Optical Instruments

Single-lens camera:
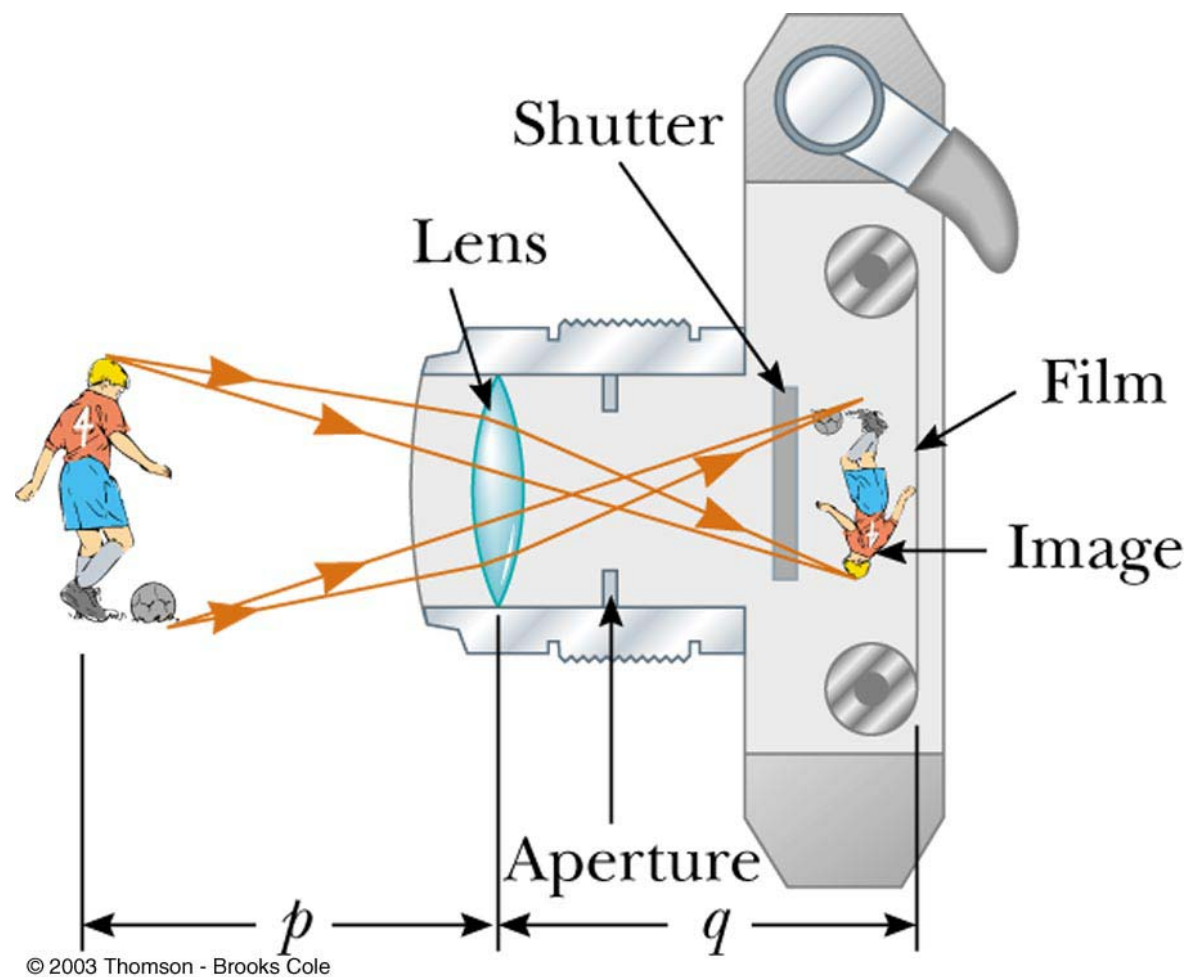
Usually, $p \gg q$;

