Geometric Optics, Pt. III: Optical Instruments

Knight Ch. 35

Physics 2C, Spring 2025

Agenda Today (May 29 & June 3, 2025)

- Multiple Lenses in general
  - Cameras; specific camera terms
- The eye
  - Nearsightedness vs. Farsightedness
  - Astigmatism?
- Systems that magnify; Microscopes & Telescopes
- Dispersion; chromatic aberration

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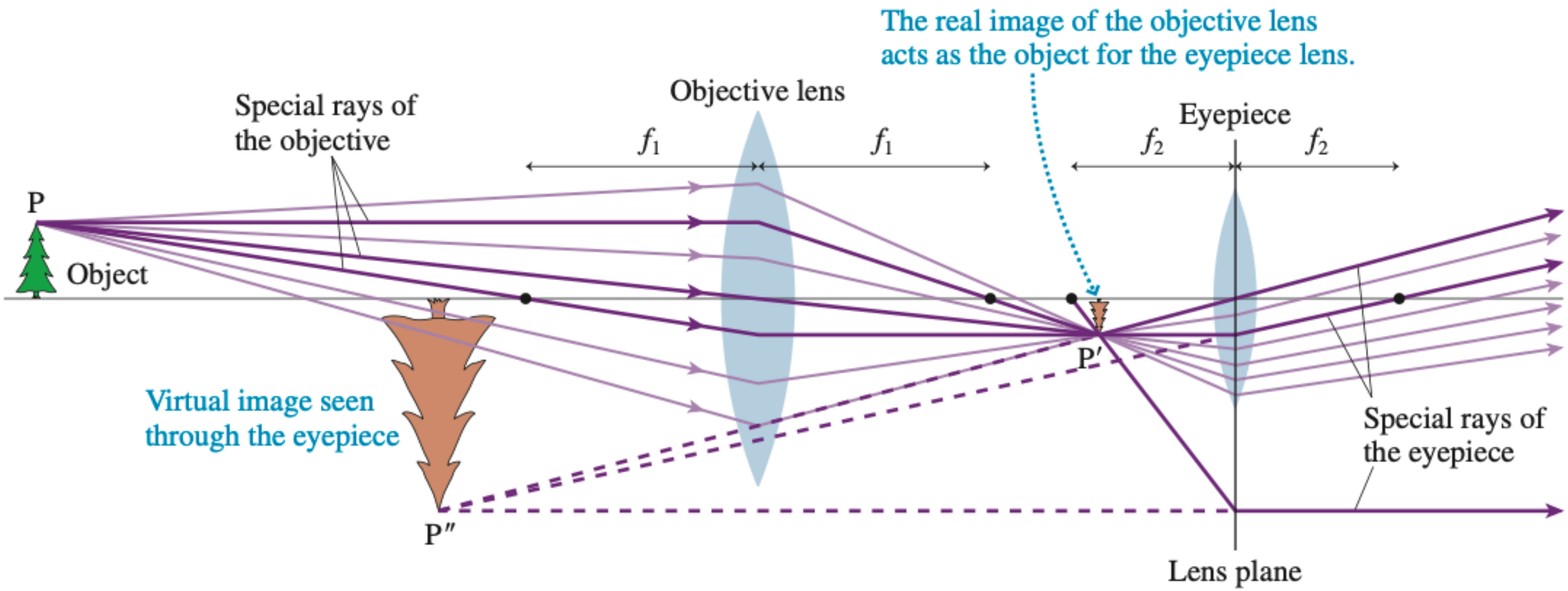
Mulitple Lenses

The image of the first lens acts as the object for the second lens.

FIGURE 35.1 Ray-tracing diagram of a simple astronomical telescope.



Example

A converging lens of focal length 50cm is 10cm away from another converging lens of focal length 50cm. By considering a distant object (at infinity), find the effective focal length of the composite lens system, assuming the composite “lens” is located at the midpoint of the lenses.

Combined Power of Two Adjacent Lenses

Two lenses right next to each other satisfy $1/f_1 + 1/f_2 = 1/f_{\text{tot}}$

Cameras: basic properties

- Cameras often focus on objects with $s \gg f$. In this limit, the lens equation becomes $1/s' = 1/f \implies s' = f$, and therefore the magnification is $m = -s'/s = -f/s$.

- Cameras have a range of zoom levels because of their ability to change their effective focal lengths.
    - Since $m \propto f$, this means there is a range of magnification levels (i.e., we can “zoom” in and out).
    - For example, if a camera has a 3X zoom, then $f_{\text{low}} < f_{\text{eff}} < f_{\text{high}} = 3f_{\text{low}}$.

