Physics 294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
- Quizzes by iclicker (sometimes hand-written)
- Average on 2nd exam (so far)=71/120
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

Ray tracing for lenses and mirrors

s=object distance=p

Green arrow = object, orange arrow = image, black dots = focal points

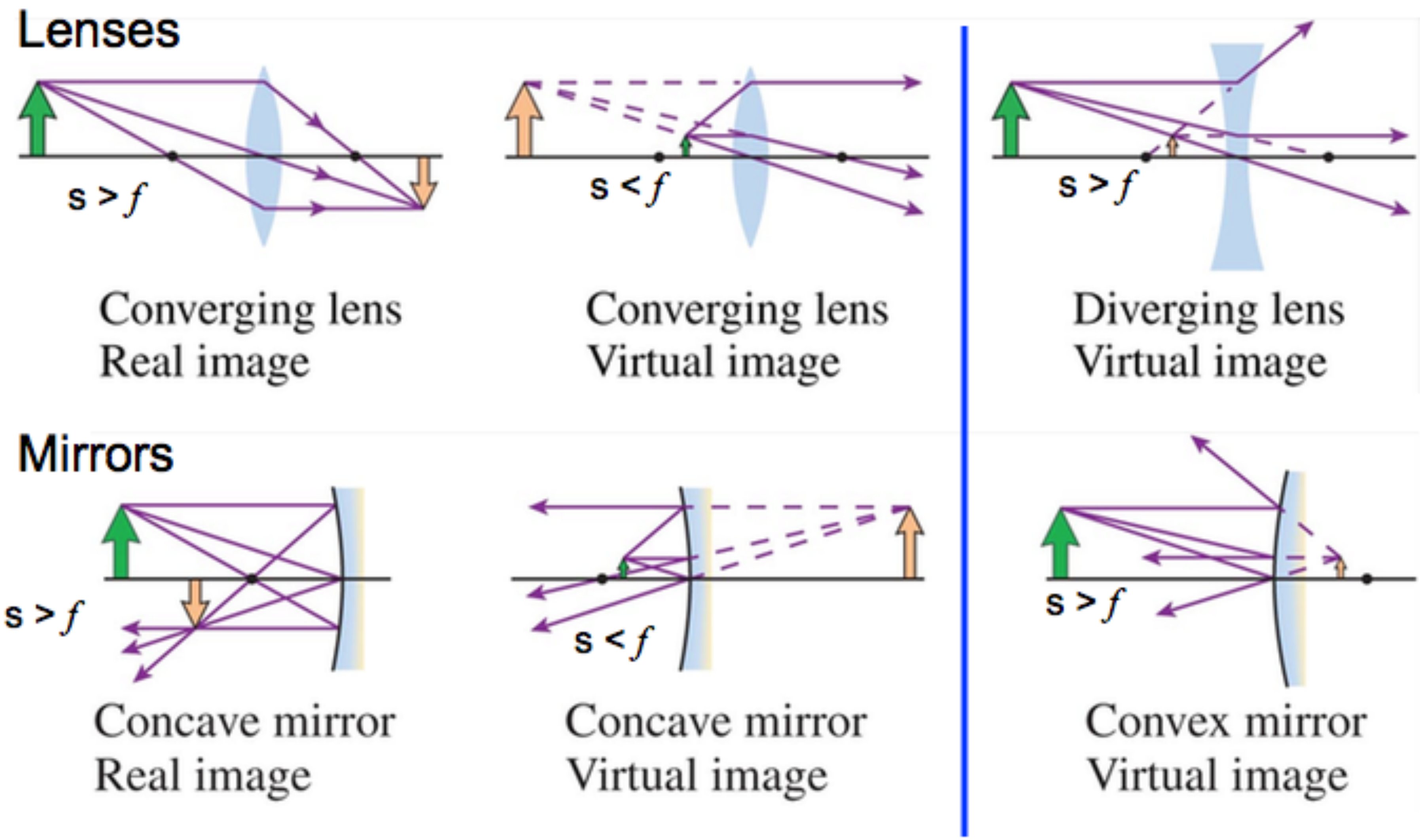
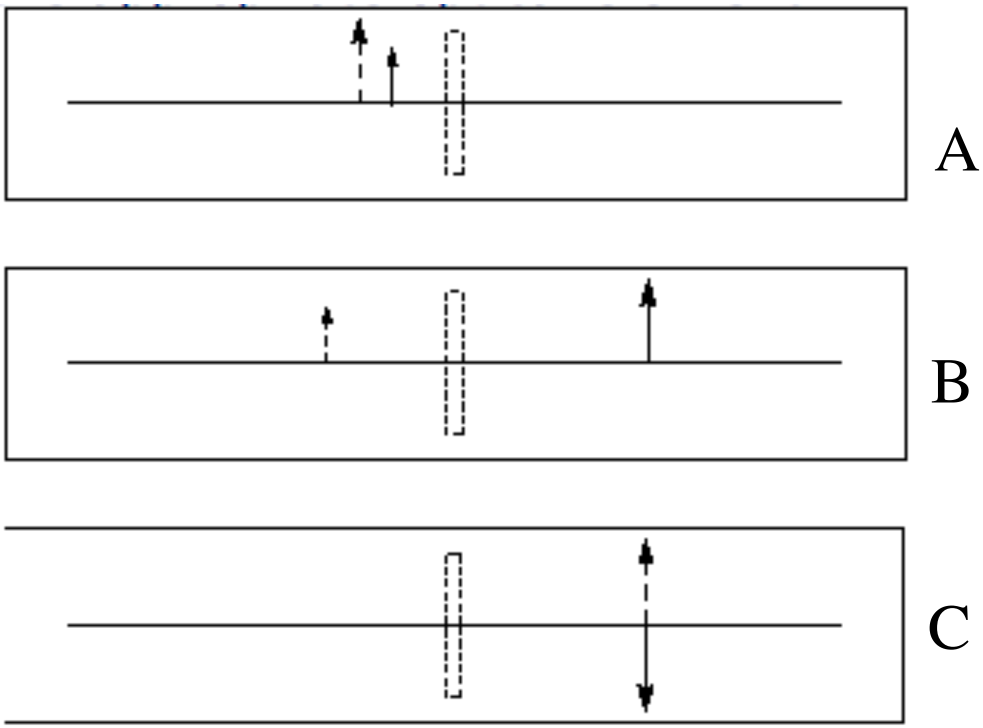


Image primer

Orientation	*Side*	*Size*	
Upright (same direction as object) **Virtual image**	Same	Smaller	→diverging lens
		Equal	→window glass
		Larger	→converging lens
	Opposite	Smaller	→convex mirror
		Equal	→plane mirror
		Larger	→concave mirror
Inverted (opposite direction as object) **Real image**	Same	Smaller	
		Equal	concave mirror
		Larger	
	Opposite	Smaller	
		Equal	converging lens
		Larger	

Whose optical element is it anyway?

- The solid arrow represents the object, the dashed arrow the image
- What optical element is present?



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- The solid arrow represents the object, the dashed arrow the image
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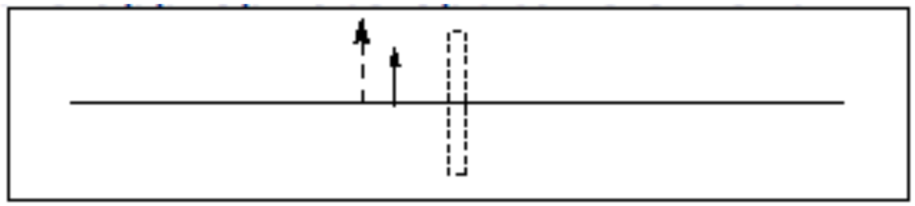
- A) image is upright, magnified, same side as object
  - converging lens



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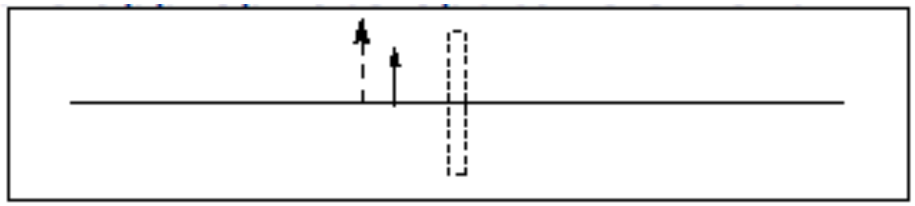
Inverted (opposite direction as object) **Real image**	Same	Smaller	} concave mirror
		Equal	
		Larger	
	Opposite	Smaller	} converging lens
		Equal	
		Larger	

Whose optical element is it anyway?

