PHYS 111
1ST semester 1439-1440

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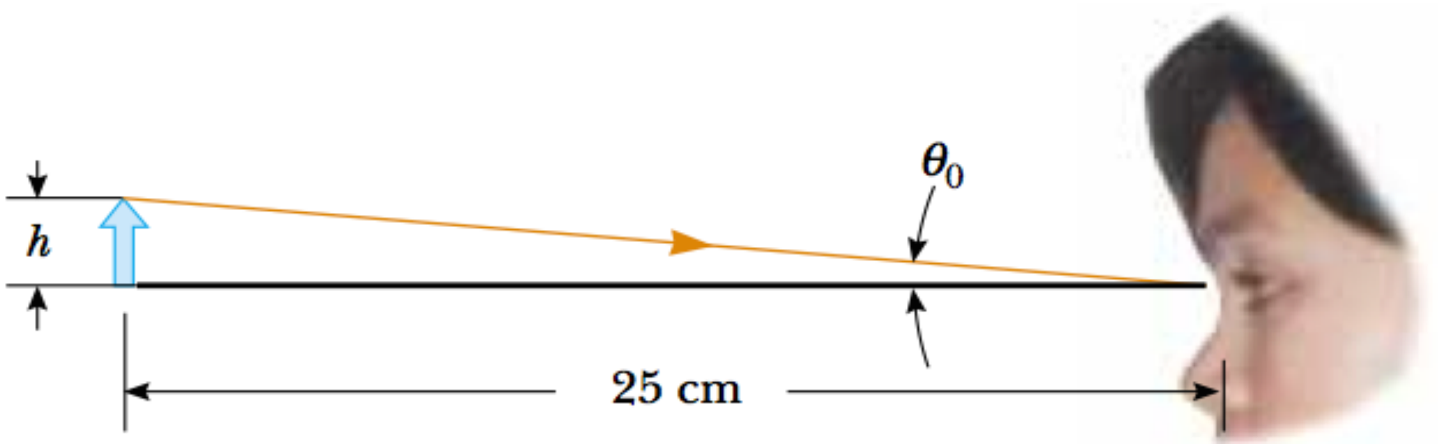
Lecture 20

Chapter 36
Image Formation

36.8 The Simple Magnifier

- The simple magnifier consists of a single converging lens. This device increases the apparent size of an object.
- Suppose an object is viewed at some distance *p* from the eye. The size of the image formed at the retina depends on the angle θ subtended by the object at the eye.
- As the object moves closer to the eye, θ increases and a larger image is observed.
- An average normal eye cannot focus on an object closer than about 25 cm, the **near point**. Therefore, θ is maximum at the near point.

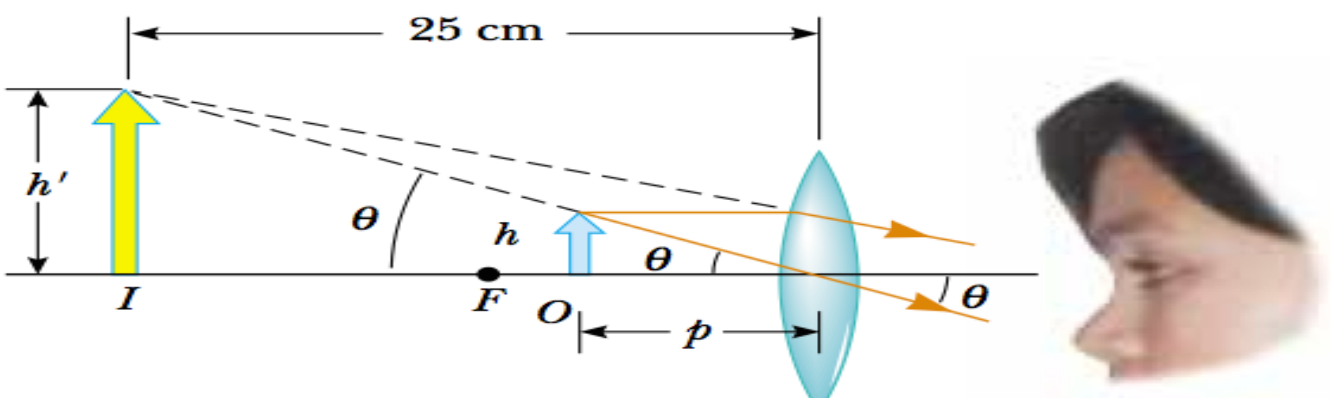


(a)

