**PHY132H1F**
**Introduction to Physics II**
**Lecture 6, September 28, 2009**

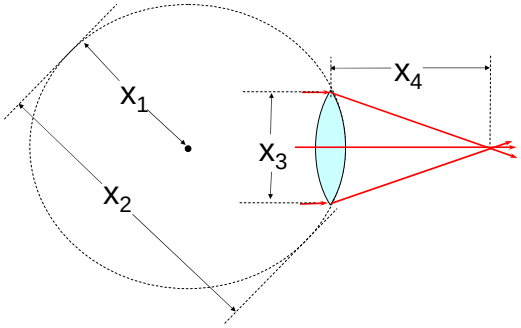
Today, Chs. 23, 24:

- Lenses
- The Thin Lens Equation
- Magnification of lenses
- Lenses used in combination
- Resolution of Optical Instruments

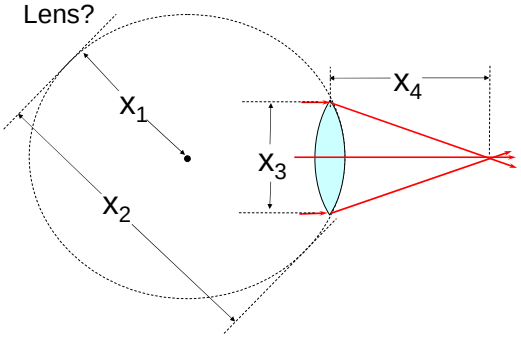
## Lenses

- Formed by two curved boundaries between transparent media.
- Lenses often have spherical surfaces (lens-maker's equation). The curved surfaces are parts of large spheres of radius $R_1$ or $R_2$.
- ***Every*** lens shaped like a circle has a diameter, D, and focal length, $f$.
- The ratio of ($f$ / $D$) is called "f-number". For example, an "f/6" lens has a focal length of 6 times its diameter ["6" is the f-number].

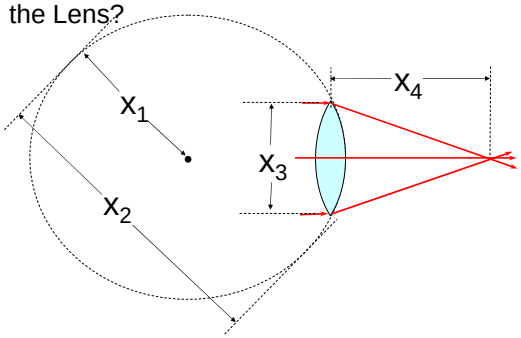
**In Class Question 1.** Please write on the same page as the mini-homework for today. Which quantity is the Diameter, $D$, of the Lens?



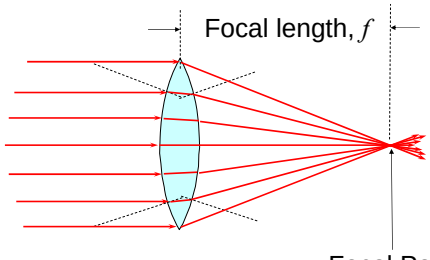

**In Class Question 2.** Please write on the same page as the mini-homework for today. Which quantity is the Focal Length, $f$, of the Lens?




**In Class Question 3.** Please write on the same page as the mini-homework for today. Which quantity is the Radius of curvature, $R_1$ or $R_2$, of the Lens?

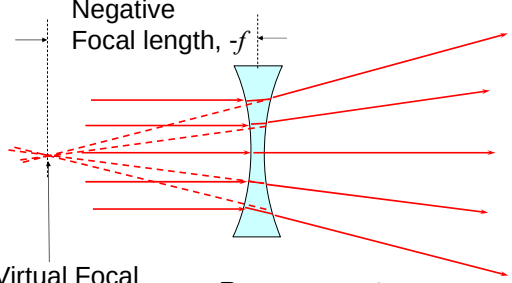



## Converging Lens

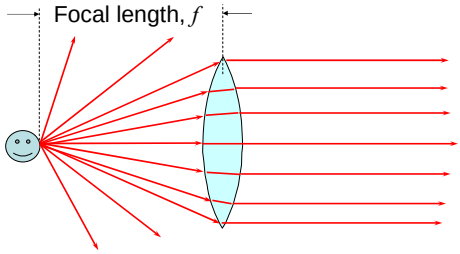



NOTE: Focal length is defined for initially parallel rays.