- The solid arrow represents the object, the dashed arrow the image
- What optical element is present?
- A) image is upright, magnified, same side as object
  - converging lens
- B) image is upright, opposite side as object, smaller than object
  - convex mirror



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  - converging lens
- B) image is upright, opposite si as object, smaller than object
  - convex mirror
- C) image is inverted, same side as object, same size as object
  - concave mirror

Orientation	*Side*	*Size*	
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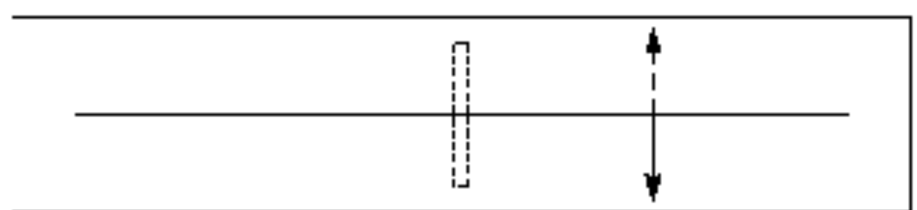
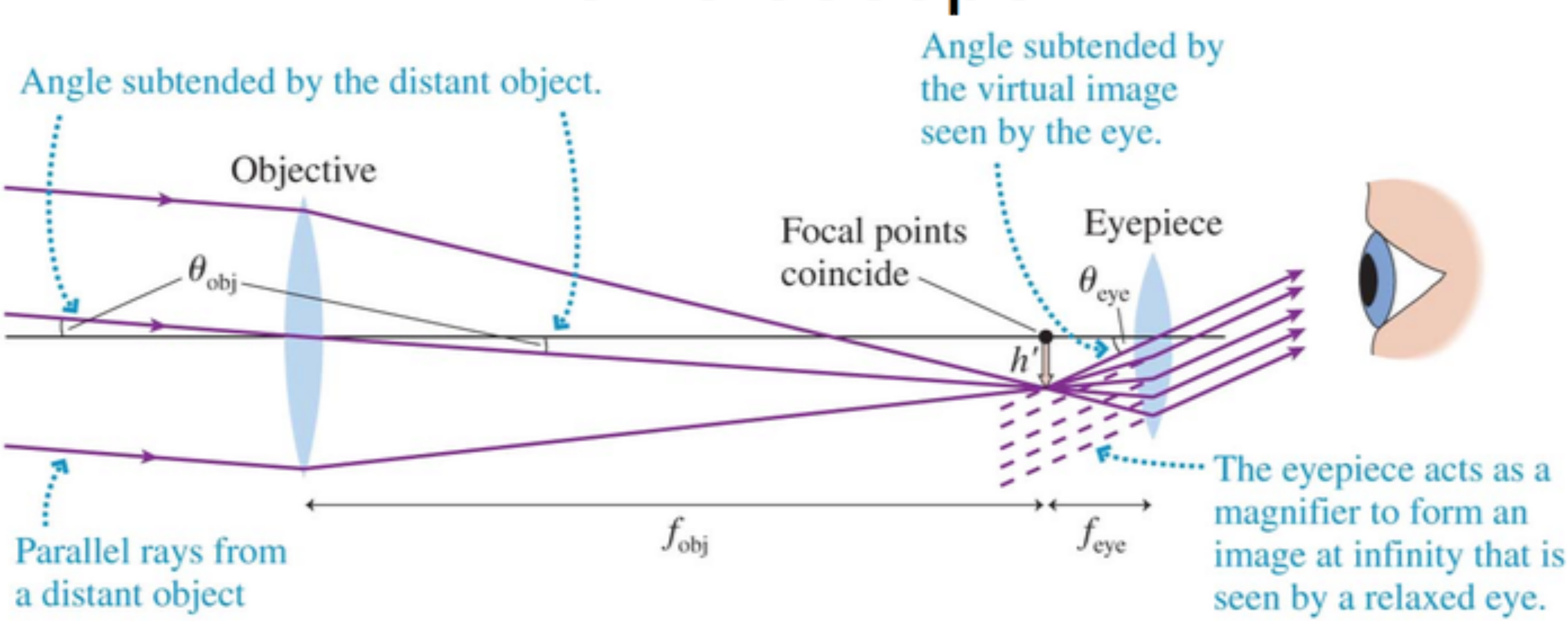


Telescope



$$\tan\theta_{obj} \approx \theta_{obj} = -\frac{h'}{f_{obj}}$$

$$\tan\theta_{eye} \approx \theta_{eye} = \frac{h'}{f_{eye}}$$

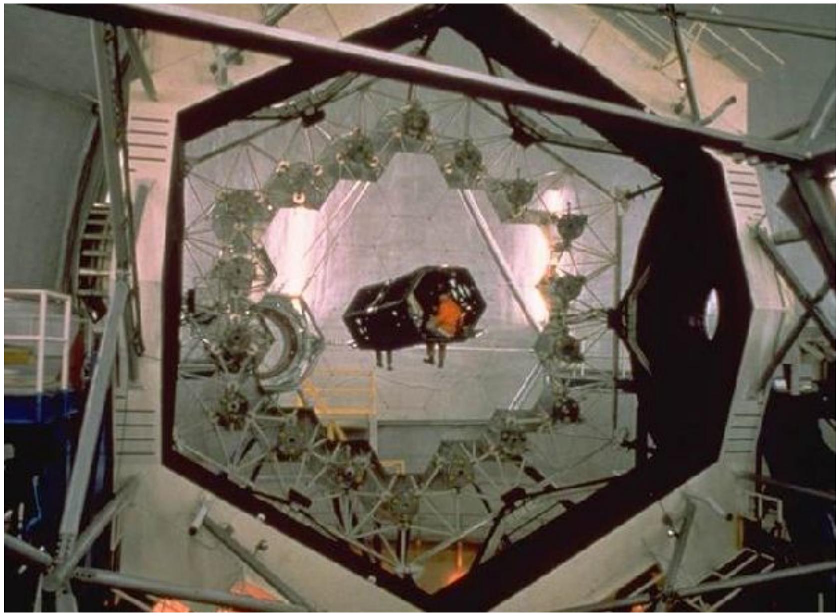
$$M = \frac{\theta_{eye}}{\theta_{obj}} = -\frac{f_{obj}}{f_{eye}}$$

Minus sign indicates an inverted image

A telescope uses an objective lens with a focal length ≈ the tube length (this is the reverse of the microscope which uses a very short focal length objective lens).

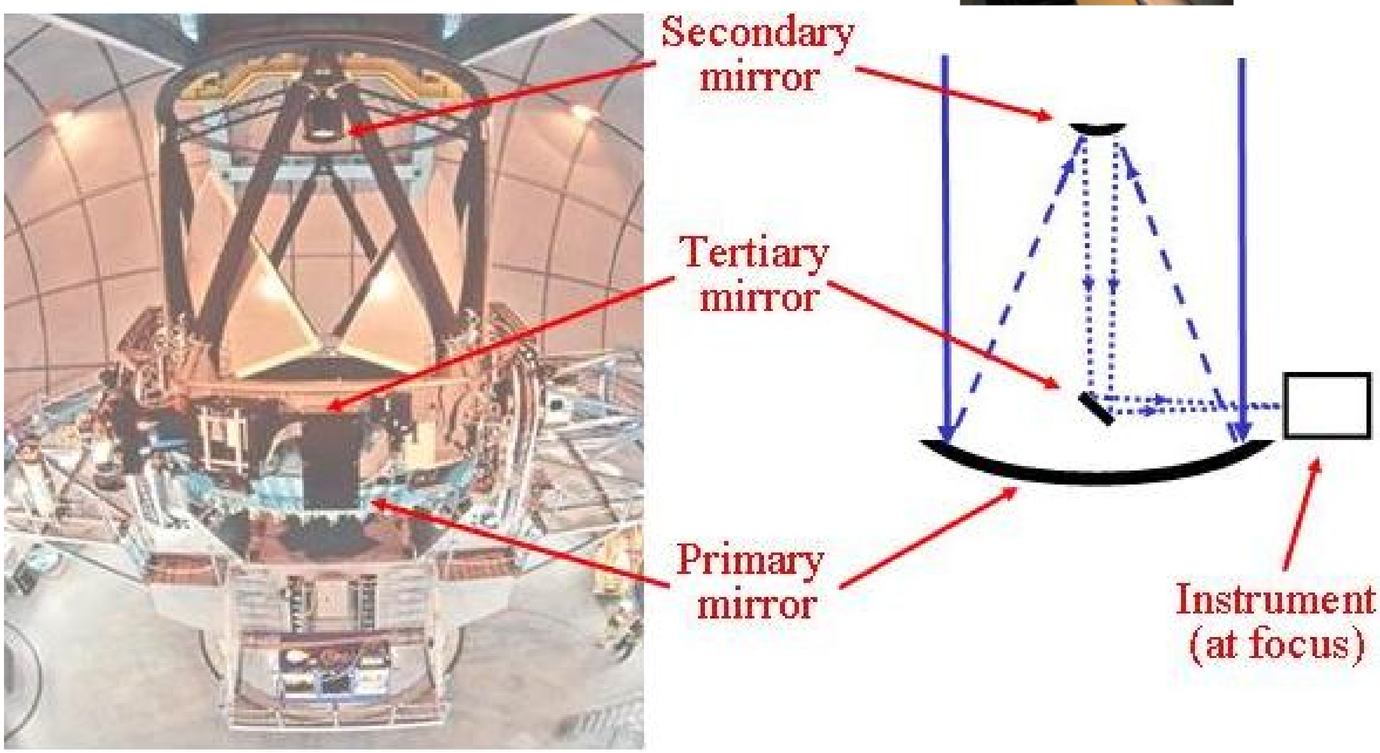
Reflecting telescopes

- Most large telescopes are reflecting telescopes
  - no chromatic aberration
  - only one surface has to have a precise polish
  - mirrors are easier to support because they can be supported from the back