36.8 The Simple Magnifier

- To increase the apparent angular size of an object, a converging lens can be placed in front of the eye with the object located at point *O*, just inside the focal point of the lens.
- At this location, the lens forms a virtual, upright, enlarged image.
- We define **angular magnification** *m* as the ratio of the angle subtended by an object with a lens in use (angle θ) to the angle subtended by the object placed at the near point with no lens in use (angle θ_0)

$$m \equiv \frac{\theta}{\theta_0}$$



(b)

36.8 The Simple Magnifier

- The angular magnification is a maximum when the image is at the near point of the eye—that is, when q = - 25 cm.

$$\tan\theta_0 \approx \theta_0 \approx \frac{h}{25} \qquad \text{and} \qquad \tan\theta \approx \theta \approx \frac{h}{p}$$

$$m_{\max} = 1 + \frac{25\text{ cm}}{f}$$

- Although the eye can focus on an image formed anywhere between the near point and infinity, it is most relaxed when the image is at infinity. For the image formed by the magnifying lens to appear at infinity, the object has to be at the focal point of the lens.

$$\theta_0 \approx \frac{h}{25} \qquad \text{and} \qquad \theta \approx \frac{h}{f}$$

$$m_{\min} = \frac{\theta}{\theta_0} = \frac{25\text{ cm}}{f}$$

Example 36.16 Maximum Magnification of a Lens

What is the maximum magnification that is possible with a lens having a focal length of 10 cm, and what is the magnification of this lens when the eye is relaxed?

Solution The maximum magnification occurs when the image is located at the near point of the eye. Under these circumstances, Equation 36.22 gives

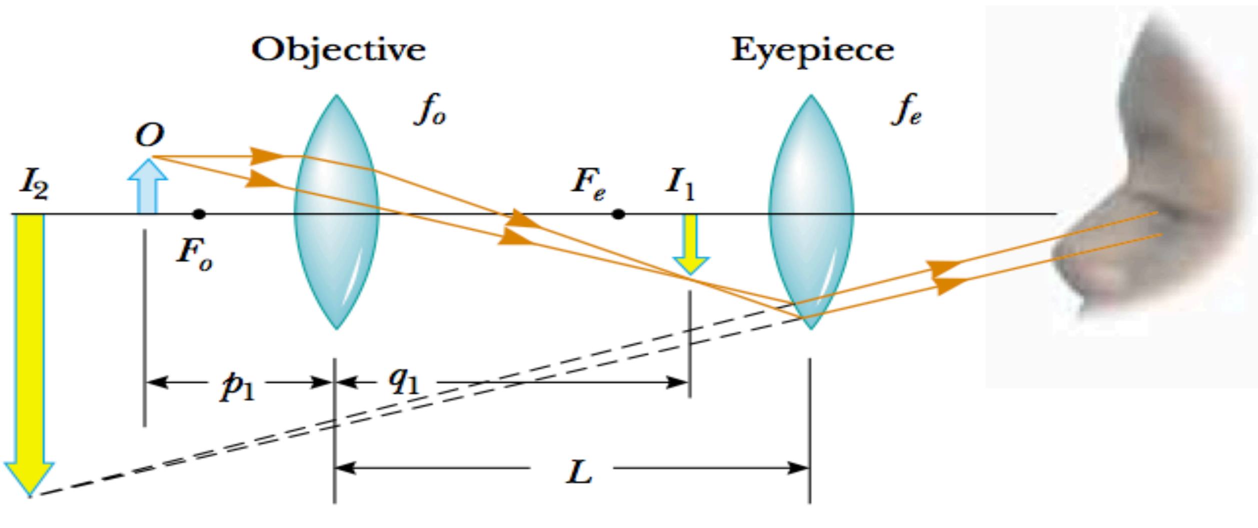
$$m_{\text{max}} = 1 + \frac{25\text{ cm}}{f} = 1 + \frac{25\text{ cm}}{10\text{ cm}} = \boxed{3.5}$$

When the eye is relaxed, the image is at infinity. In this case, we use Equation 36.23:

$$m_{\text{min}} = \frac{25\text{ cm}}{f} = \frac{25\text{ cm}}{10\text{ cm}} = \boxed{2.5}$$

36.9 The Compound Microscope

- Greater magnification can be achieved by combining two lenses in a device called a **compound microscope.**
- It consists of one lens, the *objective,* that has a very short focal length f_o < 1 cm and a second lens, the *eyepiece,* that has a focal length f_e of a few centimeters. The two lenses are separated by a distance L that is much greater than either f_o or f_e.



