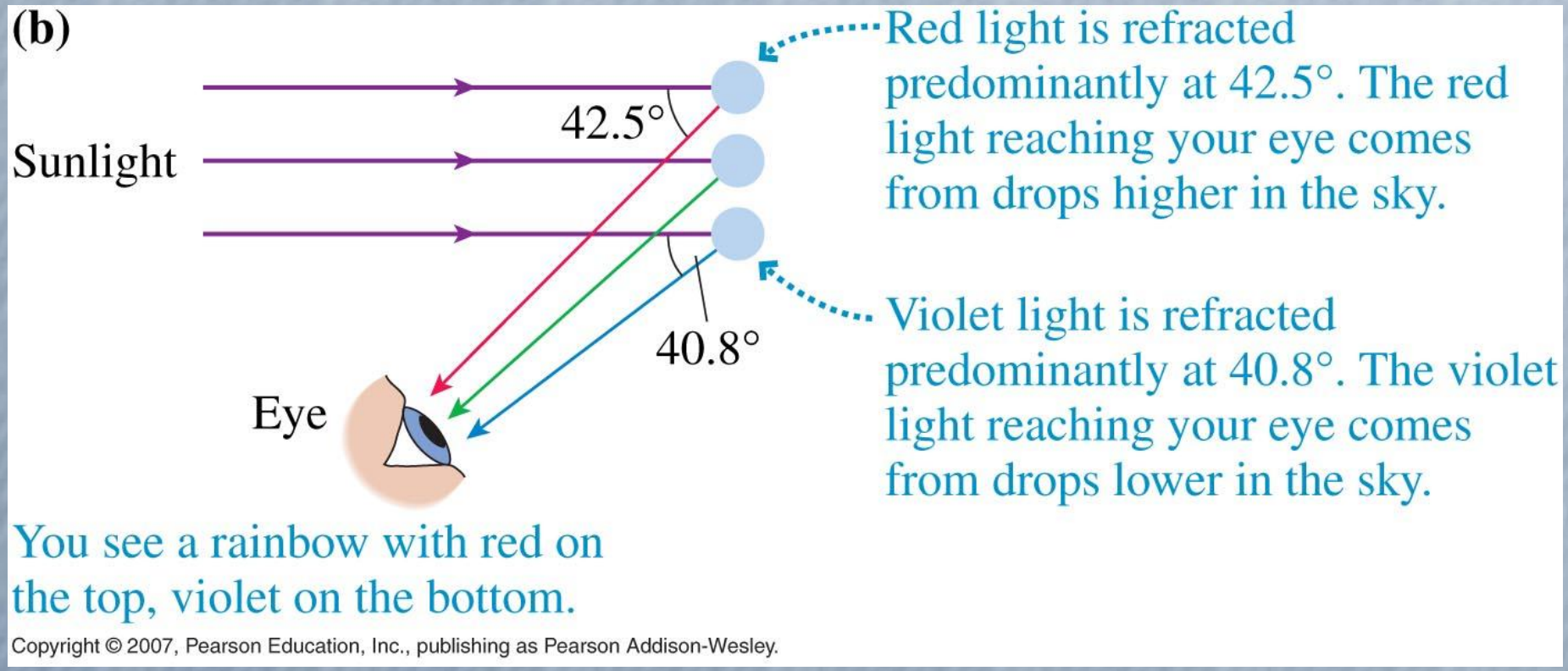


Colored Objects

- Objects have a color because they either transmit light (e.g. colored glass), or reflect light (e.g. leaves).
- An object which transmits red light is absorbing all colors other than red
- An object which reflects green light is absorbing all colors other than green.

Questions

Q. What colors are absorbed by blue glass ?

A.

Q. What color is absorbed by black paper ?

A.

Q. What color is absorbed by white paper ?

A.

Q. What color will a green apple seen through red glass be ?

A.

Questions

Q. What colors are absorbed by blue glass ?

A. All except blue.

Q. What color is absorbed by black paper ?

A. All colors

Q. What color is absorbed by white paper ?

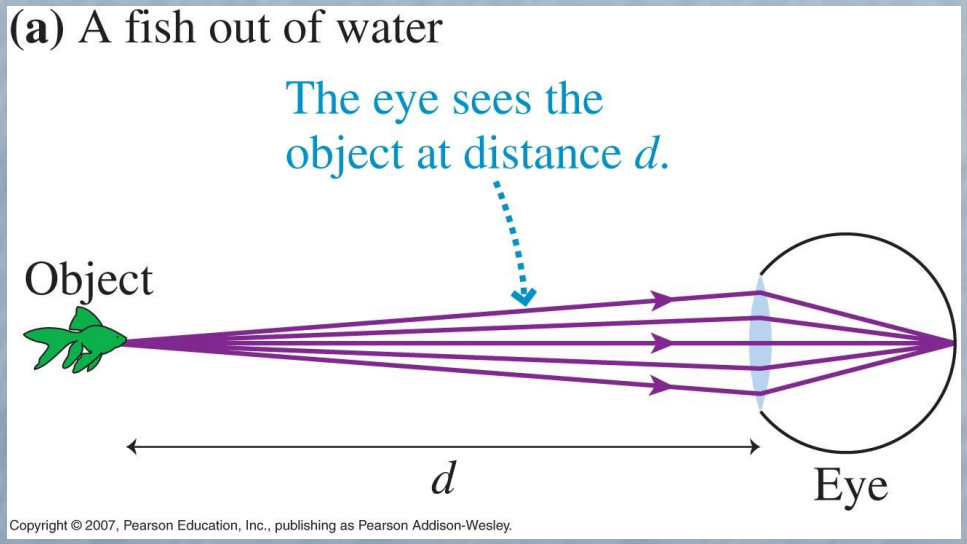
A. No colors

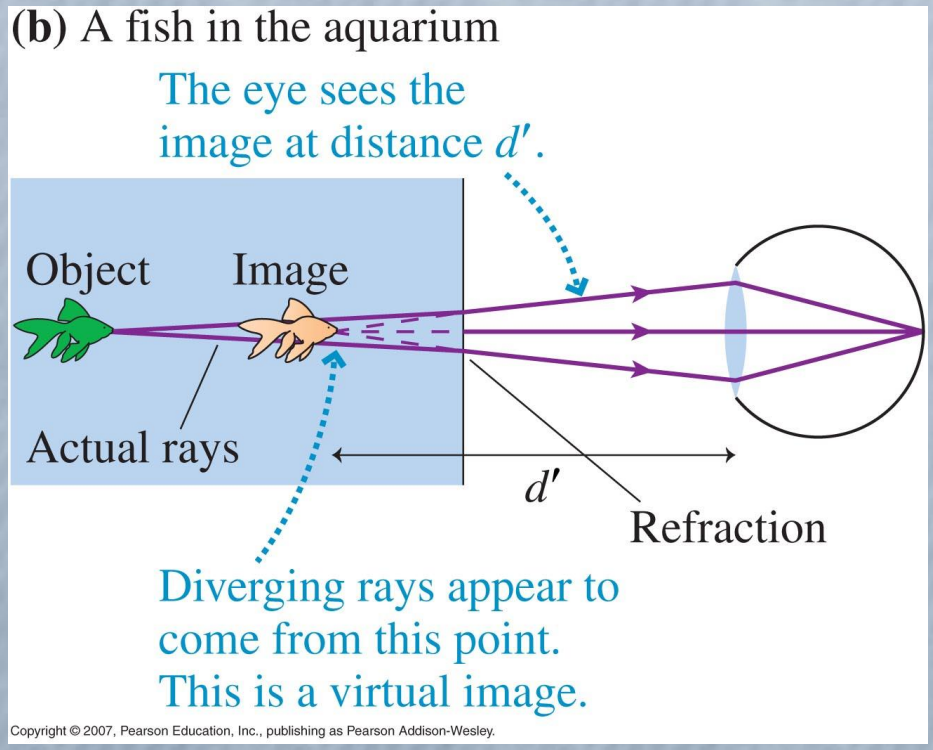
Q. What color will a green apple seen through red glass be ?