Soar telescope

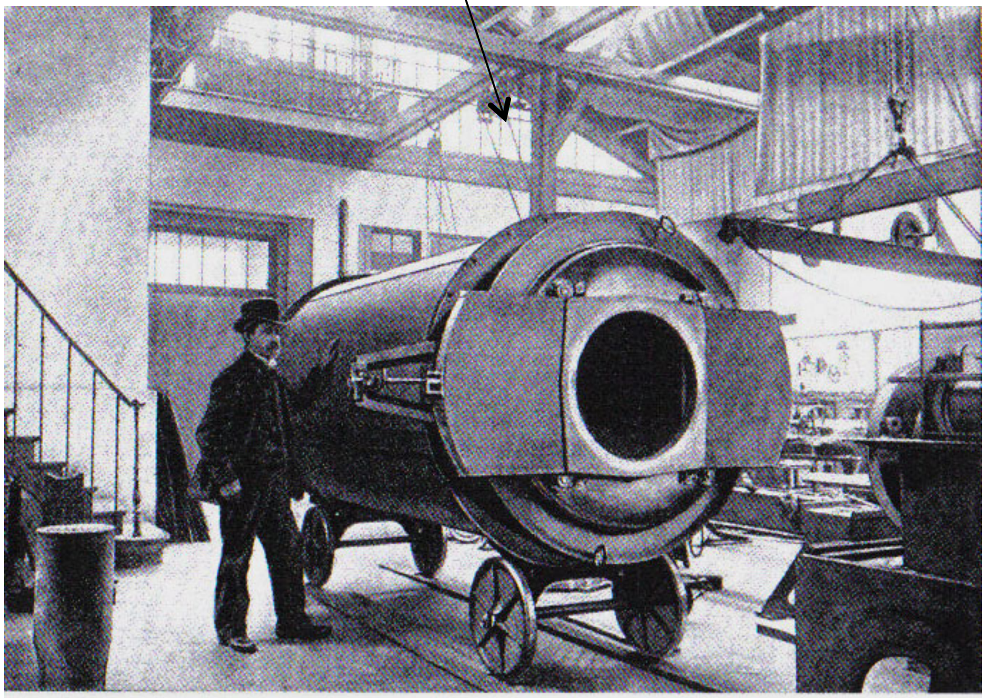
- The primary work of the astronomy group at MSU is with the SOAR telescope in Chile
  - a 4.1 m diameter mirror



Largest refracting telescope ever built

- 1.25 m diameter lens, for the Great Paris Exposition of 1900
- 60 m long
- Dismantled after the exposition

holder for eyepiece

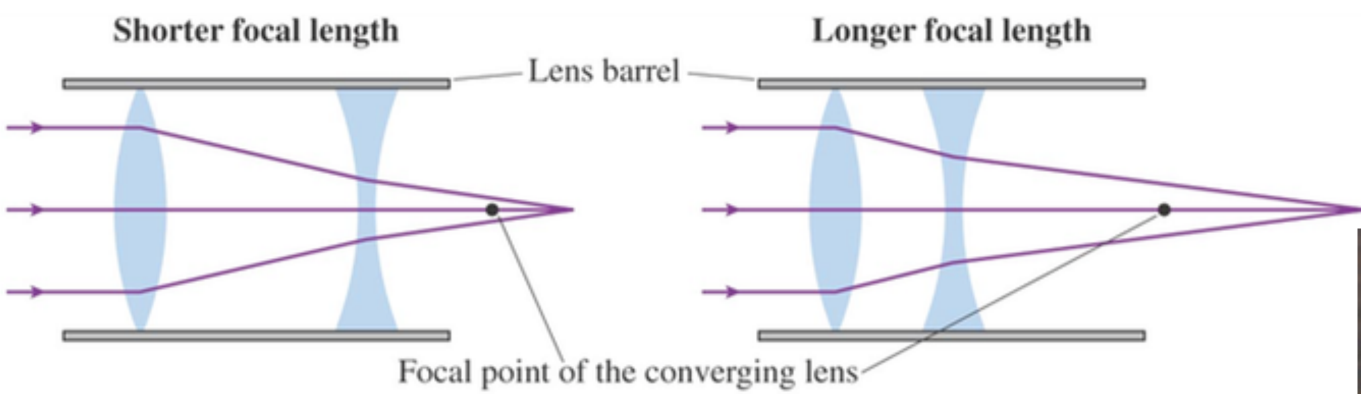


Camera

A camera "takes a picture" by using a combination of lenses to form a real, inverted image on a light-sensitive detector in a light-tight box.

A camera must focus the image and control the amount of light captured by the detector

- adjust the distance between the lens and the detector
- change the lens diameter (aperture)
- change the amount of time the shutter is open (shutter speed)



Can adjust the camera focal length by changing distances between the lenses (zooming in or out).

The light-sensitive detector used to be film. More often now is a CCD.

Lenses in combination: camera

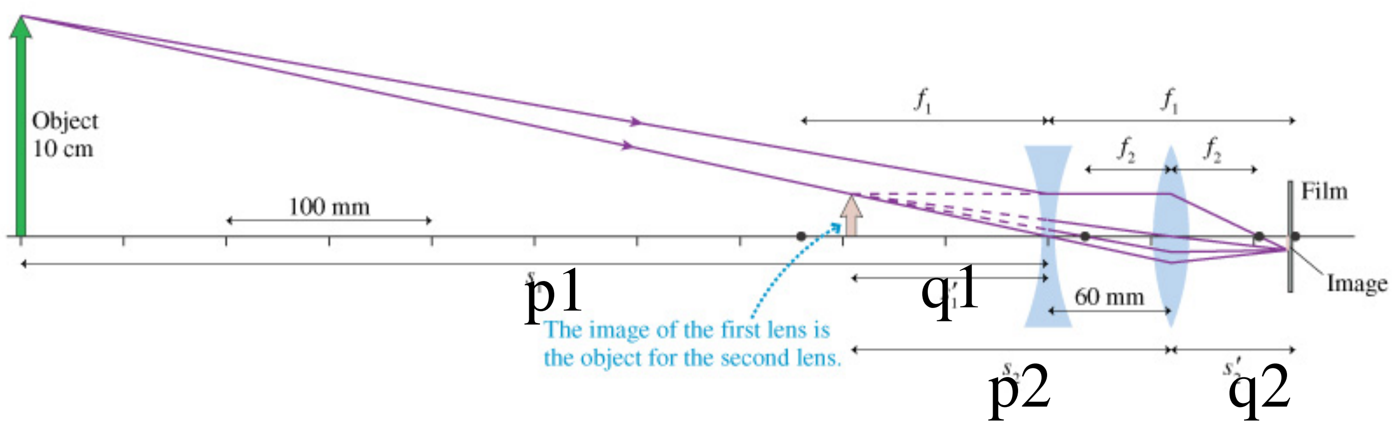
- A camera lens is most often a combination of two or more lenses
- Consider a camera lens consisting of a diverging lens with f_1=-120 cm and a converging lens with f_2=42 mm spaced 60 mm apart
- A 10 cm object is 500 mm from the first lens
- What are the location, size and orientation of the image?

- p_1=500 mm is the object distance for the first lens. Its image is a virtual image.
- Use thin lens formula

$$\frac{1}{q_1} = \frac{1}{f_1} - \frac{1}{p_1} = \frac{1}{-120mm} - \frac{1}{500mm} = -0.0103mm^{-1}$$

$$q_1 = -97mm$$

- Image of first lens is now object of 2nd lens



Lenses in combination: camera

- Object distance for 2nd lens is q_2=97 mm + 60 mm =157 mm
- Apply thin lens equation again

$$\frac{1}{q_2} = \frac{1}{f_2} - \frac{1}{p_2} = \frac{1}{42mm} - \frac{1}{157mm} = 0.0174mm^{-1}$$