Cameras: Shutter Time, Aperture, etc.

Play with these here: https://canon.ca/CanonOutsideOfAuto/play

- D: diameter of the opening letting light in.
- f: focal length (proportional to image size).
- "f-number" $\equiv \dfrac{f}{D}$. The larger the f-number, the less intense the light is on the detector. An f-number of 4.0 might be written as $f/4.0$ or F4.0.

$$I \propto \frac{D^2}{f^2} = \frac{1}{(f\text{-number})^2} \quad \text{and} \quad \text{Exposure} \propto I \Delta t_{\text{shutter}}$$

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Clicker/Poll Question

Suppose a camera’s exposure is correct when the lens has a focal length of 8.0 mm. Will the picture be overexposed, underexposed, or still correct if the focal length is “zoomed” to 16.0 mm without changing the aperture or shutter speed?

A. Overexposed
B. Underexposed
C. Still Correct

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Clicker/Poll Question

To fix the exposure, what should we do to either…

1. …the aperture diameter D, or
2. …the shutter time Δt?

A. Increase D and/or increase Δt

B. Increase D and/or decrease Δt

C. Decrease D and/or increase Δt

D. Decrease D and/or decrease Δt

The Eye

Ideally, the eye should have near point 25cm and far point at ∞.

If either one is not true, we have to use corrective lenses to moves objects at 25cm/∞ to the person's actual near point / far point.

- Farsightedness (hyperopia)
  = Can't see up close
  = Need converging lenses

- Nearsightedness (myopia)
  = Can't see far away
  = Need diverging lenses

Presbyopia = age-related hyperopia

Table 34.1 Receding of Near Point with Age

Age (years)	Near Point (cm)
10	7
20	10
30	14
40	22
50	40
60	200

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Clicker/Poll Question

Grandma Shotwell's near point is at 100 cm. She buys glasses so that she can take an object ___ and instead have its image at ___.

A. at infinity, 25 cm

B. at her near point, 25 cm

C. at 25 cm, infinity

D. at 25 cm, her near point

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Clicker/Poll Question

Which of the following glasses is the best option for Grandma Shotwell?

A. +1.50

B. +2.00

C. +2.50

D. +3.00

Example

A person can see clearly up close but cannot focus on objects beyond 75.0cm. She opts for contact lenses to correct her vision.

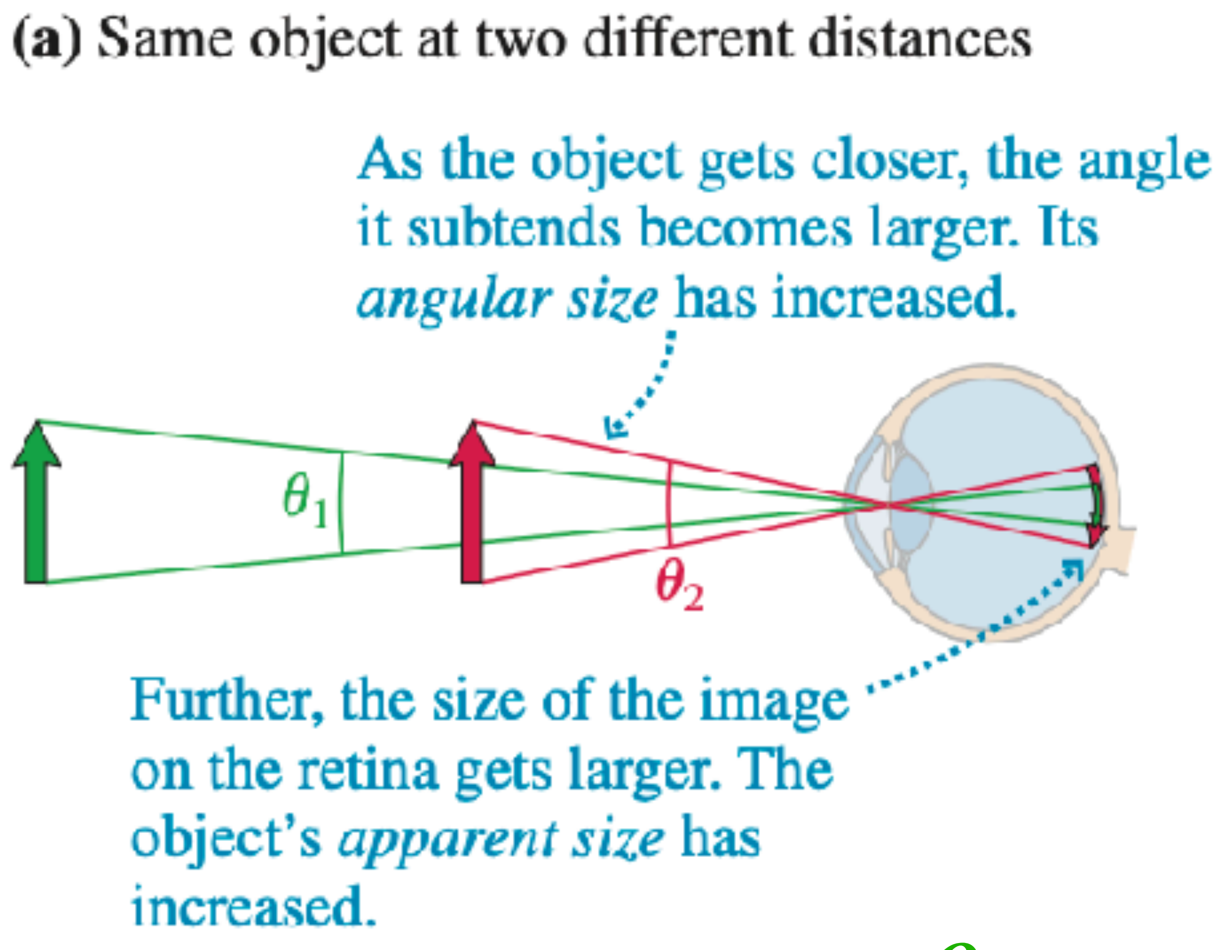
(a) Is she nearsighted or farsighted?
(b) What type of lens (converging or diverging) is needed to correct her vision?
(c) What focal length contact lens is needed, and what is its power in diopters?