A. black

Images from Refraction

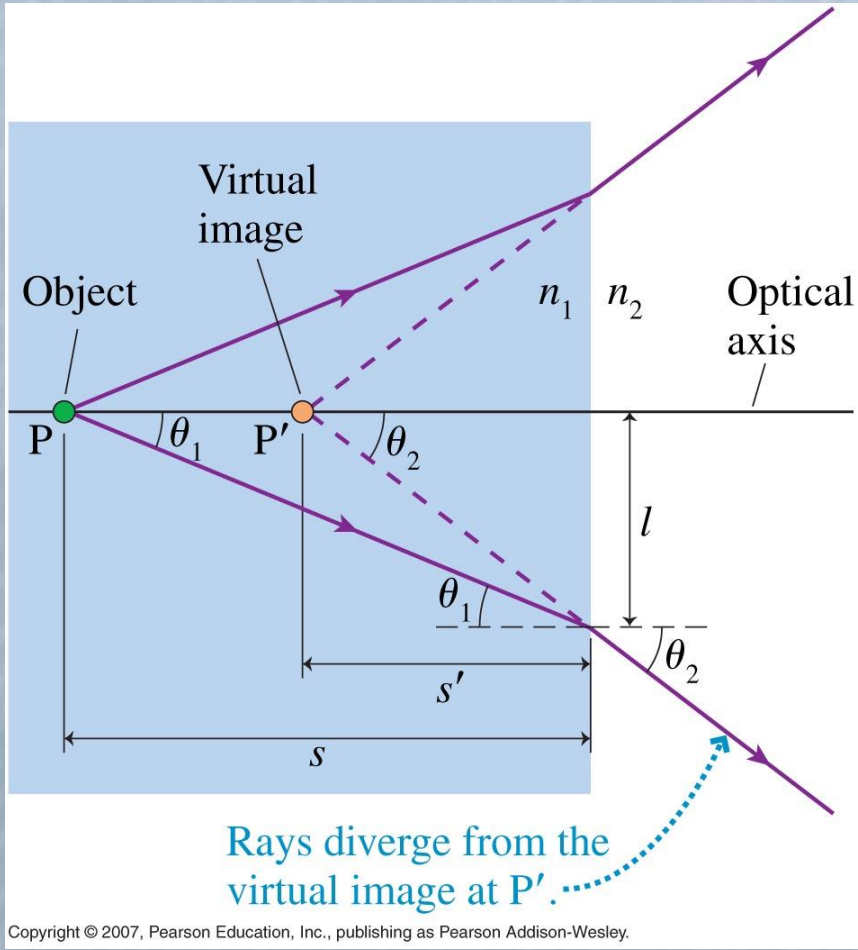
Images in water (either a tank, or viewed through an underwater face mask) appear larger and closer:





Images from Refraction

- Rays from the object are refracted when they meet the water-air boundary.
- We can calculate the apparent distance, s' from the edge of the tank or face mask.

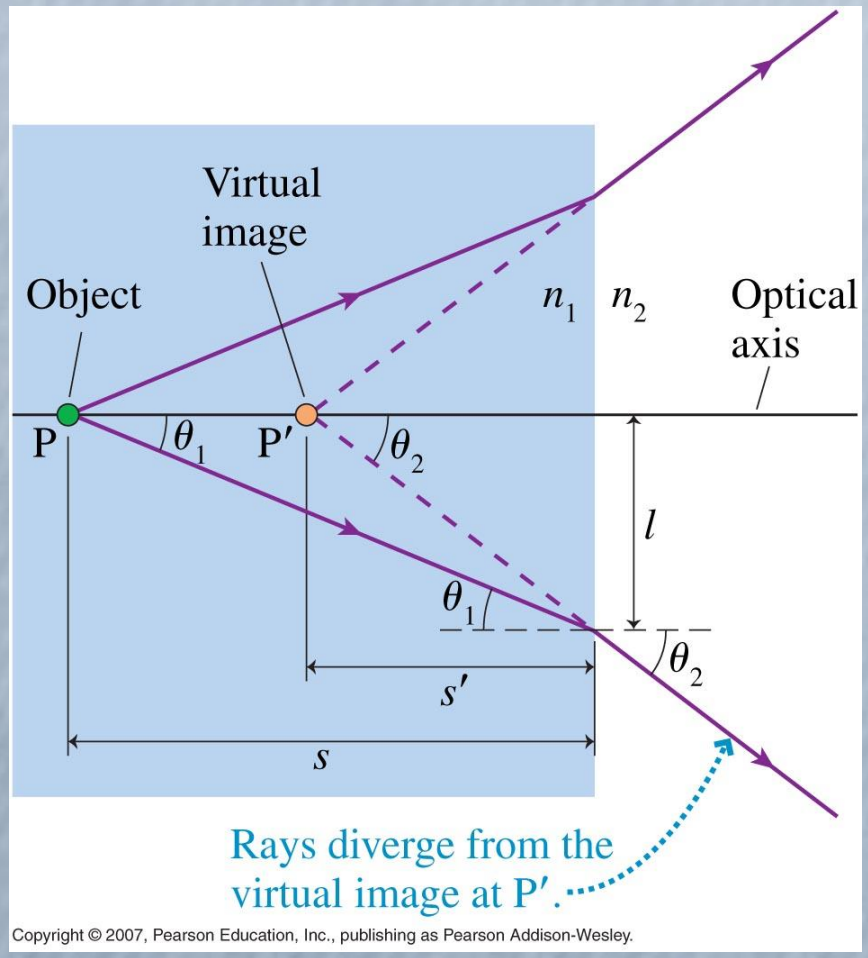


Images from Refraction

- The ratio of the actual and apparent distances from the boundary is related to the ratio of the tangents

$$l = s\tan\theta_1 = s'\tan\theta_2$$

$$s' = s\frac{\tan\theta_1}{\tan\theta_2}$$



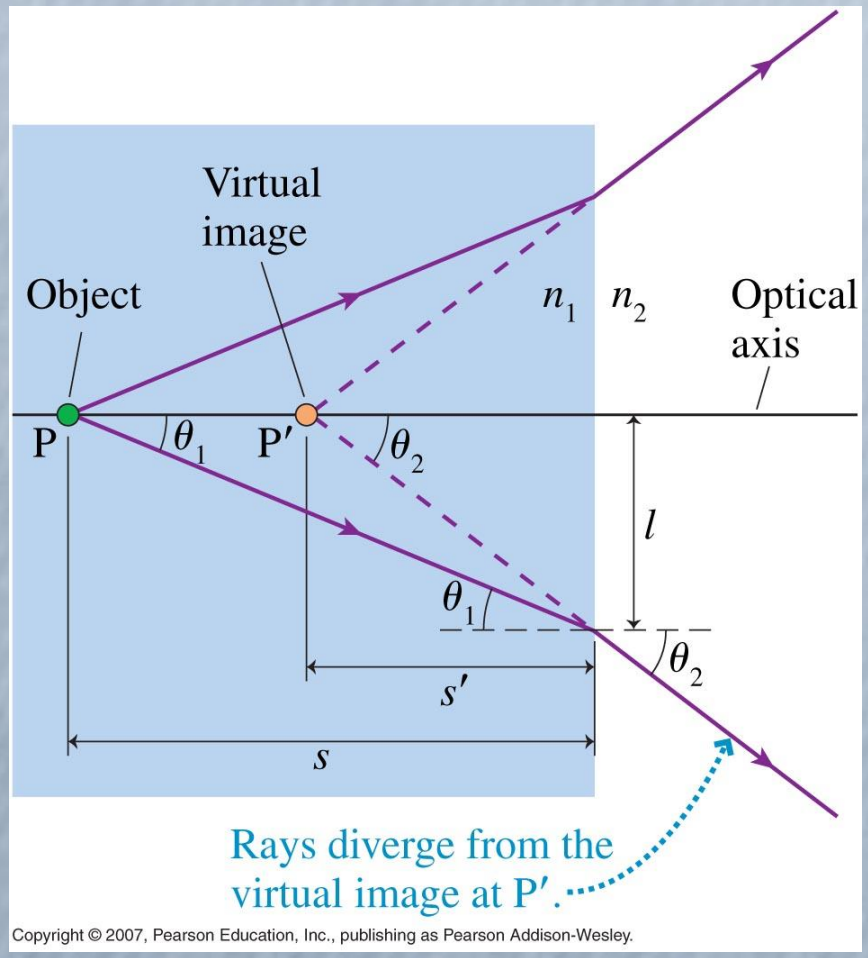
Images from Refraction

- Using the small angle approximation, and Snell's Law we find the position of the image.

$$s' = s\frac{\tan\theta_1}{\tan\theta_2} \approx s\frac{\sin\theta_1}{\sin\theta_2}$$