$$q = \frac{pf}{p-f} \approx f$$

Real image on the film;
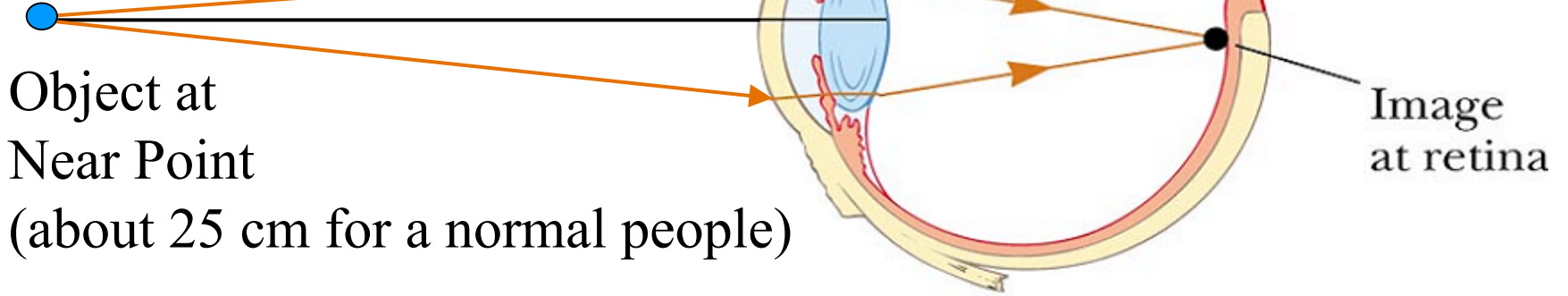

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$$M = -\frac{h'}{h} = -\frac{q}{p} = \frac{f}{f-p} \approx -\frac{f}{p}$$