Review Example (too difficult?)

A myopic person has far point 0.667m. A lens with the correct prescription for them consists of a concave meniscus where one side has radius of curvature 50cm. What is the radius of curvature of the other side?

Angular Magnification and Magnifying Glasses

FIGURE 35.11 Angular size.



$$\theta_{NP} = \frac{h}{25\text{ cm}}$$

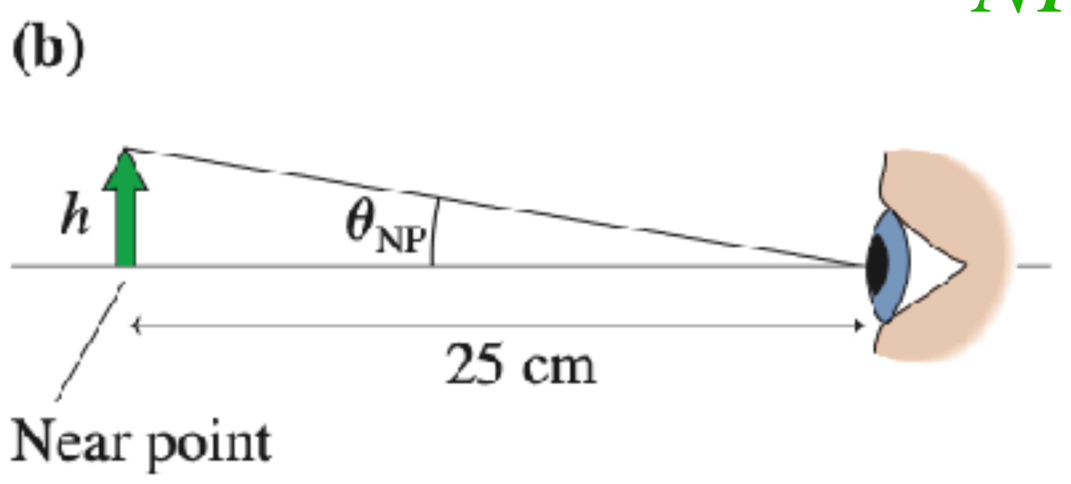
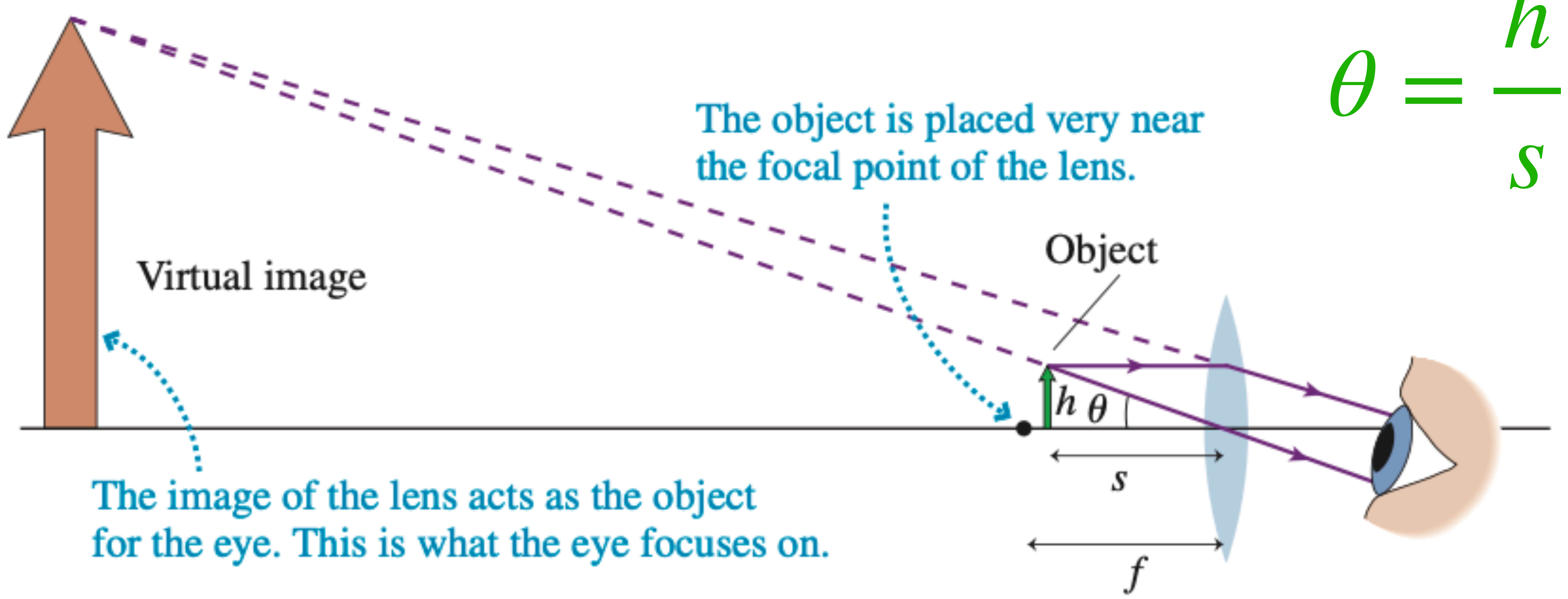


FIGURE 35.12 The magnifier.