$$q_2 = 57mm$$

- Image of lens is 57 mm behind the 2nd lens

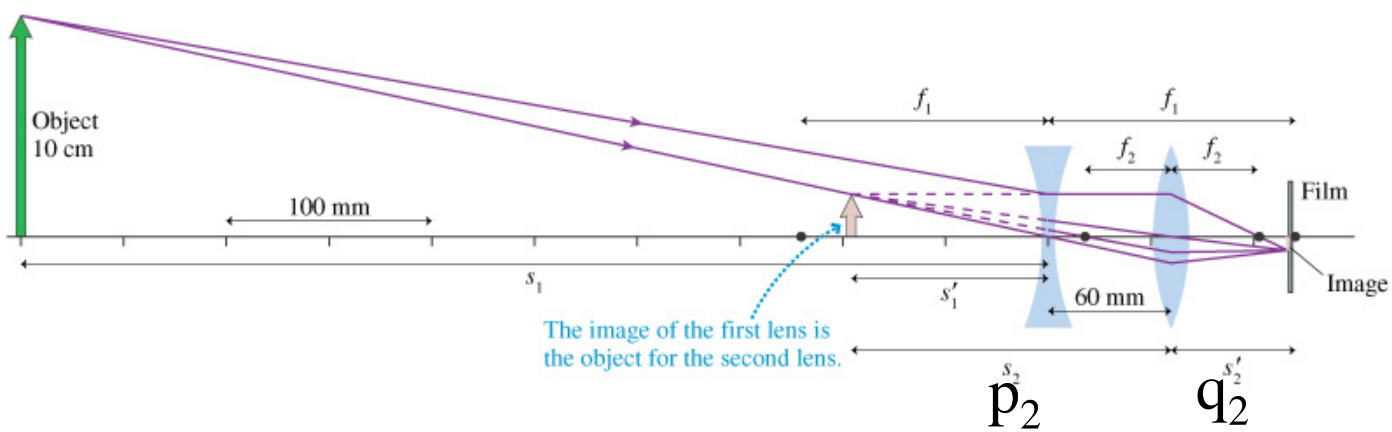
- Magnifications are

$$M_1 = \frac{-q_1}{p_1} = -\frac{-97mm}{500mm} = +0.194$$

$$M_2 = \frac{-q_2}{p_2} = -\frac{57mm}{157mm} = -0.363$$

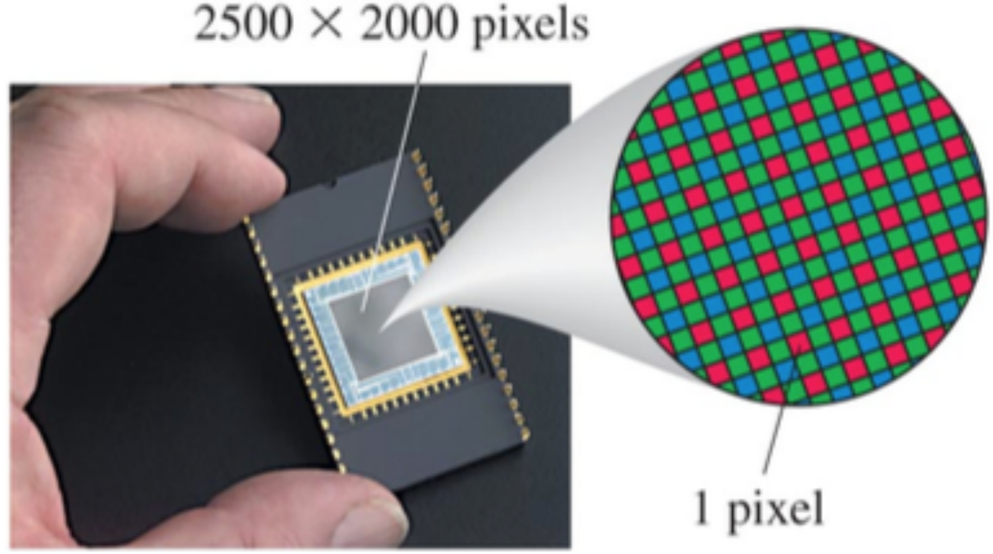
$$M = M_1 M_2 = -0.070$$

- The image is 57 mm behind the second lens, inverted and 0.70 cm tall



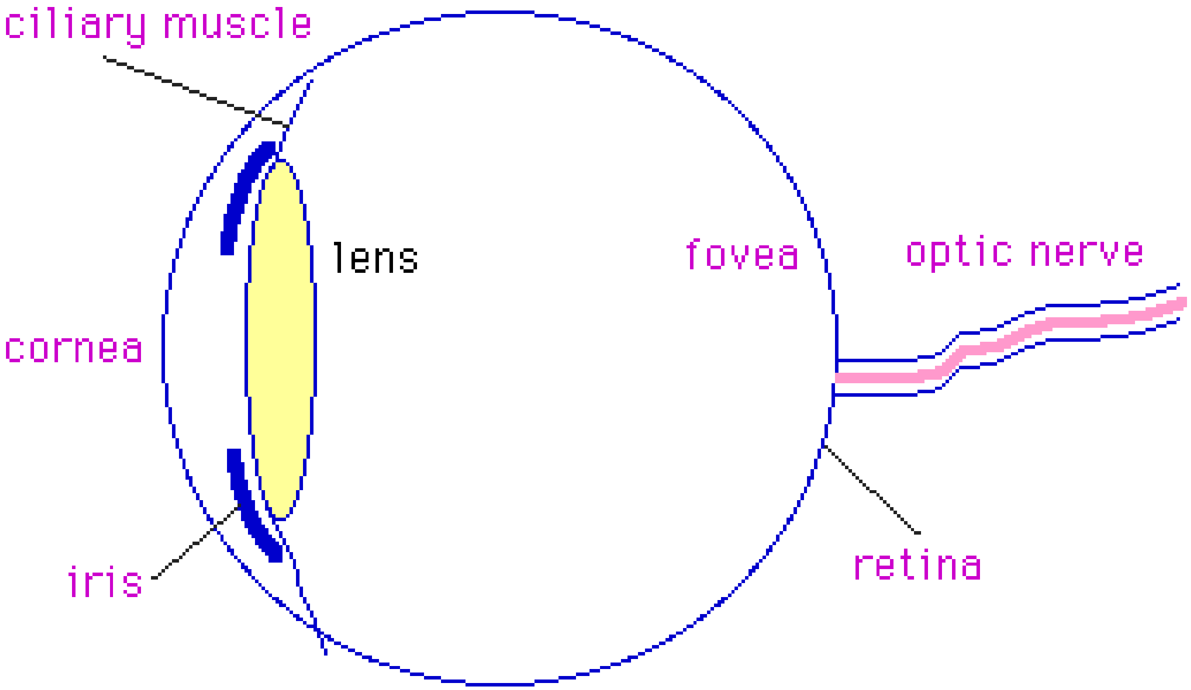
A digital image is made up of millions of *pixels*.

Use red, green or blue filters to get color information.



A CCD (charge-coupled device) chip records the digital image.

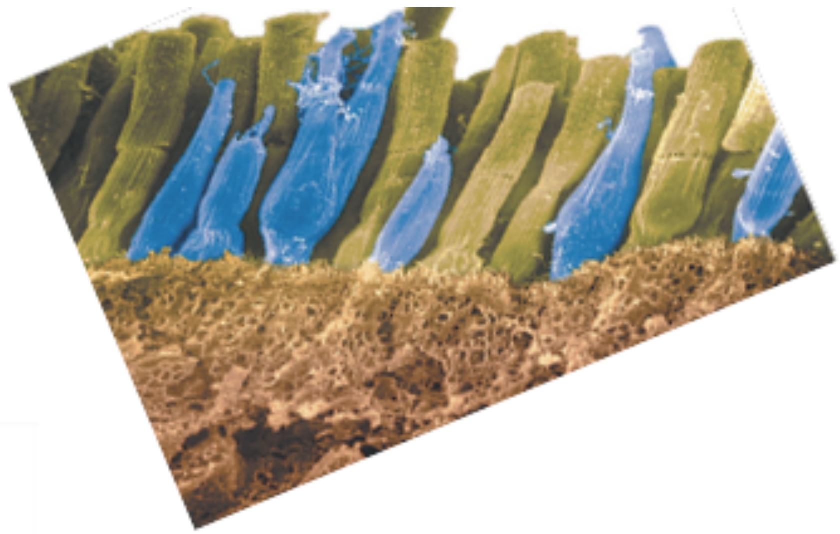
Human eye

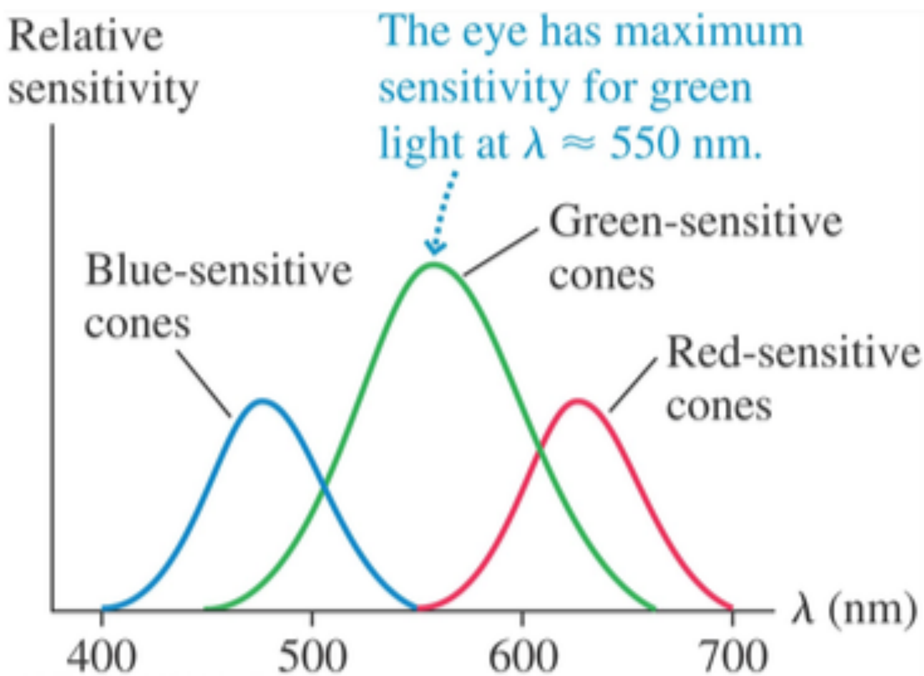


most of bending of the light occurs because the light rays are passing from air into the eyeball (n~1.33); the lens just adds the finishing touches