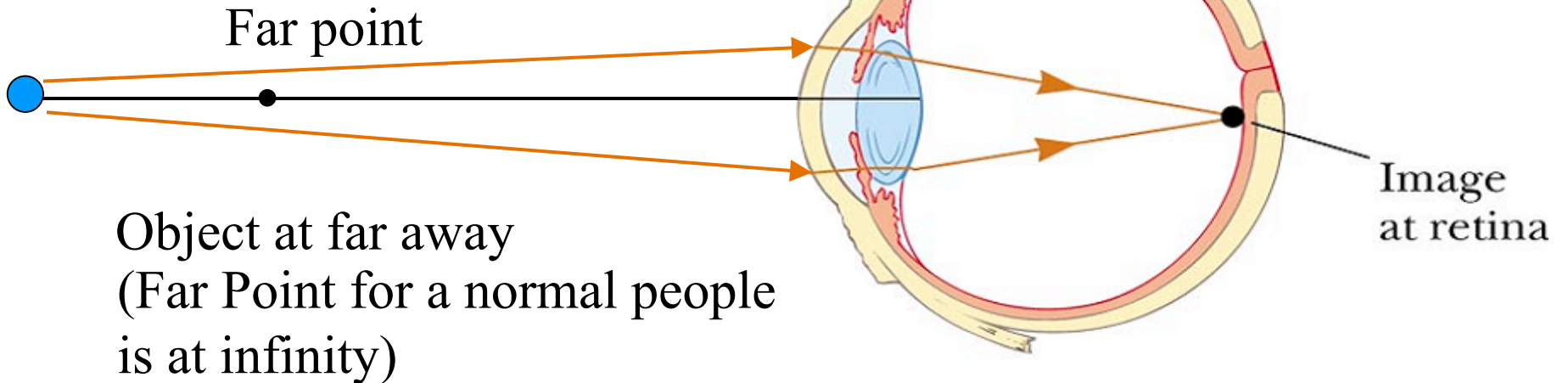Inverted image with size of image on the film: $h' = \frac{f}{p} h$
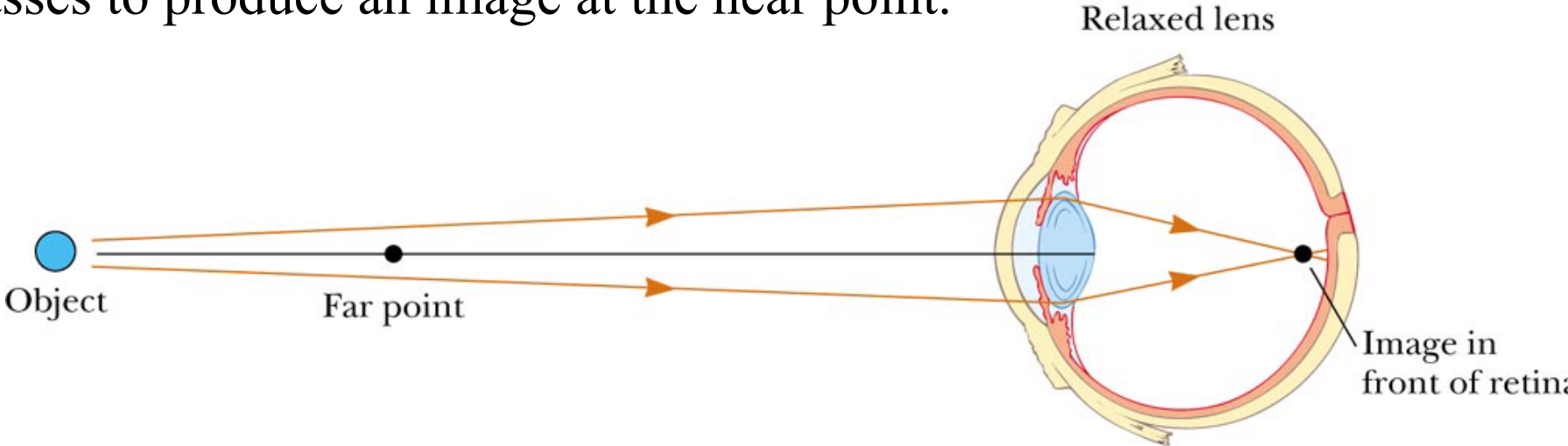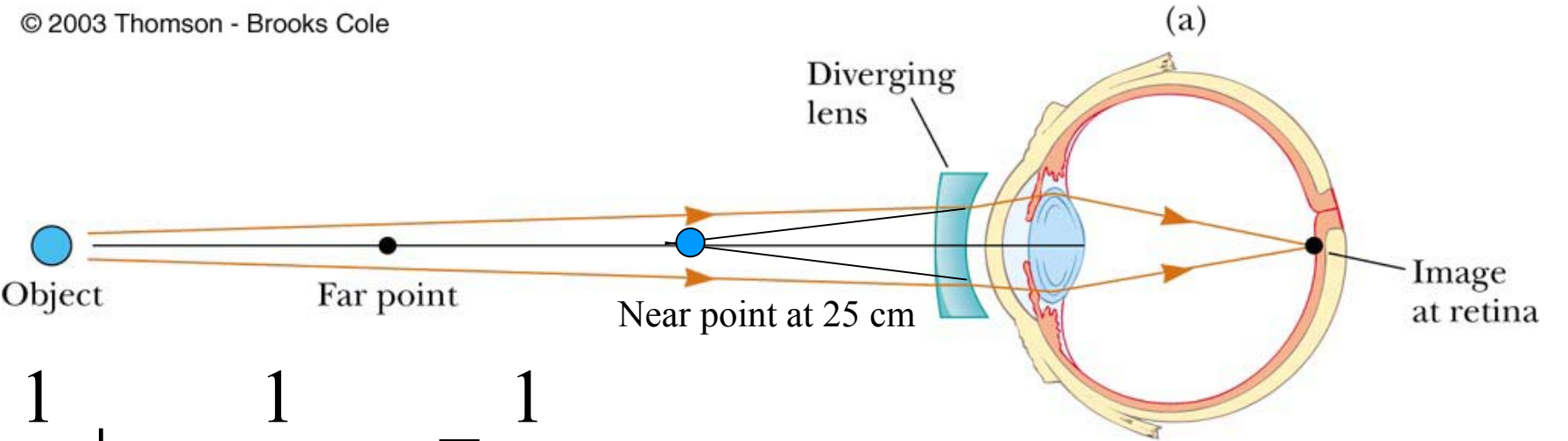
Normal Human eyes:

Relaxed lens

Object at
Near Point
(about 25 cm for a normal people)

Image
at retina

Relaxed lens

Far point

Object at far away
(Far Point for a normal people
is at infinity)

Image
at retina

Nearsighted eyes: can not see well an object at far away, for example, characters on the board. It can be corrected by wearing a diverging-lens glasses to produce an image at the near point.