$$\theta = \frac{h}{s} \approx \frac{h}{f}$$

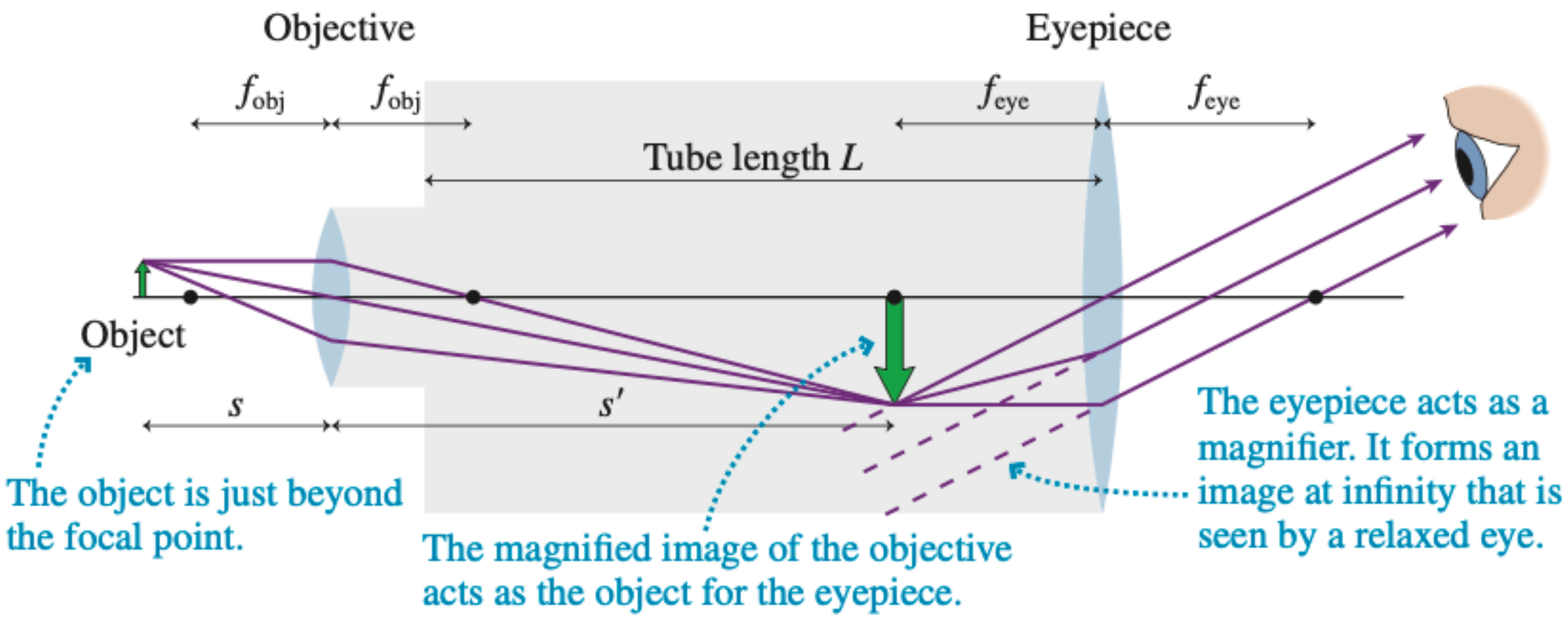
$$\text{Angular Magnification } M = \frac{\theta}{\theta_{NP}} = \frac{h/f}{h/25\text{ cm}} = \frac{25\text{ cm}}{f}$$

Often, L=160mm

Microscopes

A microscope consists of an objective lens and an eyepiece.

FIGURE 35.14 The optics of a microscope.



Object is basically at (just outside) the focus of the objective, putting the image at "infinity" (actually, L, the "tube length" of the microscope).