Retina

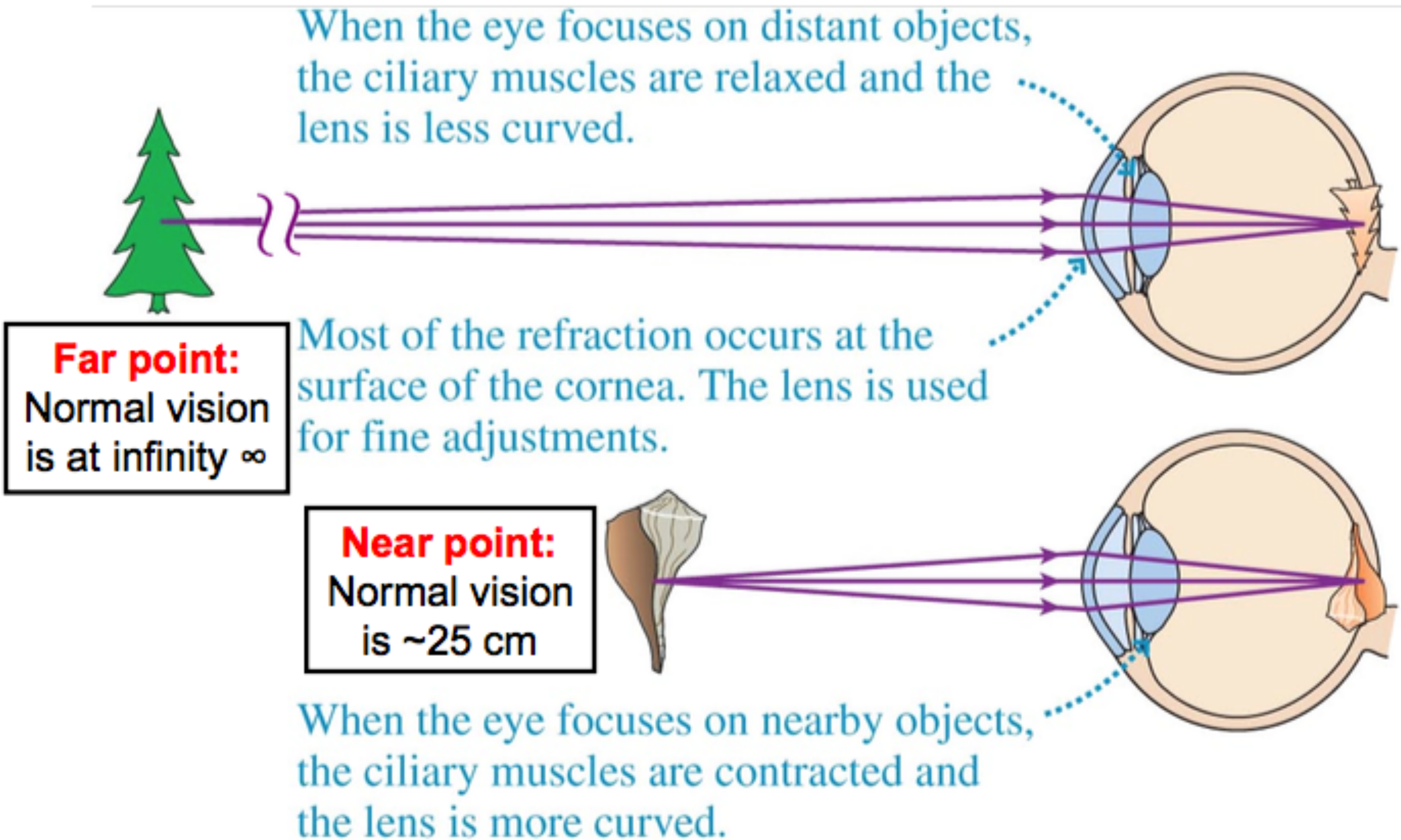
Rod cells and **Cone cells**
in a human retina



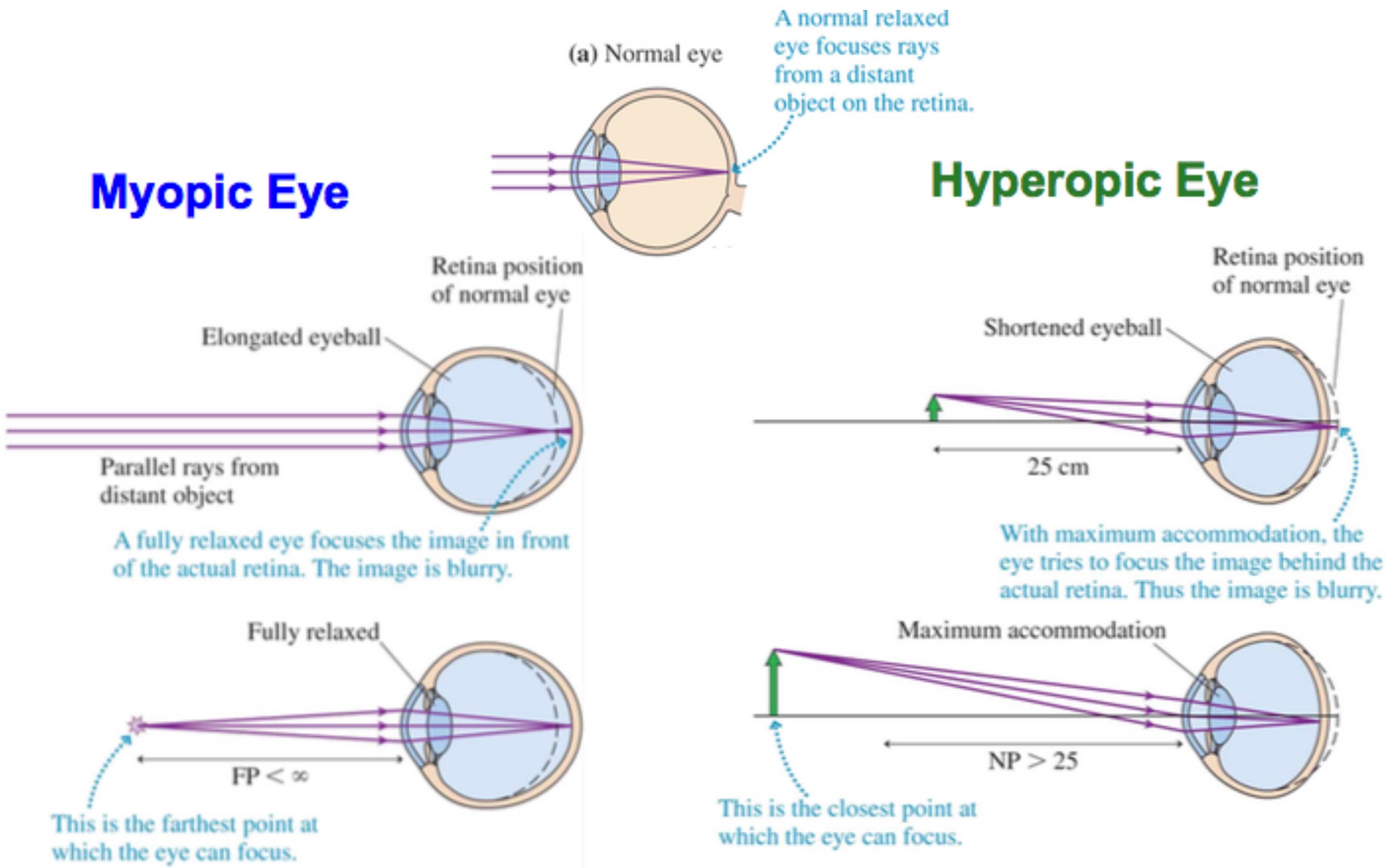


Rods are sensitive to light and dark while color vision is due to the **cones**. There are 3 types of cones and the relative response to the different cones is interpreted by your brain as light of a particular color.

Focusing


When the eye focuses on distant objects, the ciliary muscles are relaxed and the lens is less curved.
Far point:
Normal vision is at infinity ∞
Most of the refraction occurs at the surface of the cornea. The lens is used for fine adjustments.
Near point:
Normal vision is ~25 cm
When the eye focuses on nearby objects, the ciliary muscles are contracted and the lens is more curved.

Near- and far-sightedness



Thin Lens equation

- Remember this equation

$$\frac{1}{p_1}+\frac{1}{q_2}=\frac{n-1}{R_1}-\frac{n-1}{R_2}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

- Let's forget subscripts
  - p_1=p=object distance
  - q_2=q=image distance

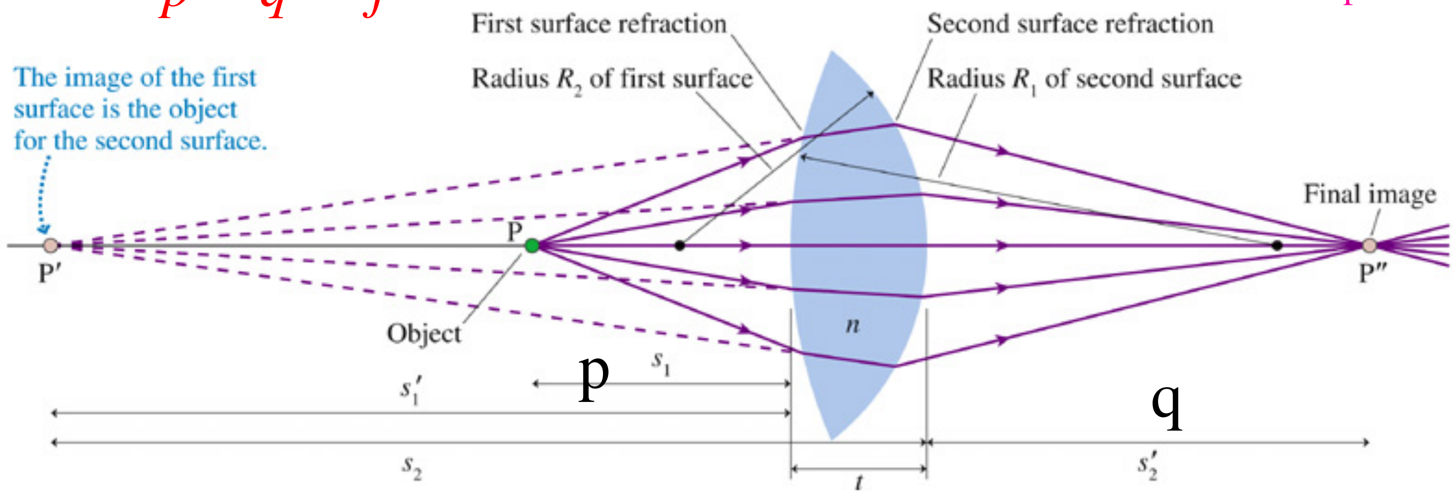
$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$