Relaxed lens

Object

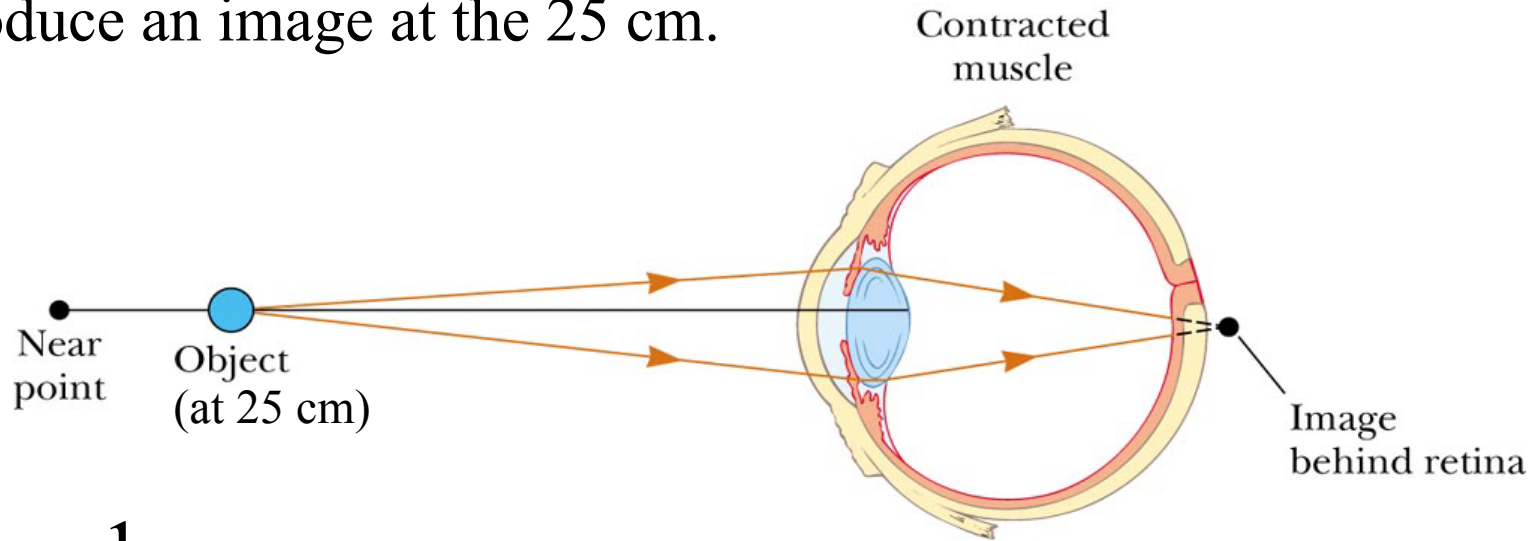Far point

Image in front of retina

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(a)