(a)

36.9 The Compound Microscope

- The lateral magnification by the objective is

$$M_o \approx -\frac{L}{f_o}$$

- The angular magnification by the eyepiece for an object (corresponding to the image at I_1) placed at the focal point of the eyepiece is

$$m_e = \frac{25\text{ cm}}{f_e}$$

- The overall magnification of the image formed by a compound microscope is defined as the product of the lateral and angular magnifications:

$$M = M_o m_e = -\frac{L}{f_o}\left(\frac{25\text{ cm}}{f_e}\right)$$

- The negative sign indicates that the image is inverted.

Problems

9. A spherical convex mirror has a radius of curvature with a magnitude of 40.0 cm. Determine the position of the virtual image and the magnification for object distances of (a) 30.0 cm and (b) 60.0 cm. (c) Are the images upright or inverted?

(a) $\frac{1}{p}+\frac{1}{q}=\frac{2}{R}$ gives $\frac{1}{30.0\text{ cm}}+\frac{1}{q}=\frac{2}{(-40.0\text{ cm})}$

$\frac{1}{q}=-\frac{2}{40.0\text{ cm}}-\frac{1}{30.0\text{ cm}}=-0.083\,3\text{ cm}^{-1}$ so $q=\boxed{-12.0\text{ cm}}$

$M=\frac{-q}{p}=-\frac{(-12.0\text{ cm})}{30.0\text{ cm}}=\boxed{0.400}$.

(b) $\frac{1}{p}+\frac{1}{q}=\frac{2}{R}$ gives $\frac{1}{60.0\text{ cm}}+\frac{1}{q}=\frac{2}{(-40.0\text{ cm})}$

$\frac{1}{q}=-\frac{2}{40.0\text{ cm}}-\frac{1}{60.0\text{ cm}}=-0.066\,6\text{ cm}^{-1}$ so $q=\boxed{-15.0\text{ cm}}$

$M=\frac{-q}{p}=-\frac{(-15.0\text{ cm})}{60.0\text{ cm}}=\boxed{0.250}$.

(c) Since $M>0$, the images are $\boxed{\text{upright}}$.

21. A cubical block of ice 50.0 cm on a side is placed on a level floor over a speck of dust. Find the location of the image of the speck as viewed from above. The index of refraction of ice is 1.309.

$$\frac{n_1}{p}+\frac{n_2}{q}=\frac{n_2-n_1}{R}=0 \text{ and } R\to\infty$$

$$q=-\frac{n_2}{n_1}p=-\frac{1}{1.309}(50.0\text{ cm})=-38.2\text{ cm}$$

Thus, the virtual image of the dust speck is **38.2 cm below the top surface** of the ice.

33. The nickel's image in Figure P36.33 has twice the diameter of the nickel and is 2.84 cm from the lens. Determine the focal length of the lens.

Figure P36.33

We are looking at an enlarged, upright, virtual image:

$$M = \frac{h'}{h} = 2 = -\frac{q}{p} \quad \text{so} \quad p = -\frac{q}{2} = -\frac{(-2.84\text{ cm})}{2} = +1.42\text{ cm}$$

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \quad \text{gives} \quad \frac{1}{1.42\text{ cm}} + \frac{1}{(-2.84\text{ cm})} = \frac{1}{f}$$

$$\boxed{f = 2.84\text{ cm}}.$$

50. A lens that has a focal length of 5.00 cm is used as a magnifying glass. (a) To obtain maximum magnification, where should the object be placed? (b) What is the magnification?

(a) From the thin lens equation: $\frac{1}{p}+\frac{1}{(-25.0\text{ cm})}=\frac{1}{5.00\text{ cm}}$ or $p=\boxed{4.17\text{ cm}}$.

(b) $M=-\frac{q}{p}=1+\frac{25.0\text{ cm}}{f}=1+\frac{25.0\text{ cm}}{5.00\text{ cm}}=\boxed{6.00}$

52. The desired overall magnification of a compound microscope is 140×. The objective alone produces a lateral magnification of 12.0×. Determine the required focal length of the eyepiece.

$$M = M_o m_e = M_o\left(\frac{25.0\text{ cm}}{f_e}\right) \Rightarrow f_e = \left(\frac{M_o}{M}\right)(25.0\text{ cm}) = \left(\frac{-12.0}{-140}\right)(25.0\text{ cm}) = \boxed{2.14\text{ cm}}$$