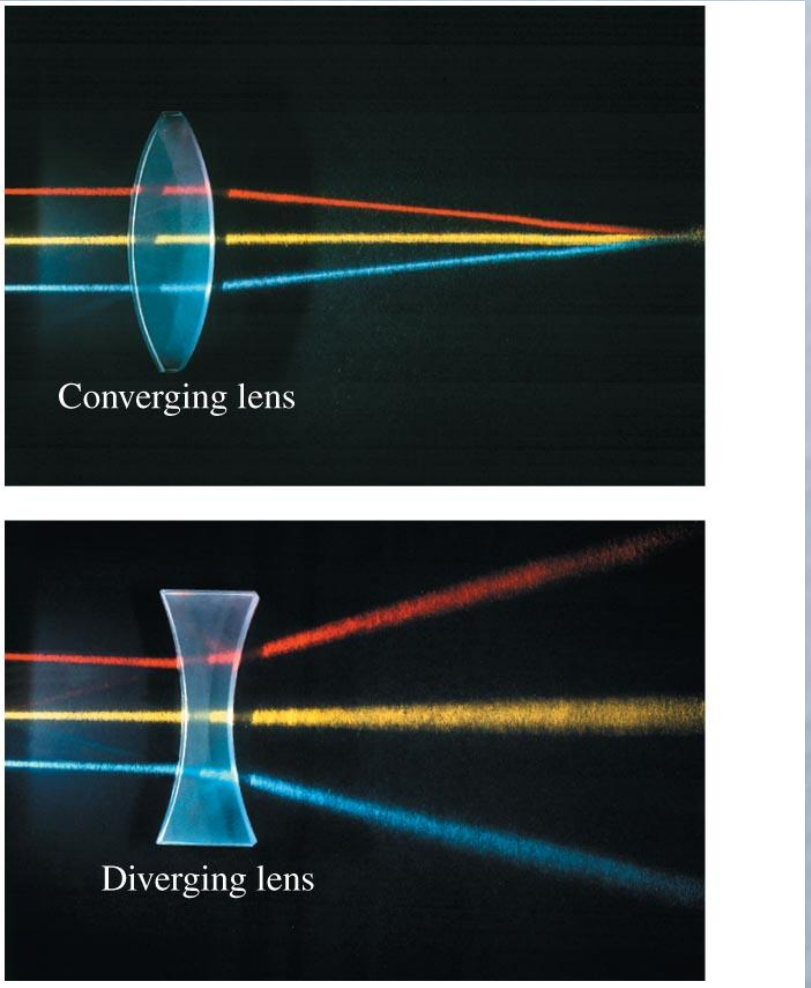
$$s' = s\frac{n_2}{n_1}$$

$$(\theta << 1)$$



Lenses

- A lens focuses light rays by refraction.
- In a converging lens, parallel rays converge to a single point, called the focal point.
- The surfaces are ground to be spherical

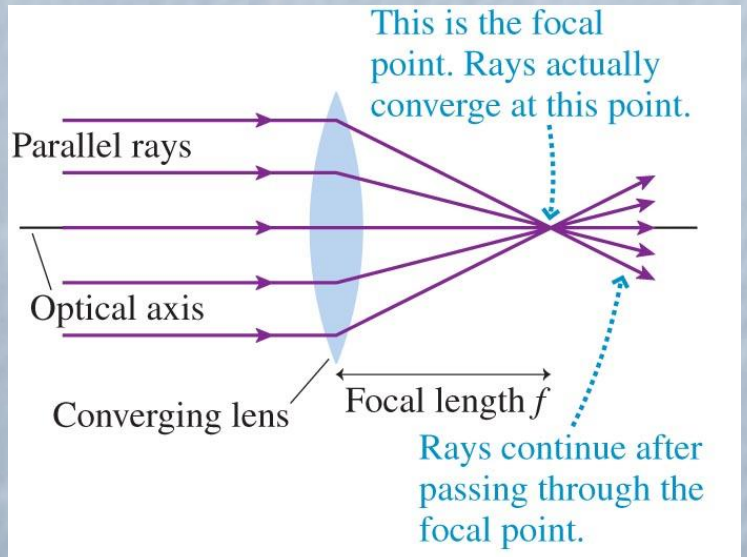


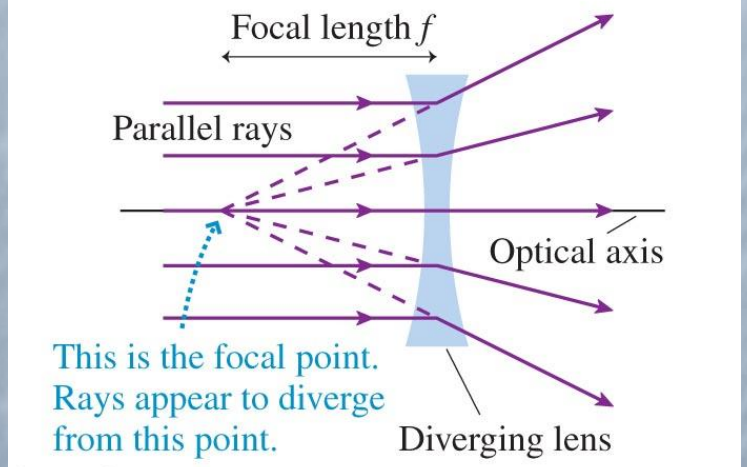
Converging and Diverging Lenses

Two types of lenses.

- Converging lens – thicker in the middle, light rays refract towards the optical axis
- Diverging lens – thinner in the middle, light rays refract away from the optical axis

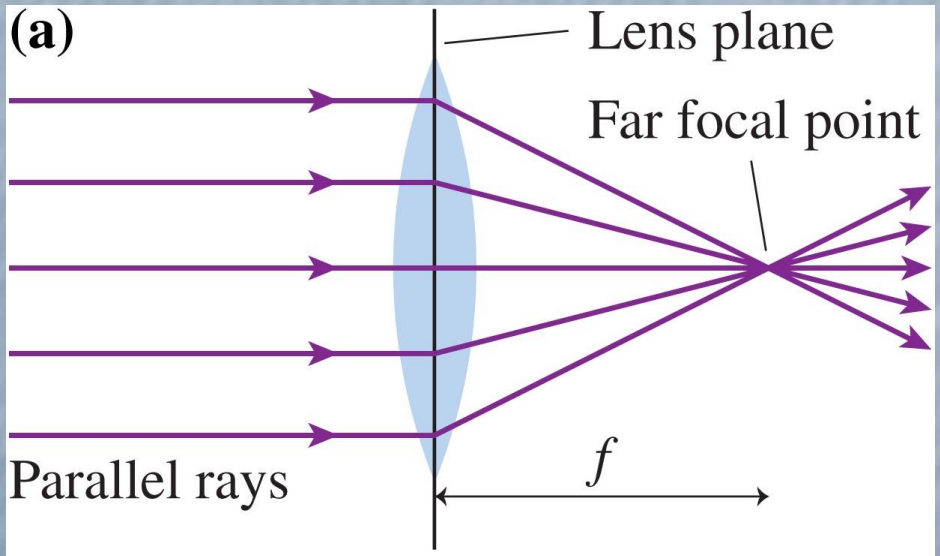
The focal point is the point from which paraxial rays converge or diverge





Converging Lenses

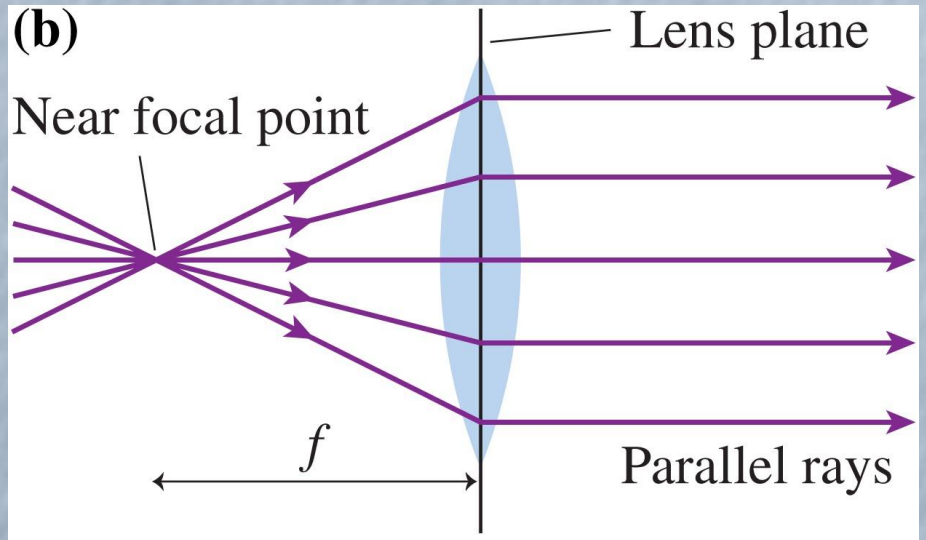
The focal length is the distance from the lens at which rays parallel to the optical axis converge. These rays are known as **paraxial rays.**



Any ray initially parallel to the optical axis will refract through the focal point on the far side of the lens.