Diverging lens
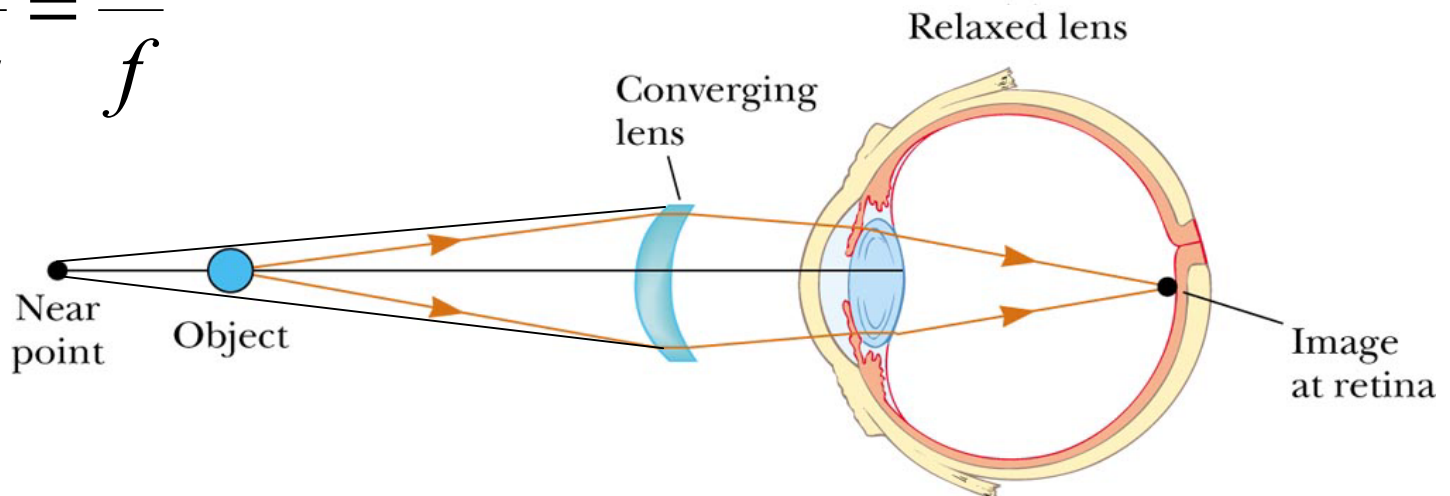
Object

Far point

Near point at 25 cm

Image at retina

$$\frac{1}{p} + \frac{1}{(-25\,\text{cm})} = \frac{1}{f}$$

(p is the far point needs to be corrected)

Farsighted eyes: can not see clearly a nearby object, for example, characters on the book, because his/her near point is much farther than that of 25 cm. It can be corrected by wearing a converging-lens glasses to produce an image at the 25 cm.

Contracted muscle

Near point
Object (at 25 cm)

Image behind retina

$$\frac{1}{25\,\text{cm}} + \frac{1}{q} = \frac{1}{f}$$

Relaxed lens

Converging lens

Near point
Object

Image at retina

(q is the near point needs to be corrected)

Magnifying glass

(1) Human eyes have the near-point of about 25 cm. Objects placed closer to the eyes than the near-point will not be seen well focused.

(2) Human eyes have limited angular resolution about 0.007°, which is equivalent to linear resolution of 30 microns if the object is placed at 25 cm in front of the eyes. For the separation smaller than 30 microns, human eyes can not distinguish it.   So optical instruments are use to magnify the ANGULAR resolution.

(3) By using a converging lens of $f < 25$ cm and placing an object within the focal length ($p < f$), a magnified, upright, virtual image can be produced at the near point ($q = -25$ cm).

(4) Angular magnification: $m \equiv \dfrac{\theta}{\theta_0} = \dfrac{\text{angle with lens}}{\text{angle without lens}} \approx \dfrac{25\,\text{cm}}{f}$

Note: we are interested in angular magnification m here instead of the lateral magnification $M = h'/h$.

θ_0

h

25 cm

(a)

25 cm

h'