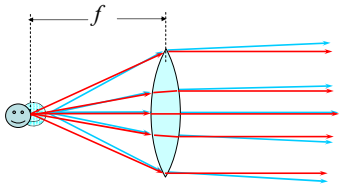
## Diverging Lens




## Diverging rays through a Converging Lens

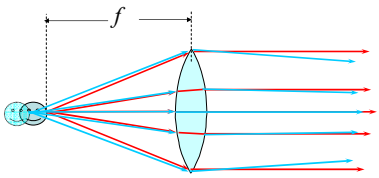



This follows from the principle of reversibility.




Discussion Question 4. What will happen to the rays emerging to the right of the lens if the face is moved a little closer to the lens?

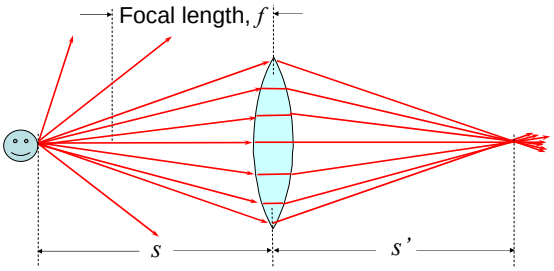
A. They will remain parallel.
B. They will diverge (spread out).
C. They will converge (toward a focus).




Discussion Question 5. What will happen to the rays emerging to the right of the lens if the face is moved a little further away from the lens?

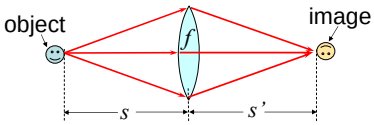
A. They will remain parallel.
B. They will diverge (spread out).
C. They will converge (toward a focus).

## Diverging rays through a Converging Lens




Thin Lens Equation: $\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$

## Thin Lens Equation: sign conventions




$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$

$s$ is positive for objects to the left of lens, negative for objects to the right of lens (virtual objects).

$s'$ is positive for images to the right of lens, negative for images to the left of lens (virtual images).

$f$ is positive for converging lenses, negative for diverging lenses.

## Magnification

$$|m| \equiv \frac{h'}{h} \qquad m = -\frac{s'}{s}$$

- The absolute magnitude of the magnification $|m|$ is defined to be the ratio of image height to object height.
- A positive value of $m$ indicates that the image is upright relative to the object. A negative value of $m$ indicates the image is inverted relative to the object.
- Note that when $s$ and $s'$ are both positive, $m$ is negative.

## The Camera

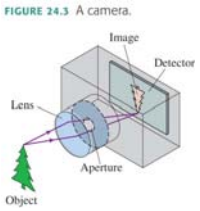


FIGURE 24.3 A camera.

- A **camera** "takes a picture" by using a lens to form a real, inverted image on a light-sensitive detector in a light-tight box.
- We can model a combination lens as a single lens with an **effective focal length** (usually called simply "the focal length")
- A *zoom lens* changes the effective focal length by varying the spacing between the converging lens and the diverging lens.

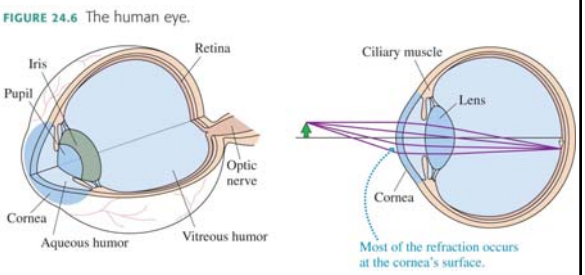


FIGURE 24.6 The human eye.