Converging Lenses

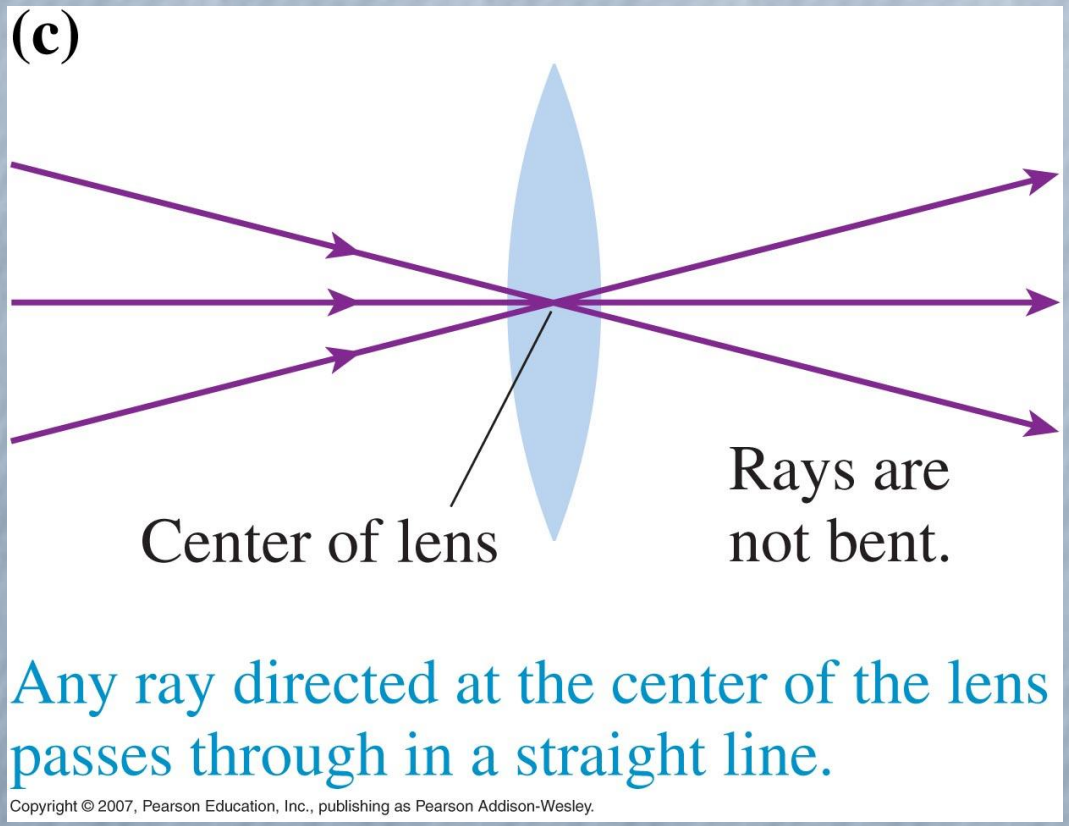
Similarly, the focal length is the distance from the lens at which rays will refract out of the lens parallel to the optical axis.



Any ray passing through the near focal point emerges from the lens parallel to the optical axis.

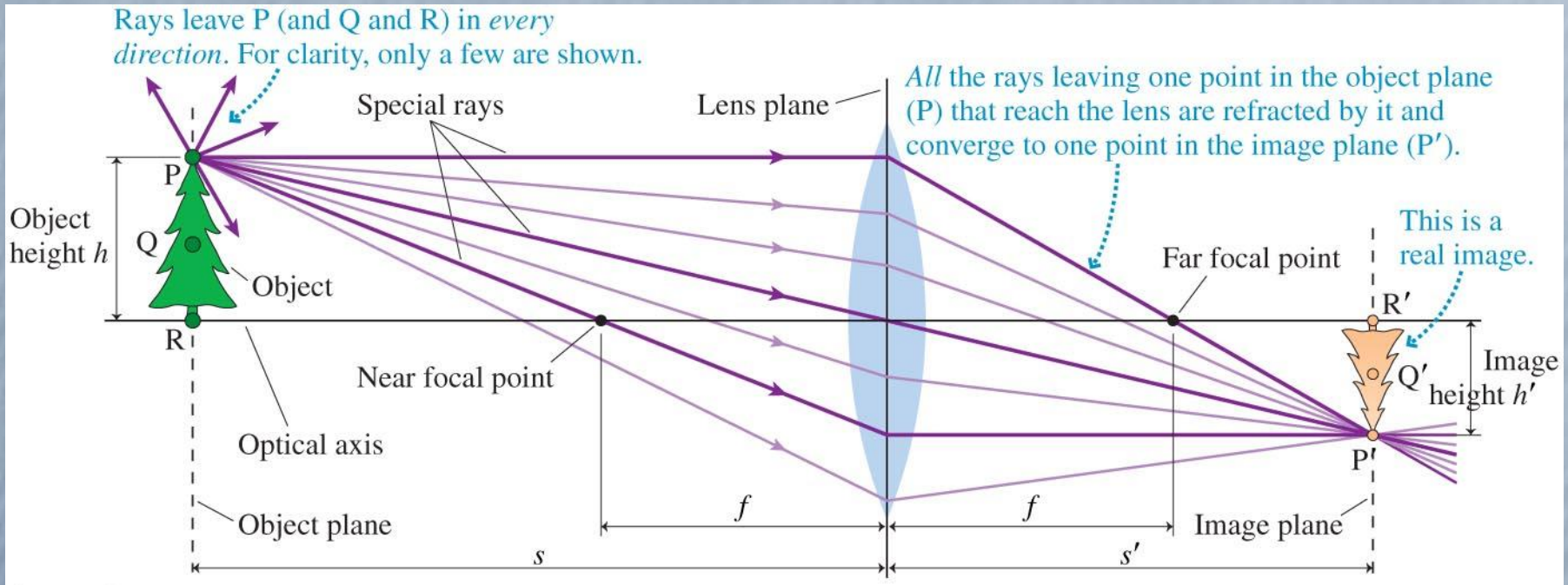
Converging Lenses

Light through the center of the lens pass through without changing angle. These rays are known as **principal rays.**



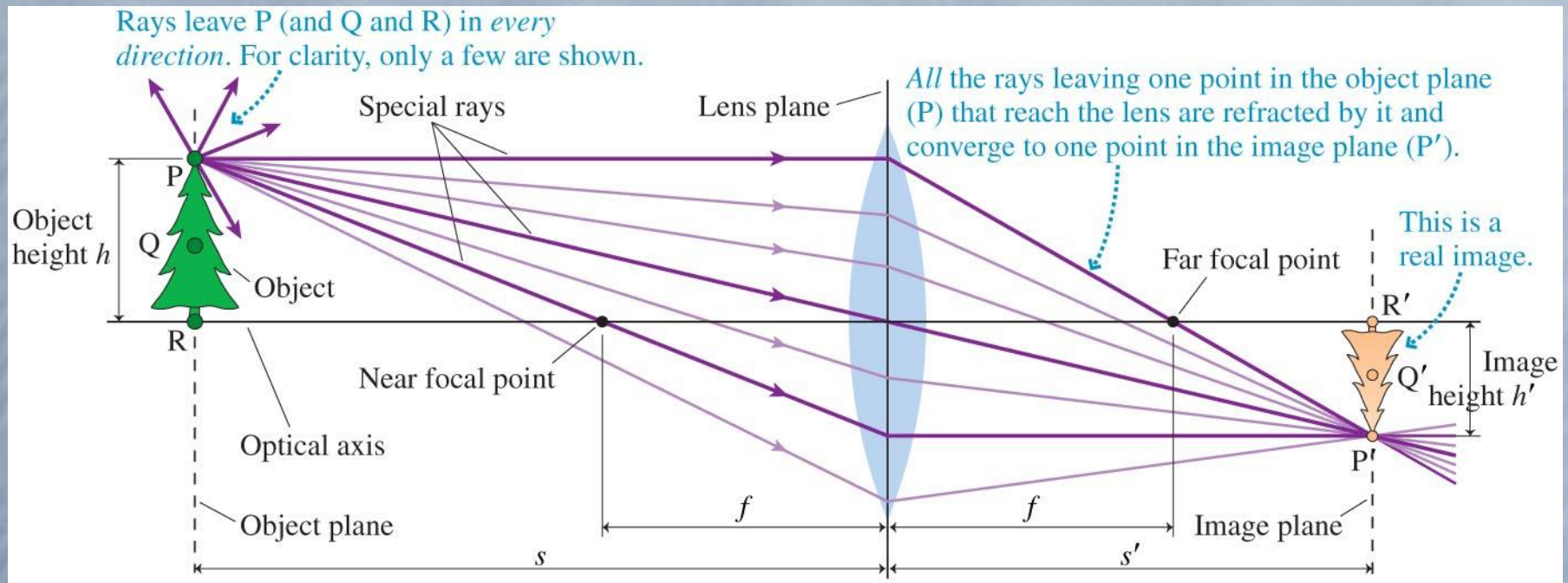
Real Images

- A real image can be seen in focus on a screen.
- Note they are always **inverted** with a simple converging lens when s>f.