θ

h

θ

θ
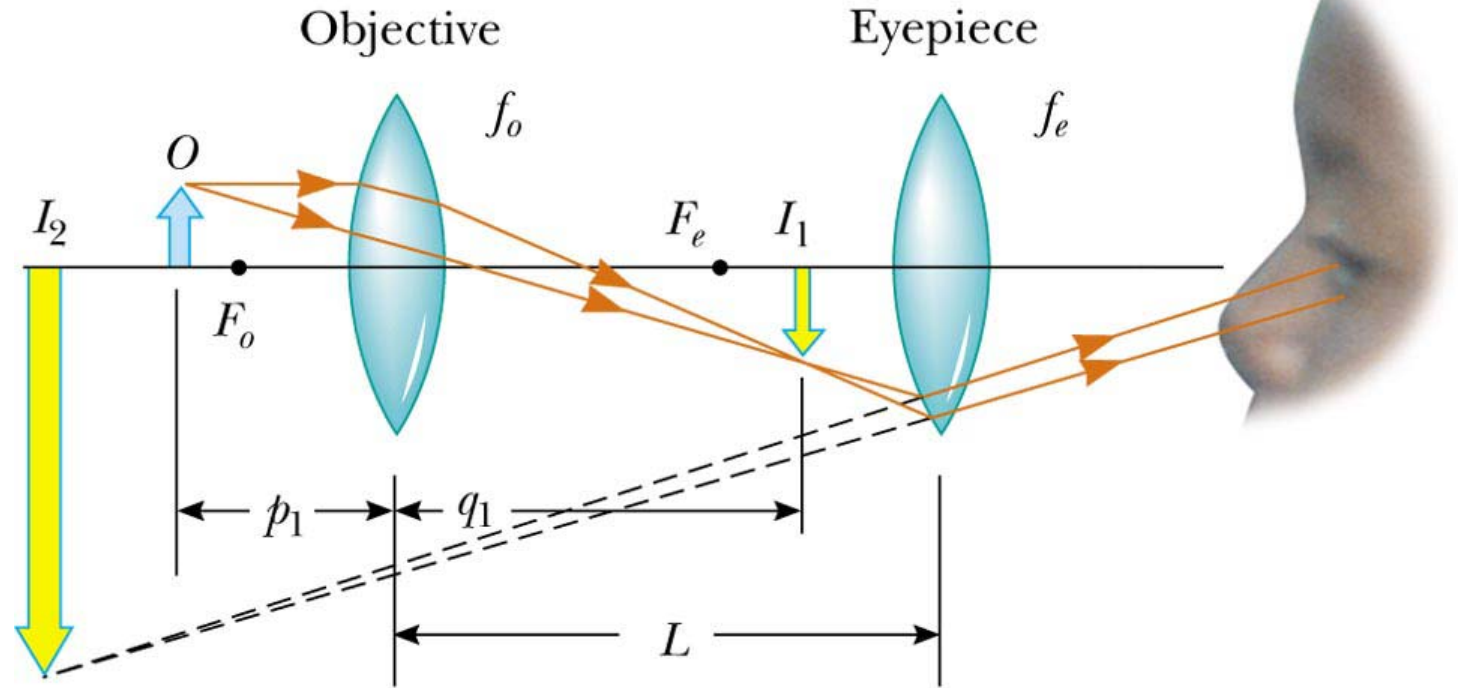
I

F

O

p

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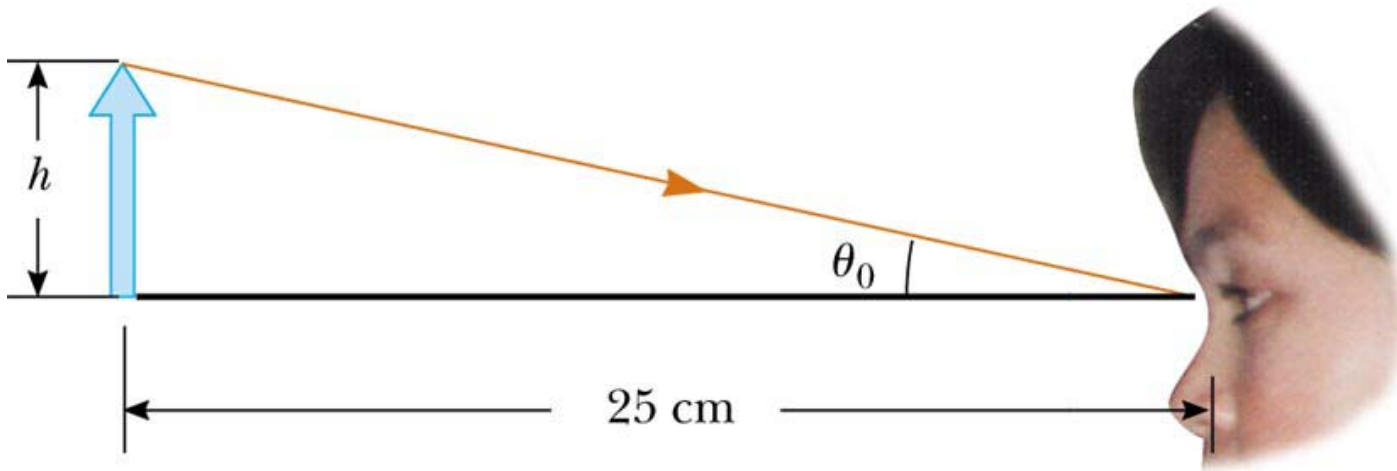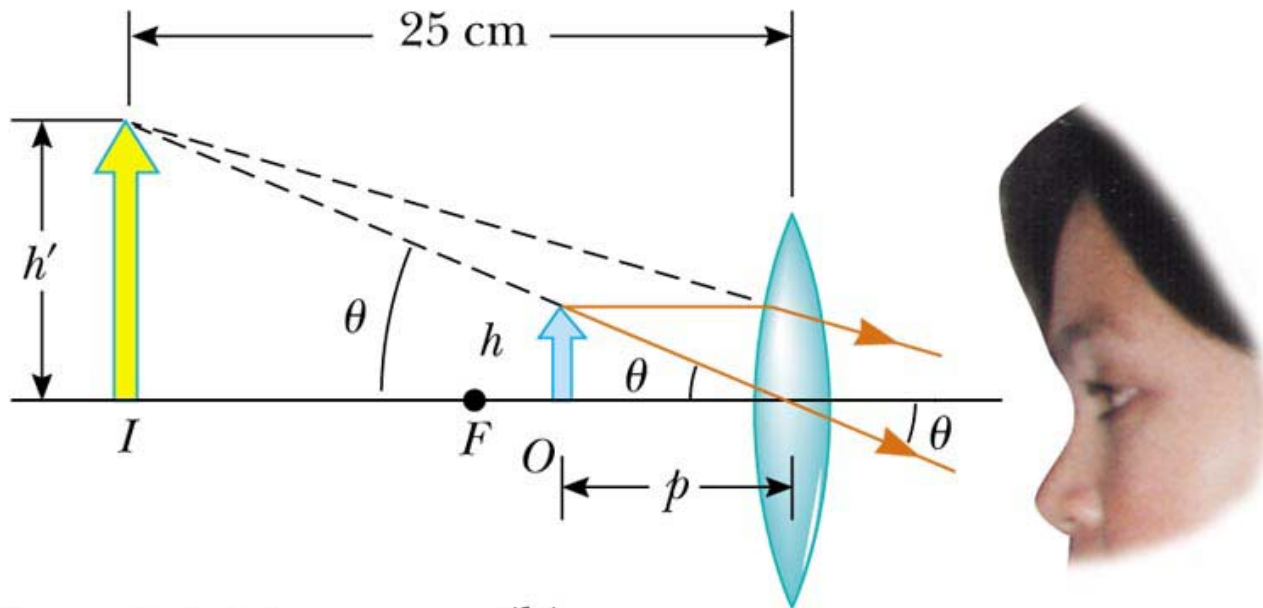
(b)

Compound Microscope

- A compound microscope consists of two lenses
  - Gives greater magnification than a single lens
  - The objective lens has a short focal length, $f_o < 1$ cm
  - The ocular lens (eyepiece) has a focal length, f_e of a few cm
- The lens are separated by a distance L
  - L is much greater than either focal length

- The approach to analysis is the same as for any two lenses in a row
  - The image formed by the first lens becomes the object for the second lens
- The image seen by the eye, I_2, is virtual, inverted and very much enlarged
- The *lateral magnification* of the microscope is