Eyepiece takes this objective-image as the new "object"; the image after the eyepiece is at infinity to be seen by a relaxed eye.

Overall angular magnification $M = m_{\text{obj}} M_{\text{eye}} = -\dfrac{L}{f_{\text{obj}}} \dfrac{25\text{ cm}}{f_{\text{eye}}}$

Example

A microscope of standard tube length 160mm has an eyepiece with 10X magnification. The total magnification of the compound microscope is 400X.

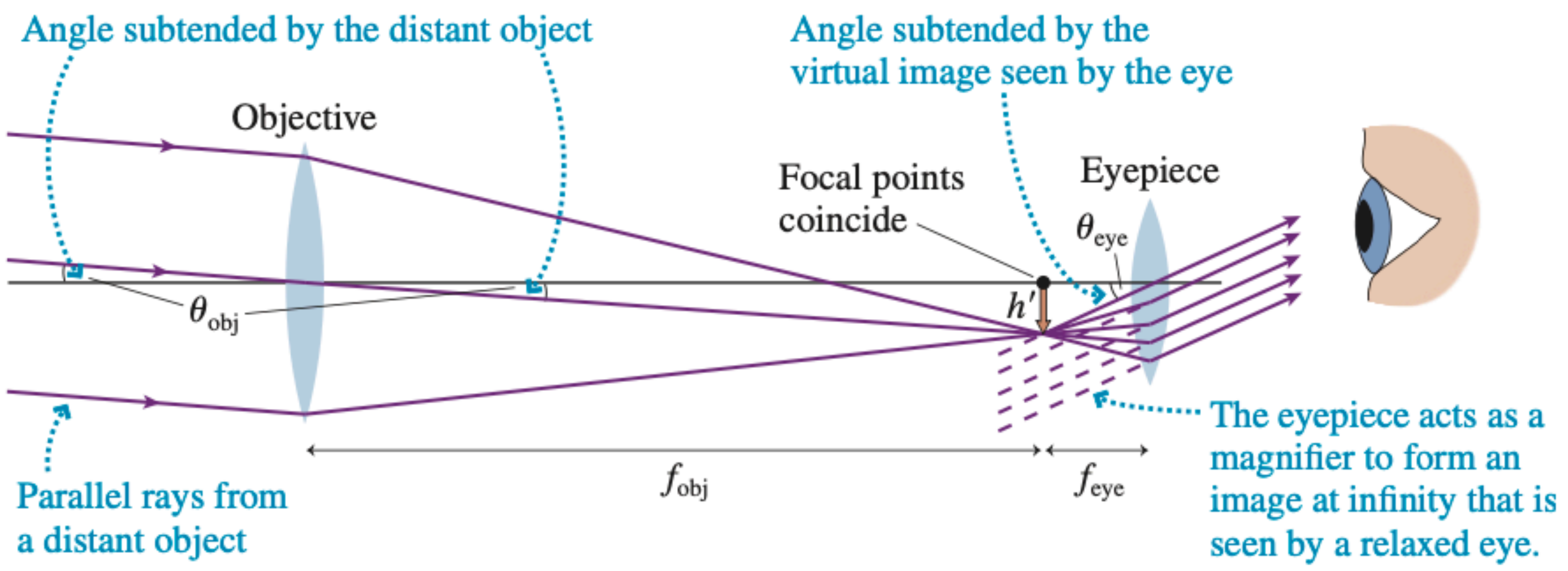
(a) What is the objective focal length?