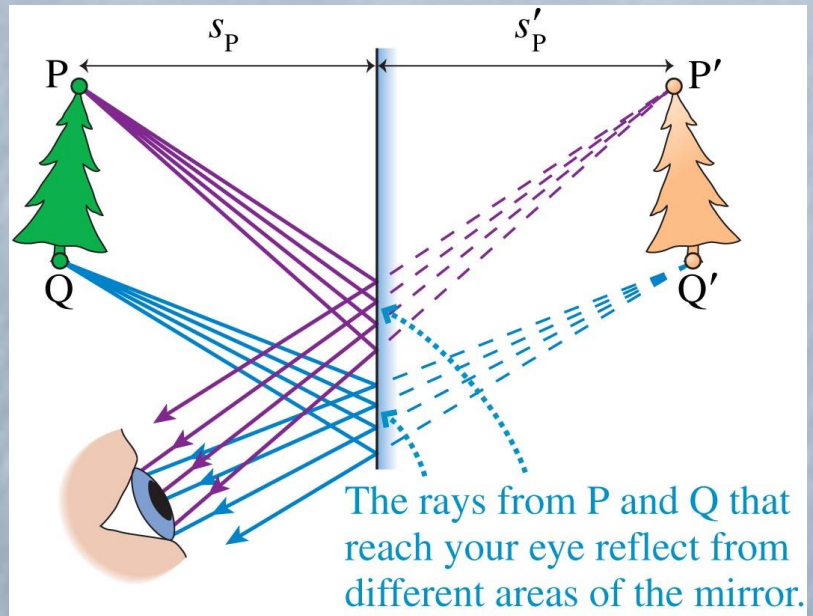
Real Images

Another definition for a real image is that the rays converge at a point at the **image plane**



Virtual Images

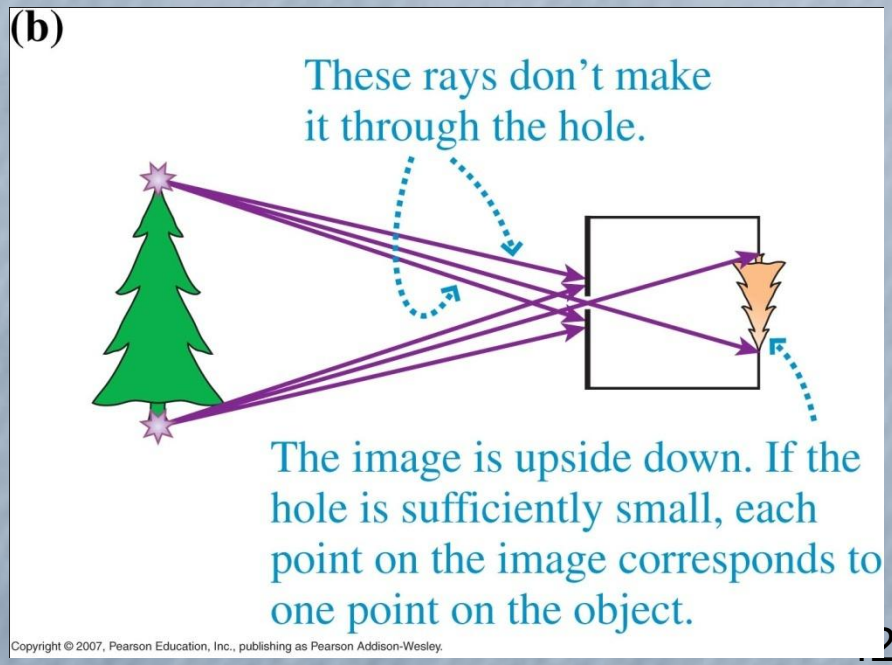
For a virtual image – the rays diverge from a point in the object plane



Pin-hole Images

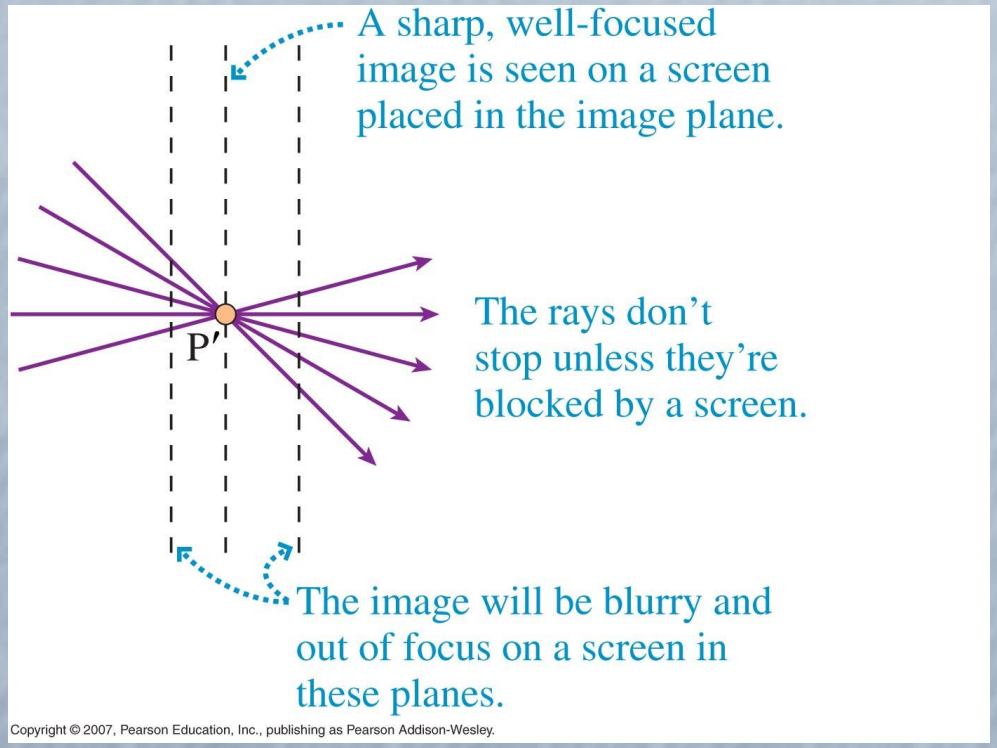
Rays for pin-hole images neither diverge nor converge (although they do project onto a screen).

Sometimes called a **projected image**



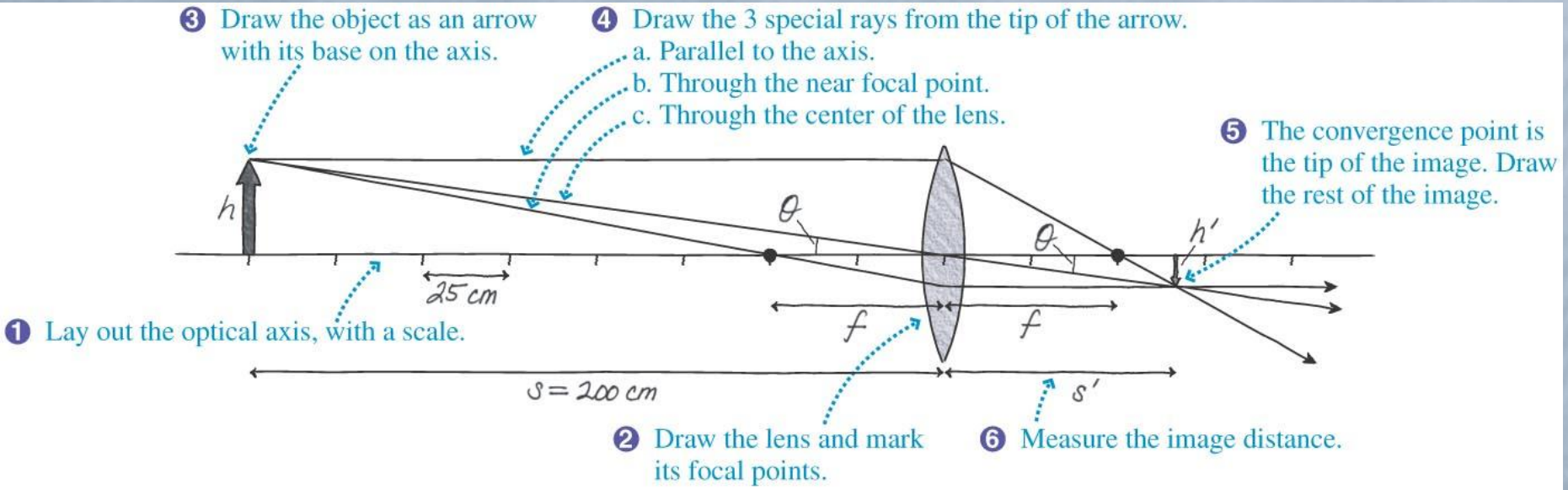
In focus images

- The image will only be in focus at the particular plane where rays from the same point on the object converge.
- The image will appear blurry if the screen is not at the image plane.