## Lenses in Combination

The analysis of multi-lens systems requires only one new rule: **The image of the first lens acts as the object for the second lens.**

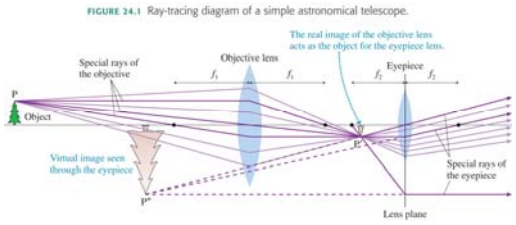


FIGURE 24.1 Ray-tracing diagram of a simple astronomical telescope.

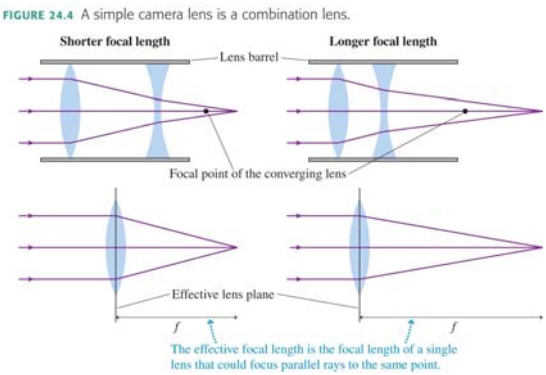


FIGURE 24.4 A simple camera lens is a combination lens.

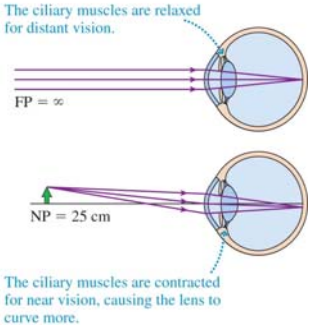


FIGURE 24.8 Normal vision of far and near objects.

**FIGURE 24.18** A lens both focuses and diffracts the light passing through.

**(a)** A lens acts as a circular aperture.

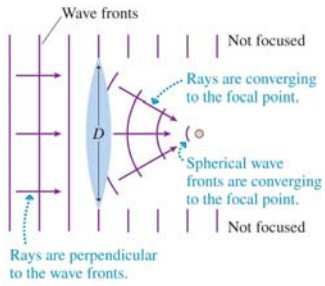



**FIGURE 24.18** A lens both focuses and diffracts the light passing through.

**(b)** The aperture and focusing effects can be separated.

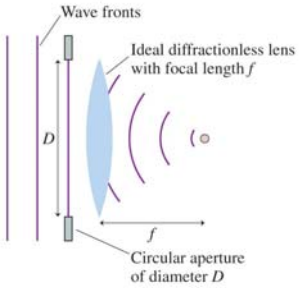
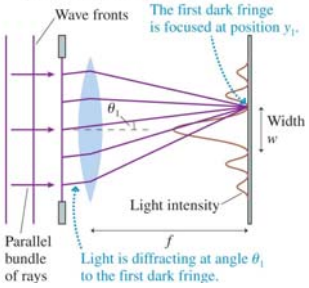



**FIGURE 24.18** A lens both focuses and diffracts the light passing through.

**(c)** The lens focuses the diffraction pattern in the focal plane.




## The Resolution of Optical Instruments

The minimum spot size to which a lens can focus light of wavelength $\lambda$ is

$$w_{\text{min}} \approx 2f\theta_1 = \frac{2.44\lambda f}{D} \qquad \text{(minimum spot size)}$$

where $D$ is the diameter of the circular aperture of the lens, and $f$ is the focal length.
In order to resolve two points, their angular separation must be greater than $\theta_{\text{min}}$, where

$$\theta_{\text{min}} = \frac{1.22\lambda}{D} \qquad \text{(angular resolution of a lens)}$$

is called the **angular resolution** of the lens.