(b) If looking at a $8\ \mu$m red blood cell, what is the size of the image of the blood cell after passing through the objective (but before the eyepiece)?

Telescopes

A telescope also consists of an objective lens and an eyepiece.

FIGURE 35.15 A refracting telescope.



Object is basically at infinity; objective puts an image at a point very close to the far focal point.

Eyepiece takes this objective-image as the new "object"; the image after the eyepiece is at infinity to be seen by a relaxed eye.

Overall angular magnification $M = \dfrac{\theta_{\text{eye}}}{\theta_{\text{obj}}} = -\dfrac{f_{\text{obj}}}{f_{\text{eye}}}$

Example

The eyepiece of a refracting telescope has a focal length of 9.00cm. The distance between objective and eyepiece is 1.80m, and the final image is at infinity. What is the angular magnification of the telescope?

Dispersion; Chromatic Aberration

The index of refraction is slightly wavelength-dependent.

FIGURE 35.18 Dispersion curves show how the index of refraction varies with wavelength.

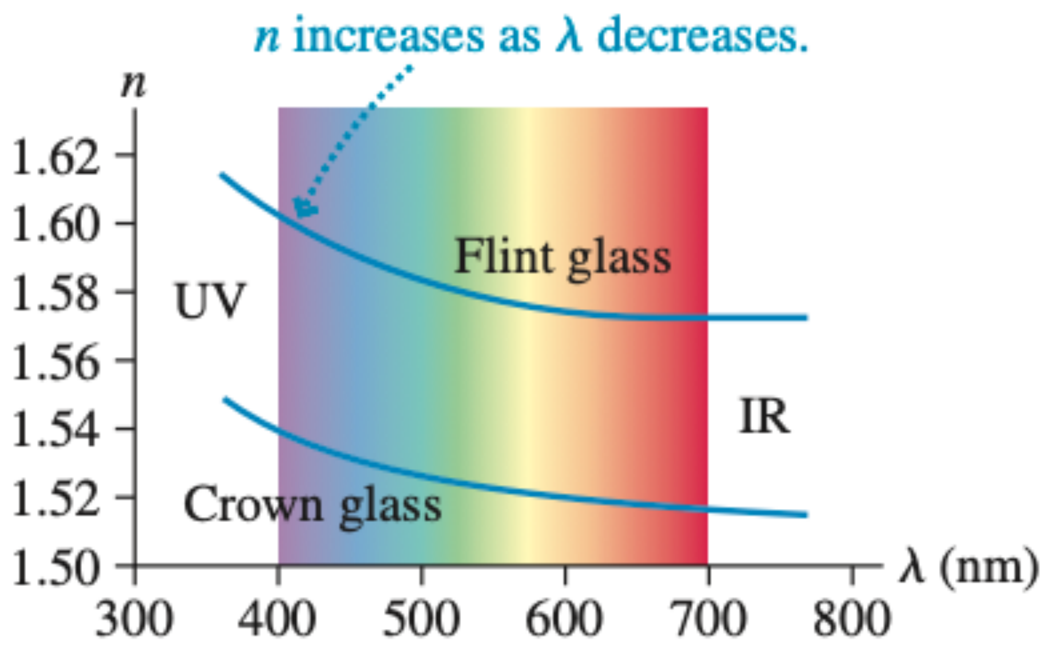


TABLE 35.1 A brief summary of the visible spectrum of light

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

FIGURE 35.17 Newton used prisms to study color.