Finding images

The image properties can be found by ray tracing on scale drawings, or from calculations with similar triangles.



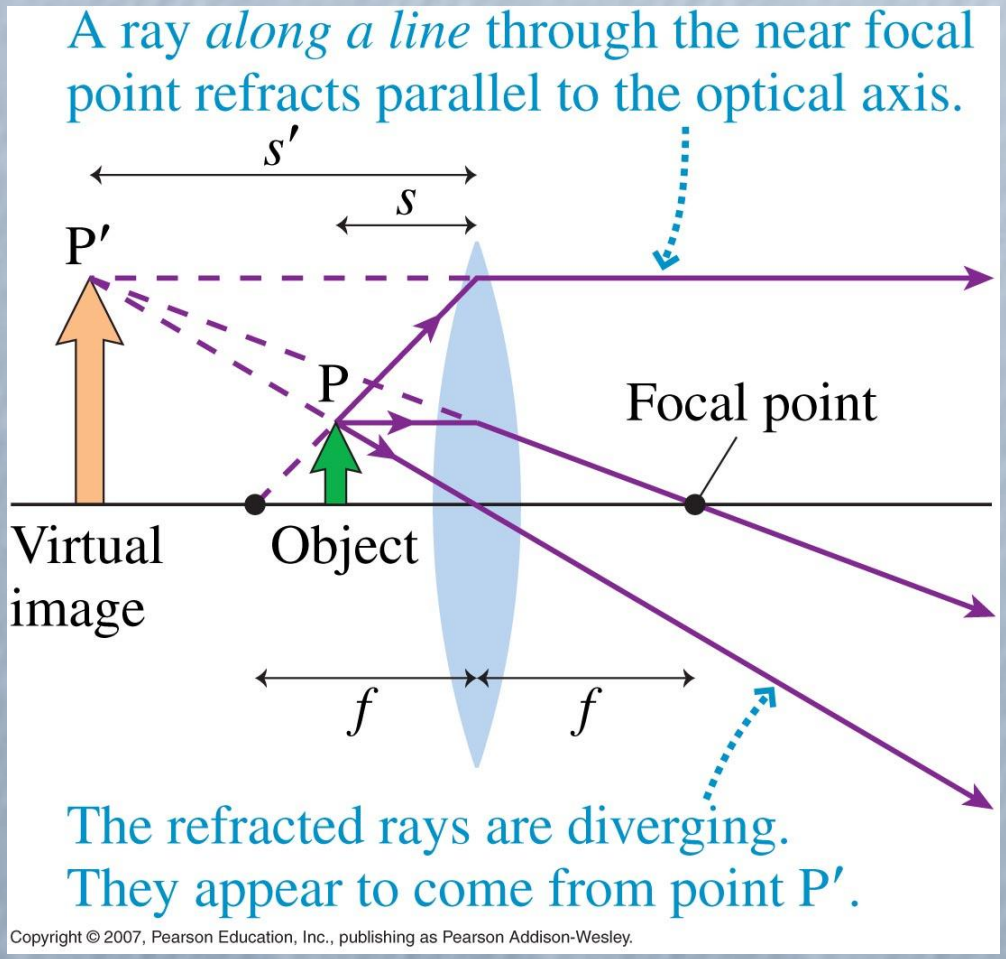
Magnification

Magnification is the ratio of the size of the image to the object and depends on the focal length and object distance. For a thin-lens, we have:

$$m = \frac{h'}{h} = \frac{s'}{s}$$

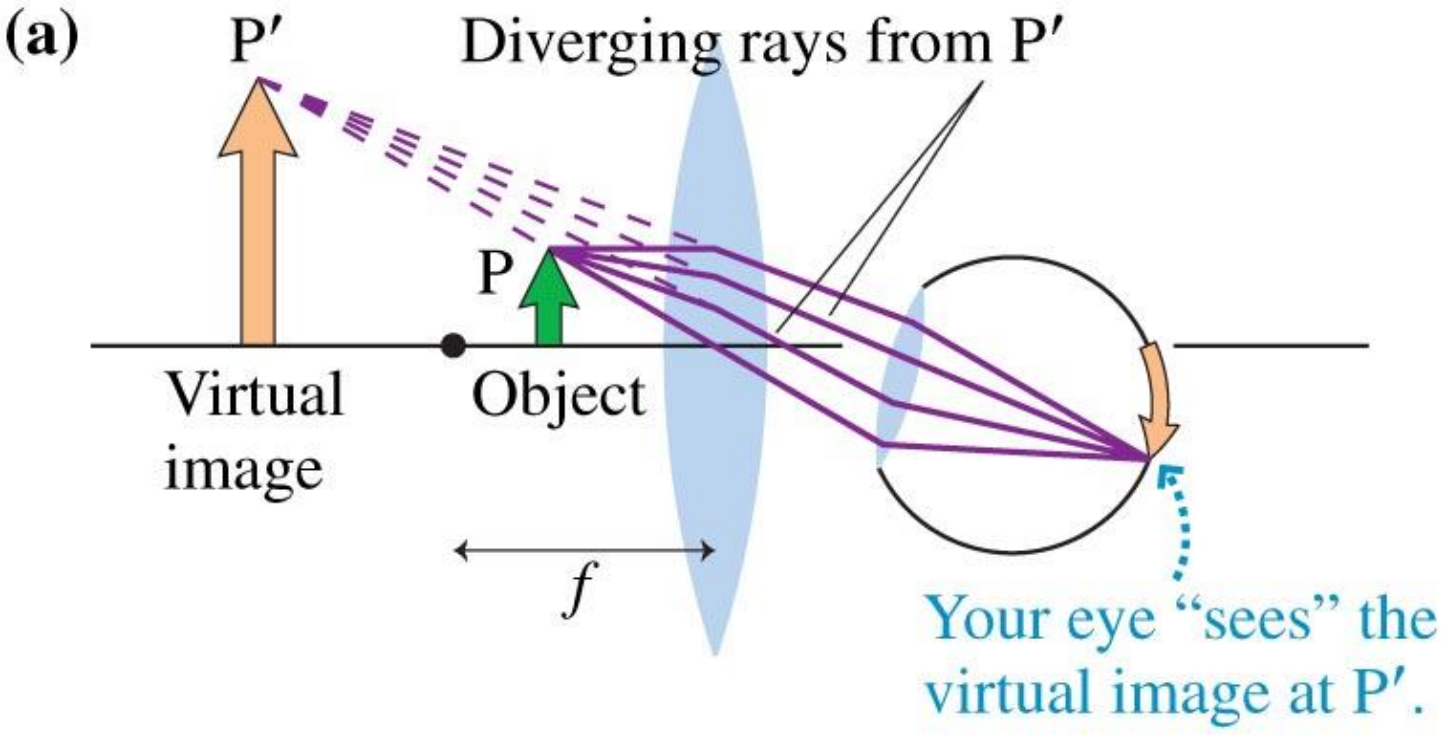
Converging lenses and Virtual Images

When an object is placed between the focal point and a lens (s<f), the image is **virtual** and **upright**