- The focal length of the lens is given by (lensmaker's equation)

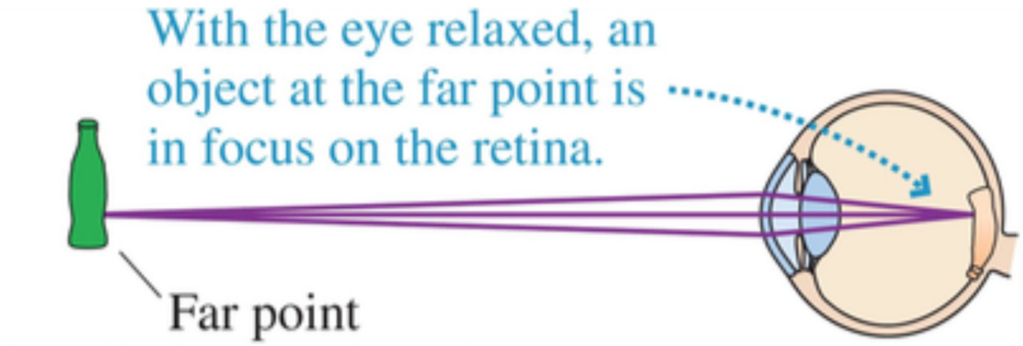
$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$P=\frac{1}{f}\longrightarrow$$ refractive power, a measure of the ability of a lens to bend rays

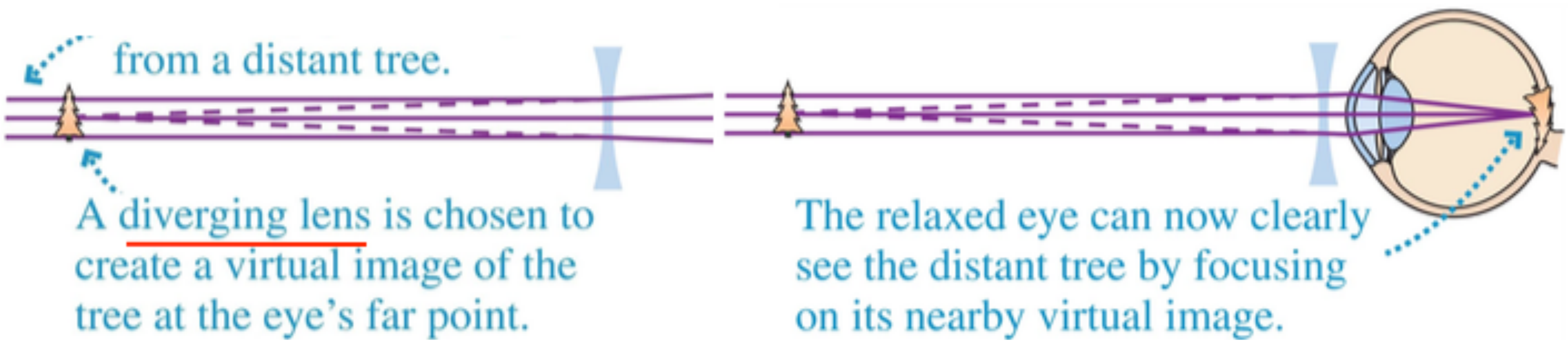
unit is diopter: 1 D = 1m^{-1}



Nearsightedness-myopia

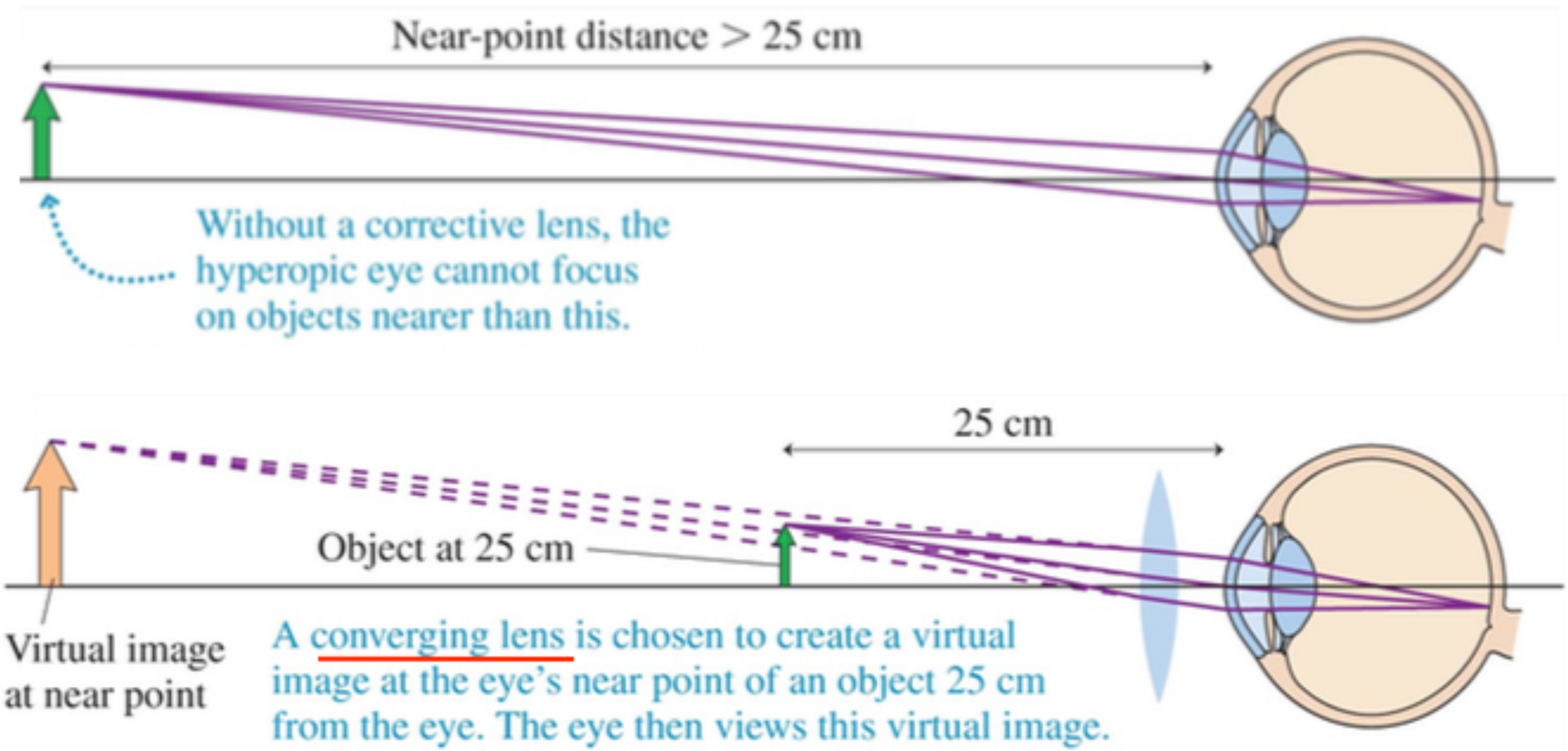


The nearsighted eye cannot focus on objects beyond their "Far point". Far point is < ∞.



object distance p=infinity; q=eye's far point (negative since it's a virtual image)
focal length f and refractive power P are both negative (since diverging lens)

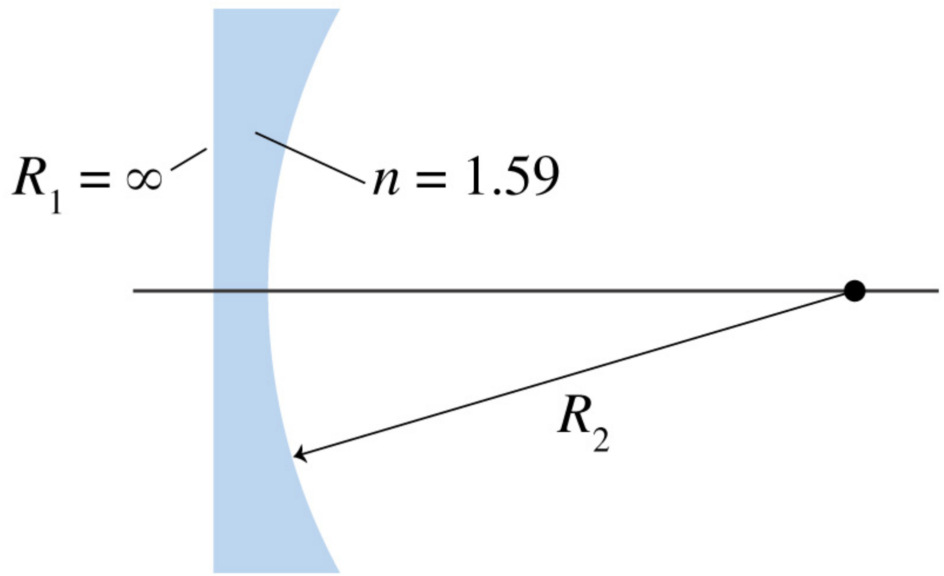
Farsightedness-hyperopia



object distance p=25 cm; image distance q = eye's near point (negative distance)
focal length f and refractive power P are both positive (converging lens)

Another example

- I want to design a lens to correct for near-sightedness (a diverging lens with a planoconcave design)
- For a focal length of -1.5 m, what is the radius of the inner surface of the lens?