$$M_l = -\frac{q_l}{p_l} \approx -\frac{L}{f_o}$$

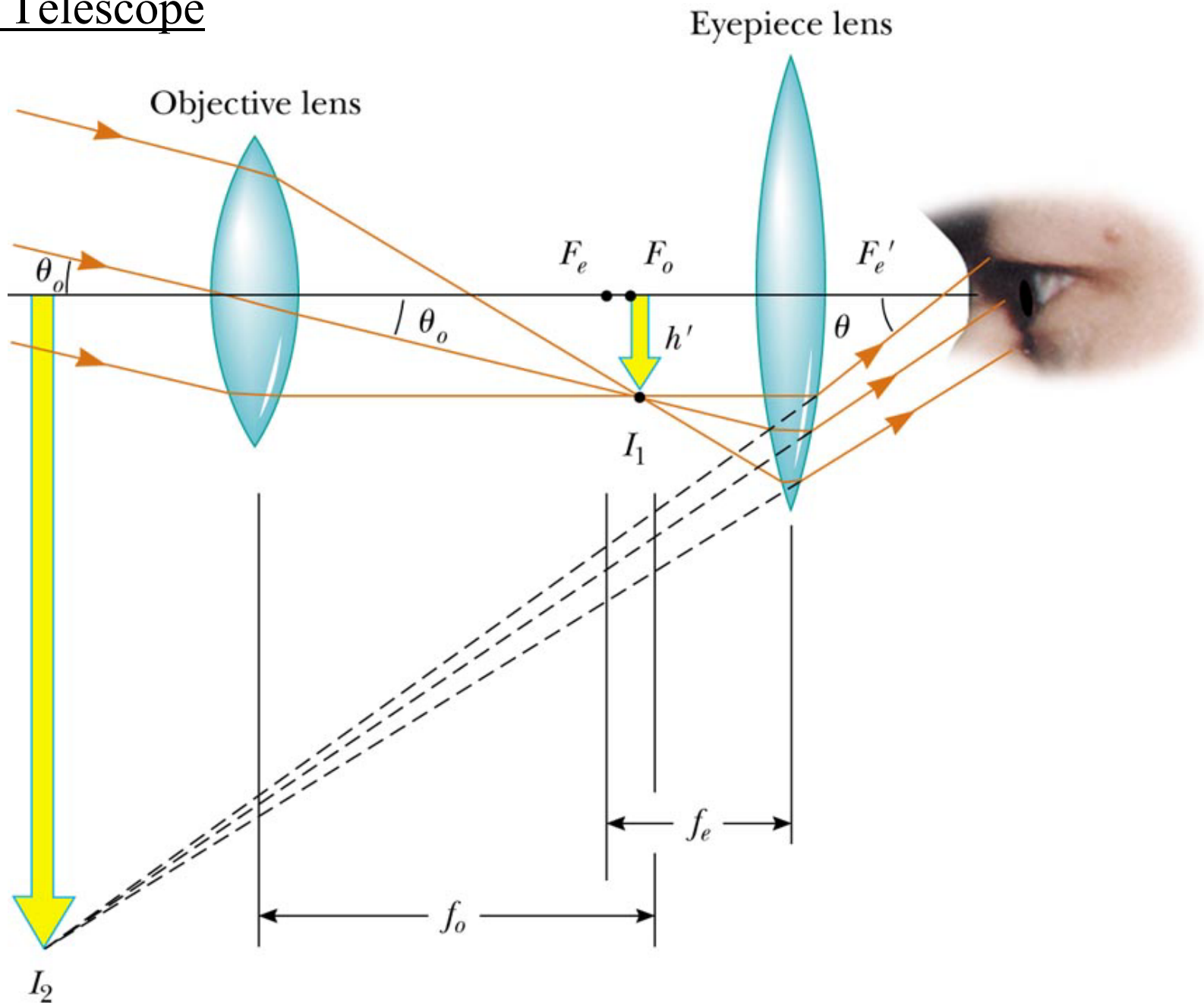- The *angular magnification* of the eyepiece of the microscope is

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

- The *overall magnification* of the microscope is the product of the individual magnifications

$$m = M_l \, m_e = -\frac{L}{f_o}\left(\frac{25 \text{ cm}}{f_e}\right)$$

Refracting Telescope

Objective lens

Eyepiece lens

θ_o

θ_o

F_e F_o

h'

I_1

F_e'

θ

f_e

f_o

I_2

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(a)

- The two lenses are arranged so that the objective forms a real, inverted image of a distance object
- The image is near the focal point of the eyepiece
- The two lenses are separated by the distance $f_o + f_e$ which corresponds to the length of the tube
- The eyepiece forms an enlarged, inverted image of the first image
- The angular magnification depends on the focal lengths of the objective and eyepiece

$$m = \frac{\theta}{\theta_o} = -\frac{f_o}{f_e}$$

- Angular magnification is particularly important for observing nearby objects
  - Very distance objects still appear as a small point of light