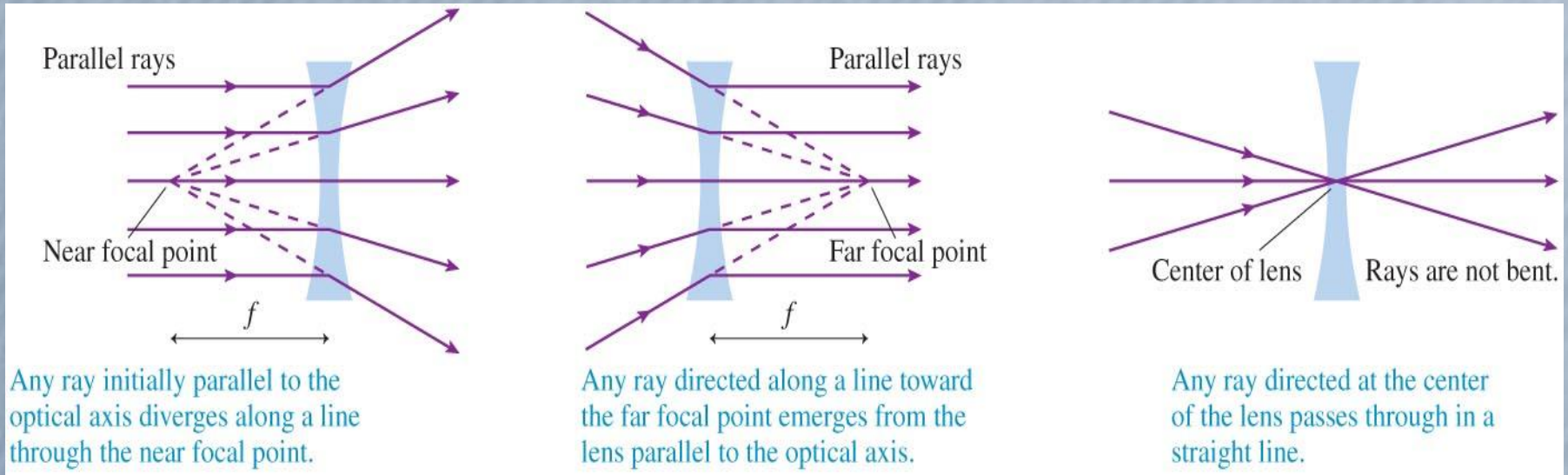
Converging lenses and Virtual Images

The virtual image is enlarged and not inverted, but **upright.**



Diverging lenses

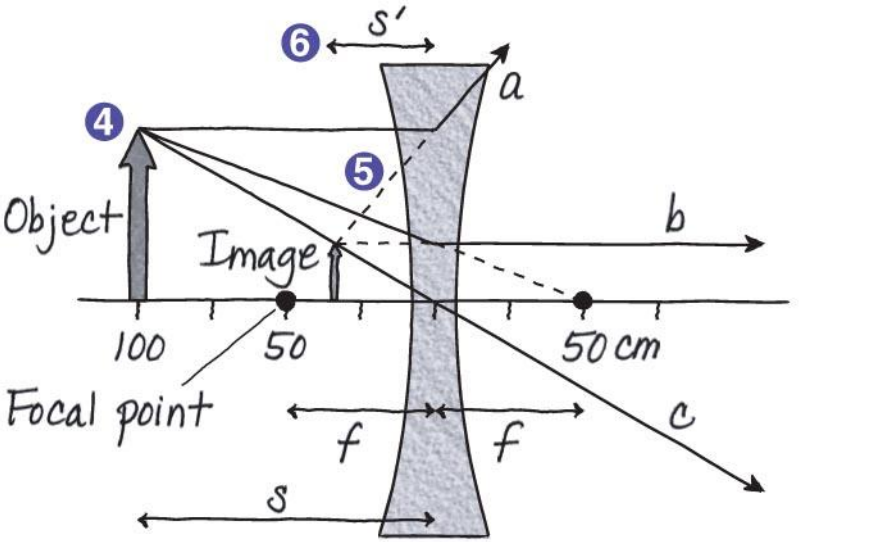
Thinner in the middle. Usually used with other lenses for magnification and focusing



Diverging lenses

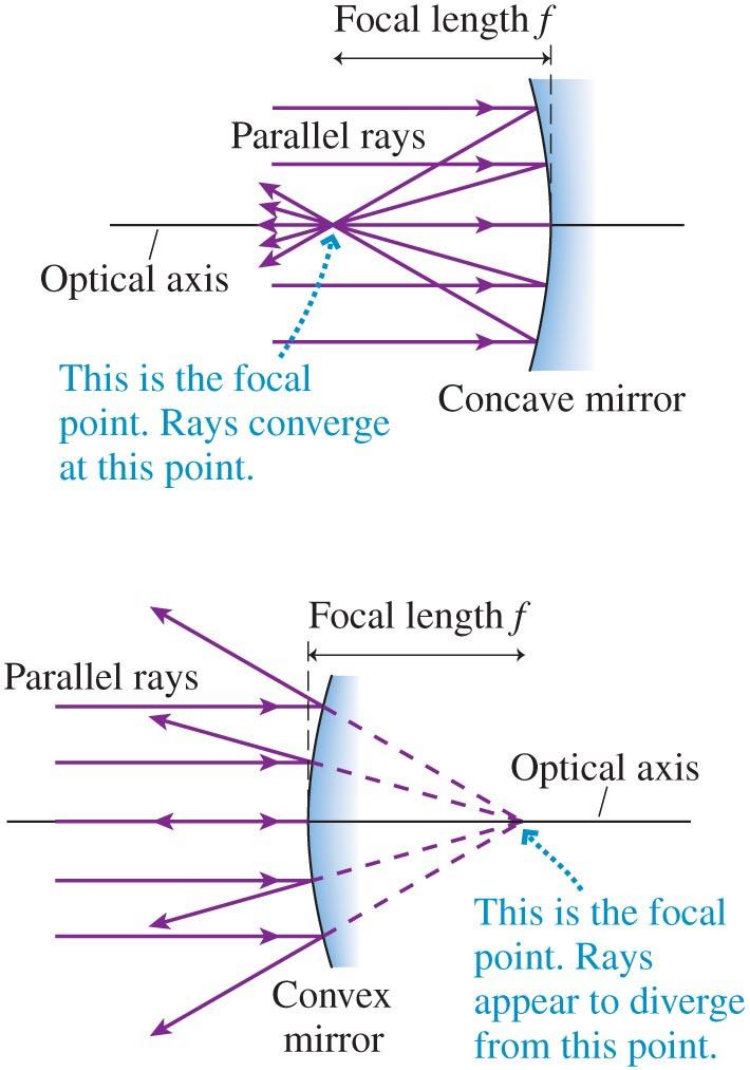
Use the same rules to find the image –

- Trace the principle ray through the center of the lens
- Trace the two paraxial rays through the focal points
- Images are **virtual** and **upright**



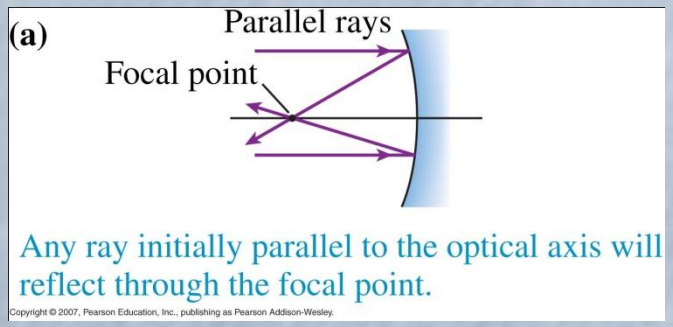
Spherical Mirrors

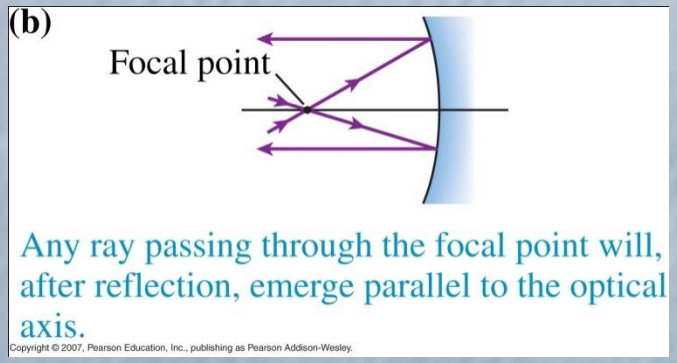
- Concave spherical mirrors.
- Convex spherical mirrors.
- Note that a perfectly spherical mirror will not focus exactly, but we ignore this for now.