use lensmaker's equation

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{R_2} = \frac{1}{R_1} - \frac{1}{(n-1)f} = 0 - \frac{1}{(1.59-1)(-1.5m)} = 1.13m^{-1}$$

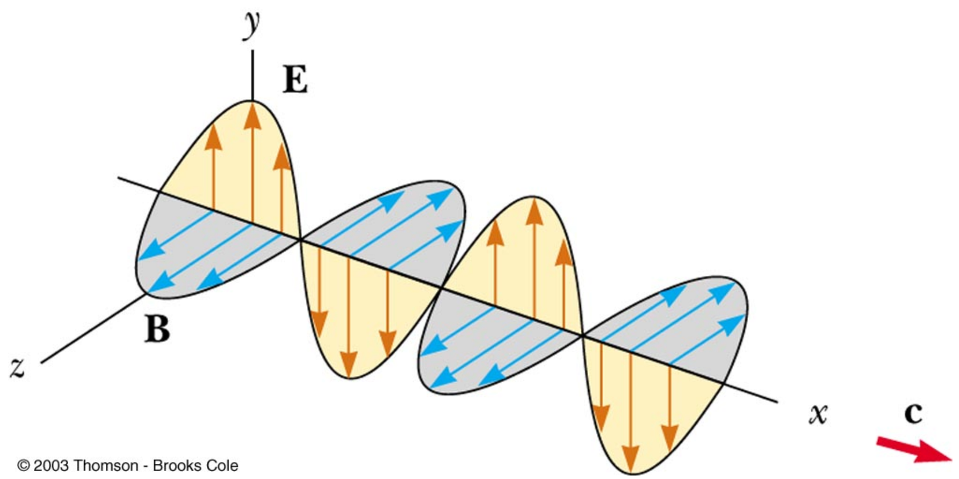
$$\boxed{R_2 = 0.885m}$$

Physical or wave optics

- In the last chapter, we have been studying geometric optics
  - light moves in straight lines ⟶
  - can summarize everything by indicating direction of light using a ray
  - light behaves essentially the way a stream of particles (photons) would
- This has worked well for a number of phenomena
  - reflection
  - refraction
- …and has helped us to understand the workings of
  - mirrors
  - thin lenses
- But our particle theory of light gives out when we try to understand phenomena like interference, diffraction and polarization
  - just doesn't work
- Have to resort to wave or physical optics (in this chapter)
  - …and treat light like a wave
- The first thing we'll look at is interference of light waves
  - not easy to observe because of the short wavelengths of light involved ($4X10^{-7}$ m to $7X10^{-7}$ m)

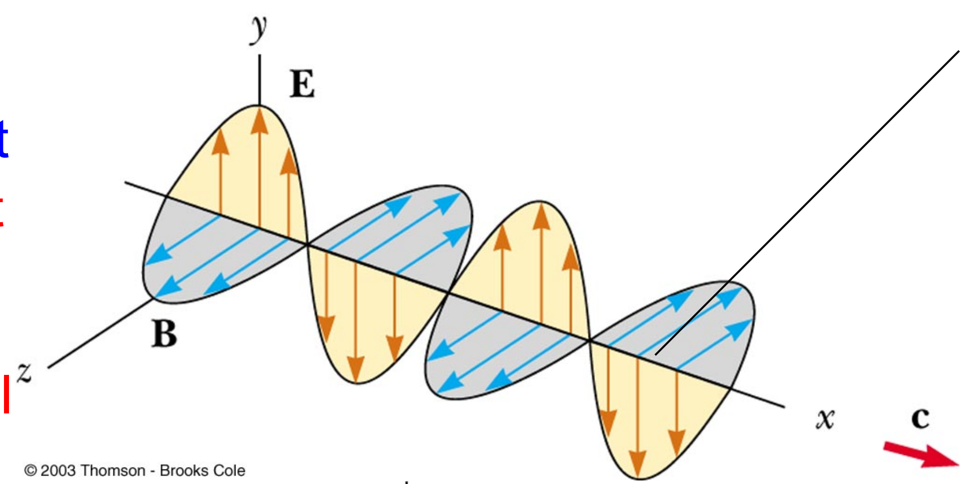
Electromagnetic waves

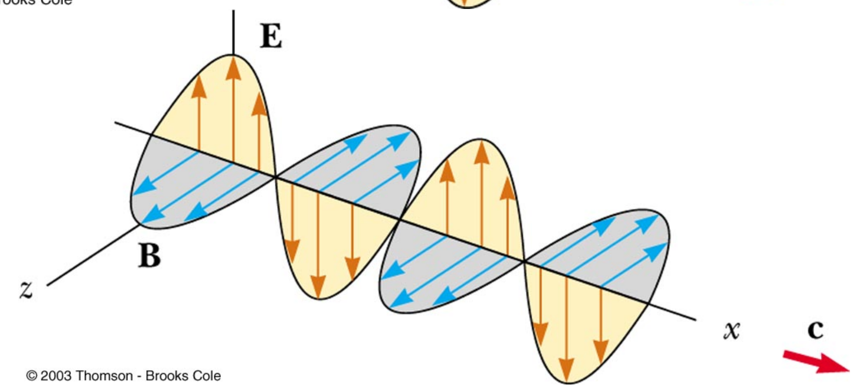
- Now we' re back to thinking of light as specifically being an electromagnetic wave
  - oscillating electric and magnetic fields perpendicular to each other propagating through space
  - equal amounts of energy stored in the electric field and in the magnetic field
  - in interactions with matter, it' s the electric component that does most of the work

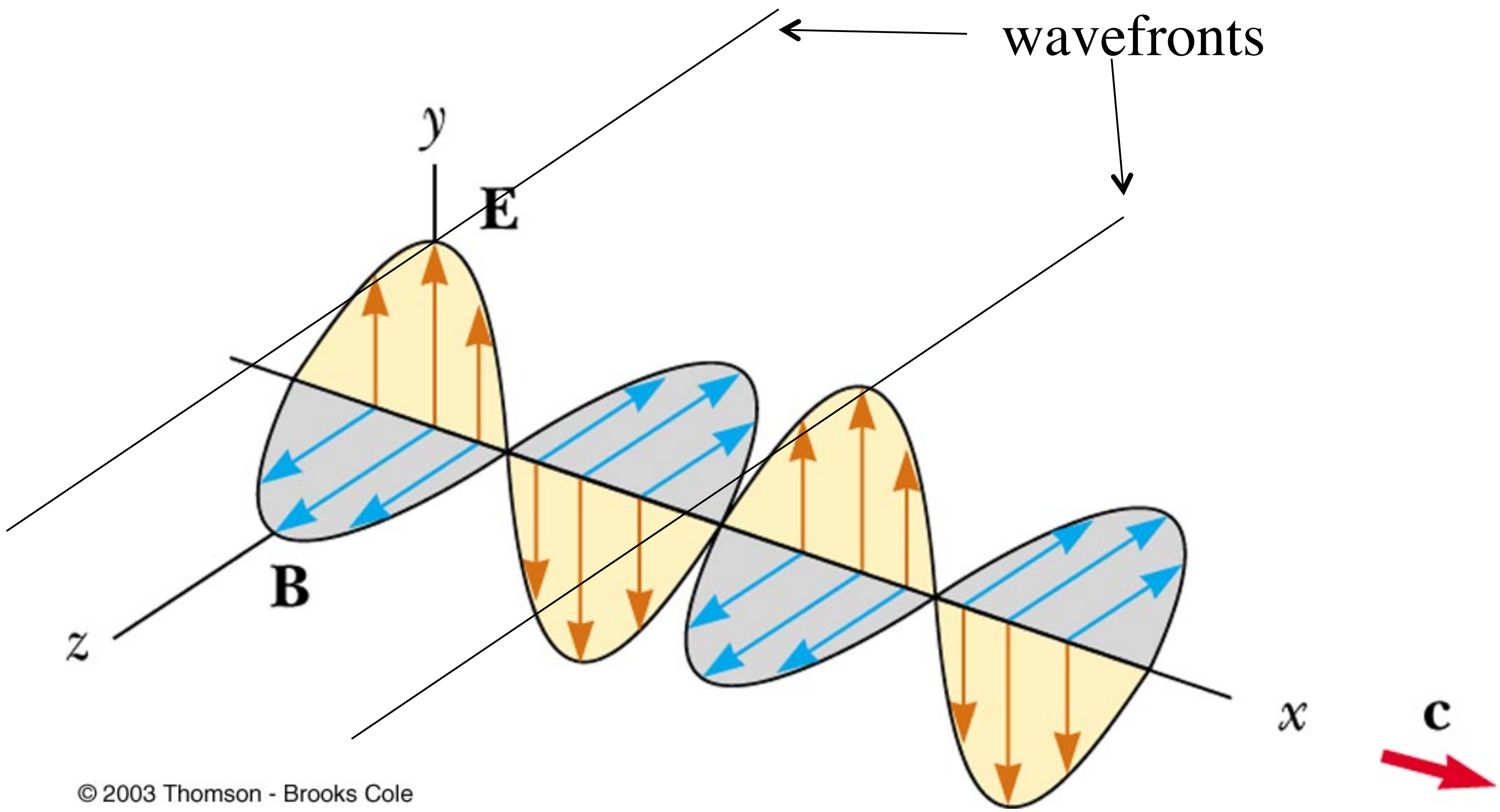


Young's Experiment

- In order to observe interference of 2 light waves, need to have 2 things present
  - sources must be coherent (same phase with respect to each other)
  - waves must have identical wavelength
- Laser produces coherent light which can be split into two light beam which then can interfere with each other
- But the first interference experiment was carried out in 1801
  - …no lasers then
  - so they had to be smart