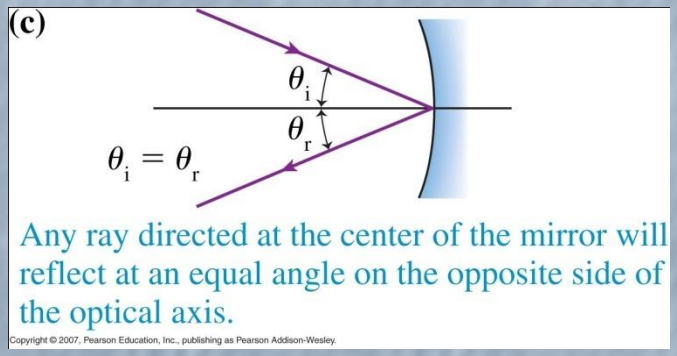


Concave Mirrors

- The focal point is the point where paraxial rays converge or diverge.
- Principle ray is reflected at an equal angle at the center of the lens



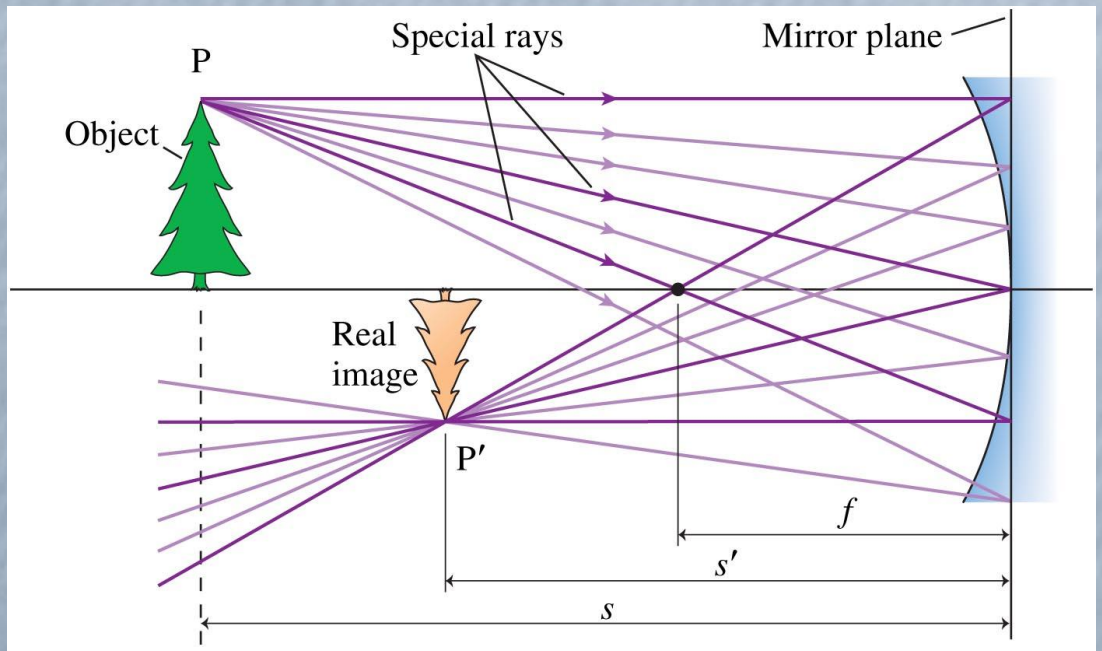




Concave Mirrors

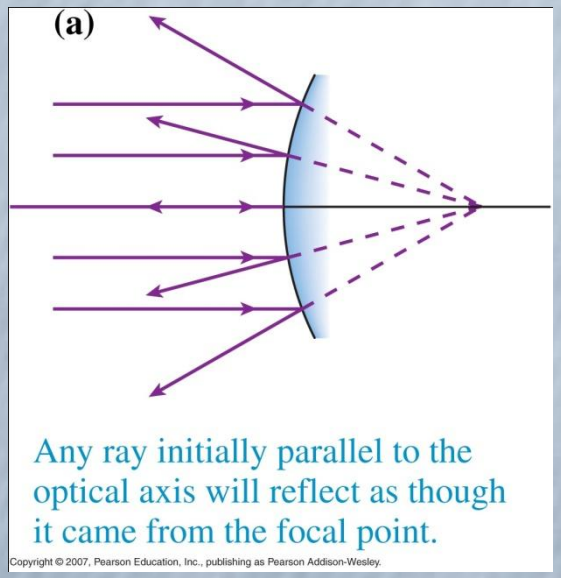
- Draw the principle ray, and the two paraxial rays to find the image.
- Applications – telescopes.

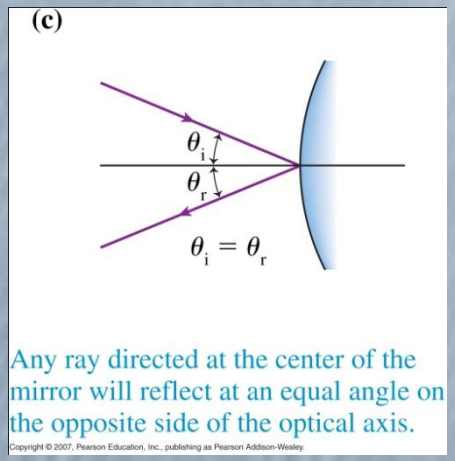
- If s>f image is inverted and real
- If s<f image is upright and virtual

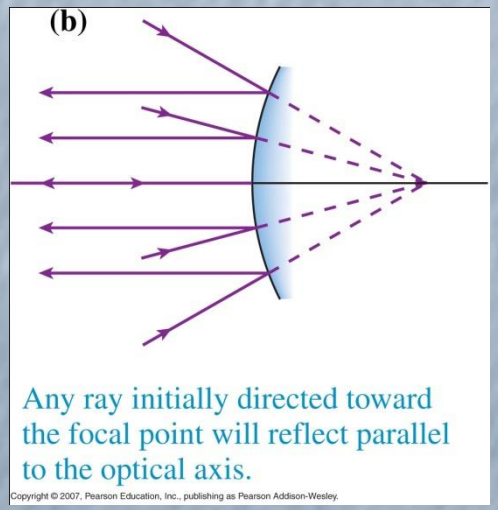


Convex Mirrors

- The focal point is the point where paraxial rays converge or diverge.
- Principle ray is reflected at an equal angle at the center of the lens

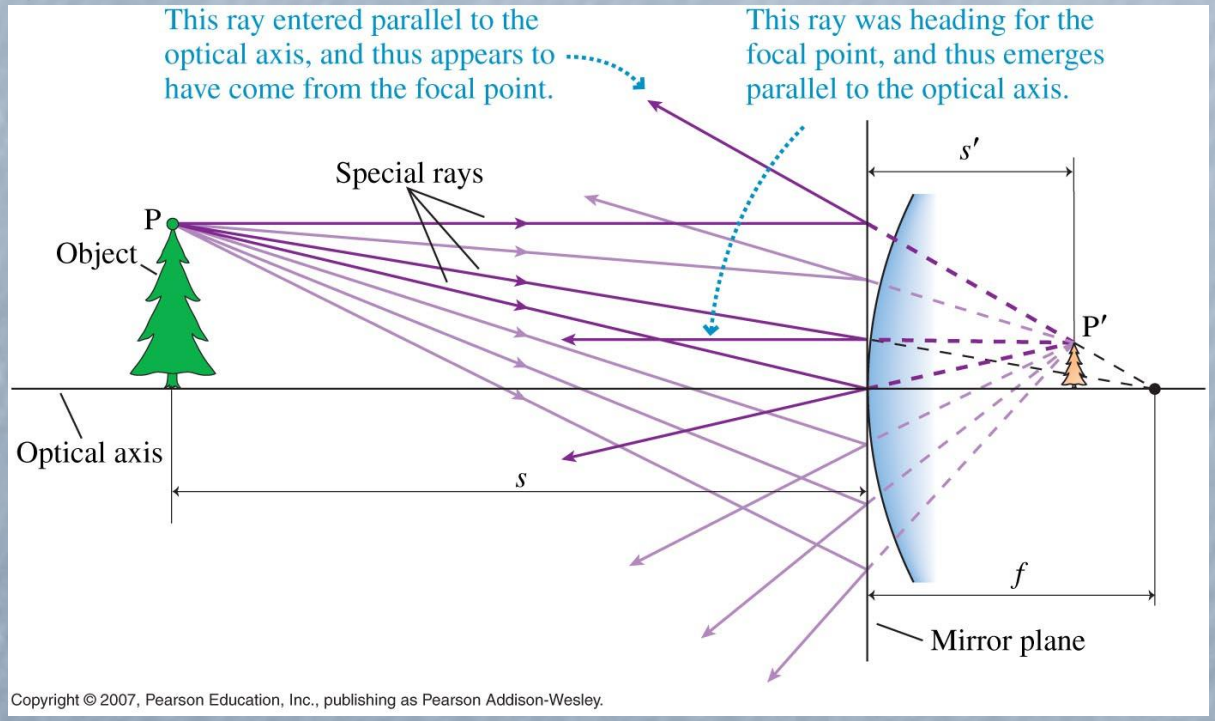






Convex Mirrors

- Draw the principle ray, and the two paraxial rays to find the image.
- Image is always upright and virtual, but “images are closer than they appear”
- Applications – wide angle mirrors,.



Summary

- Ray model
- Reflection
- Refraction, total internal reflection
- Color dispersion
- Lenses
- Image formation
- Magnification
- Spherical mirrors

Homework problems

Chapter 18 Problems

41, 49, 53, 59, 65, 66.