wavefronts
y
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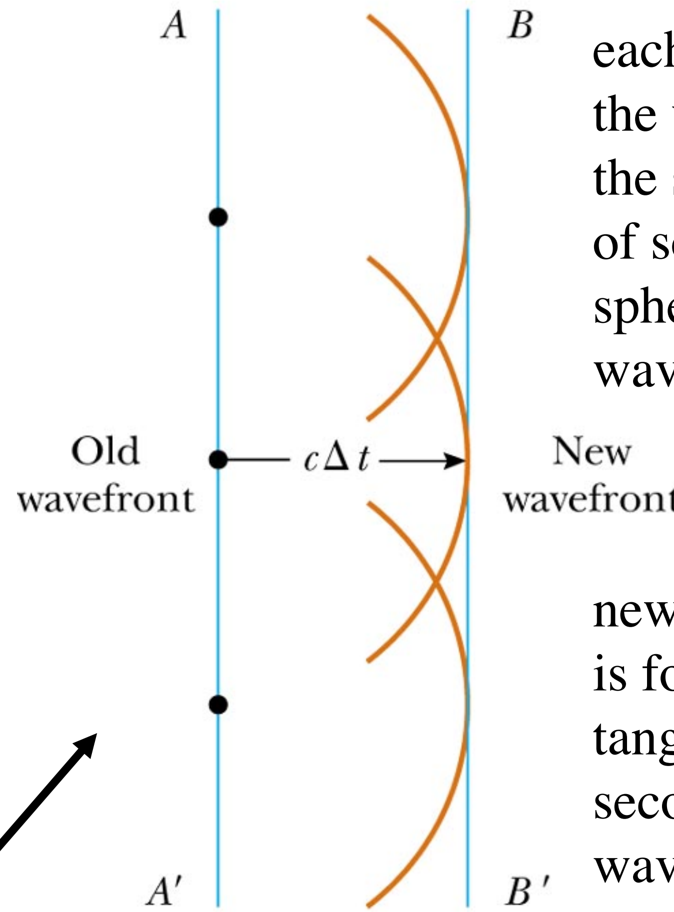
But first: Huygen’s principle

- This is Christian Huygens

Christian Huygens was a Dutch physicist and astronomer who lived between 1629-1695. He found new methods for grinding and polishing lenses,making telescopes more powerful. Using a telescope he had made, Huygens first identified Saturn’s rings and one of Saturn’s moons. Huygens also invented the pendulum clock, increasing the accuracy of timekeeping, and proposed the wave theory of light.



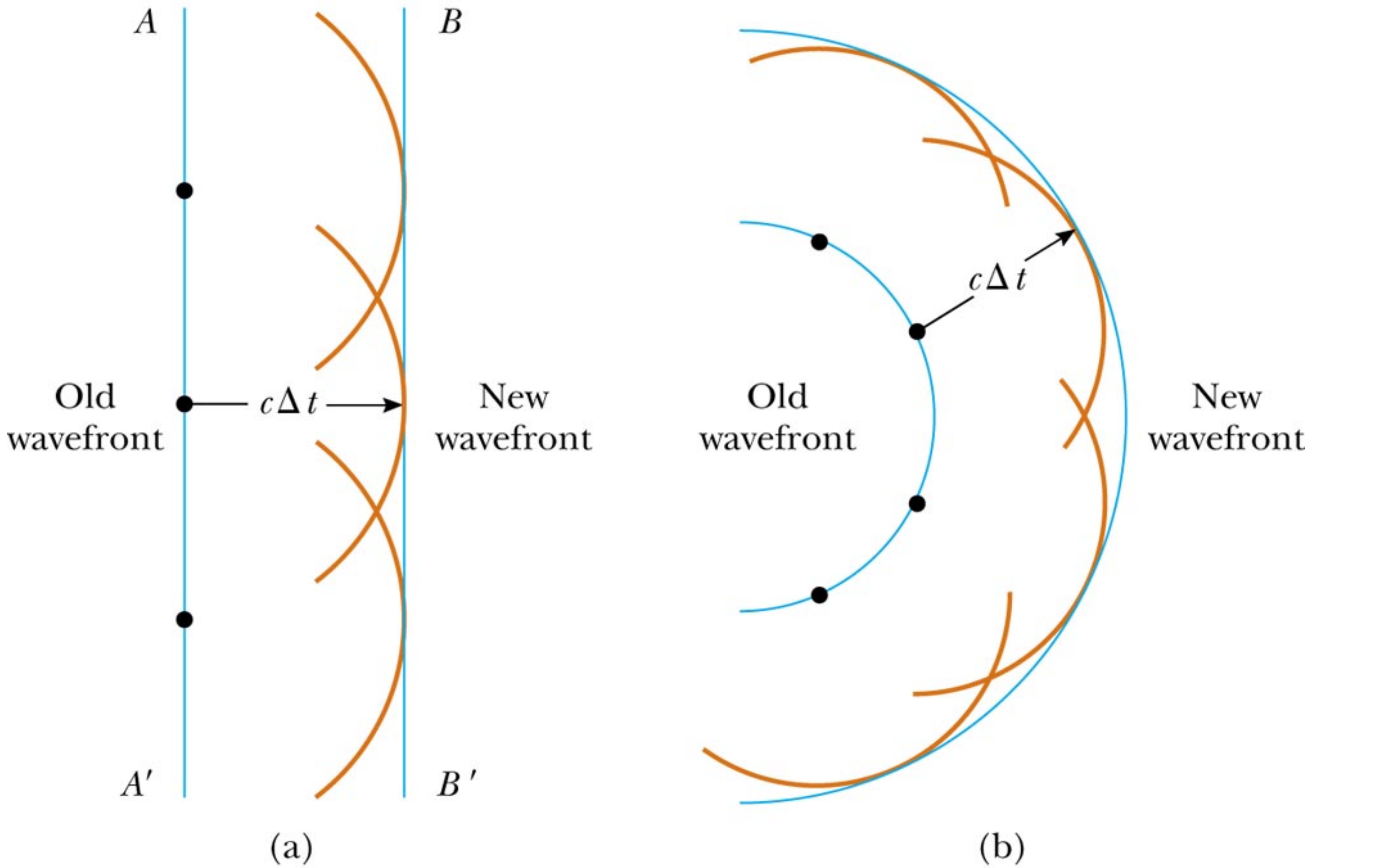
(a)

This is his principle.

each point on the wavefront is the source of secondary spherical wavelets

new wavefront is formed from tangent to secondary wavelets

Huygen’s principle



A nice laboratory for Huygen's principle

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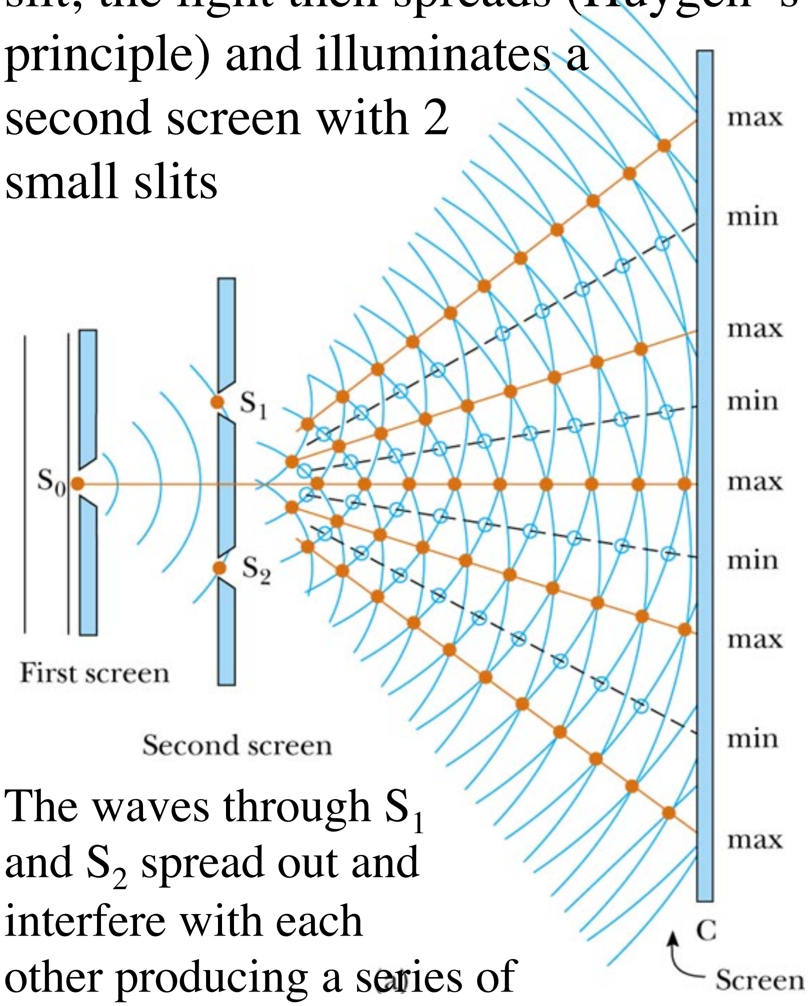
Sunlight shines through a narrow slit; the light then spreads (Huygen's principle) and illuminates a second screen with 2 small slits



The waves through S_1 and S_2 spread out and interfere with each other producing a series of bright and dark *fringes*