Hubble Space Telescope

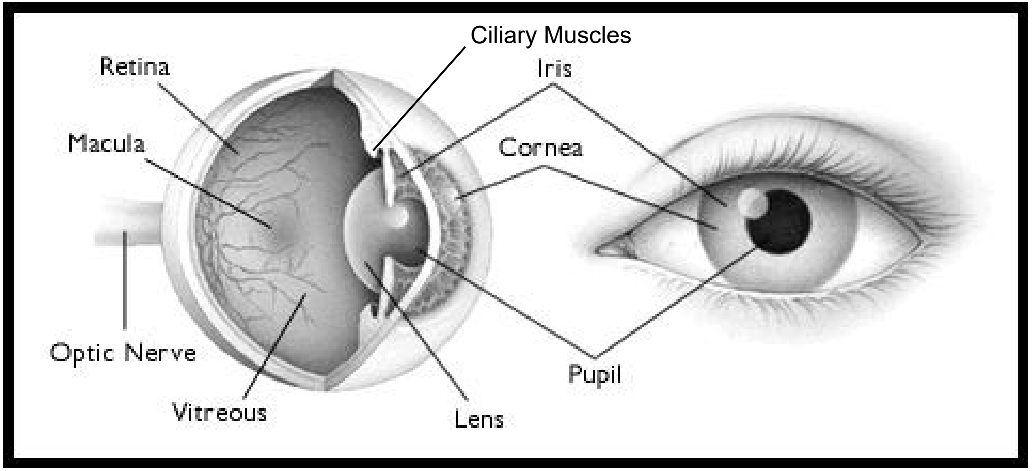
Aperture of primary mirror: 2.4 m
Mass of primary mirror: 828 kg

Before COSTAR

After COSTAR

Amazing Eye(神奇的眼睛)

- One of first organs to develop.
- 100 million Receptors 4 million
  - 200,000 /mm^2 2,500 /mm^2
  - Sensitive to single photon!
- Candle from 12 miles



ACT: Focusing and the Eye

Cornea(角膜) n= 1.38

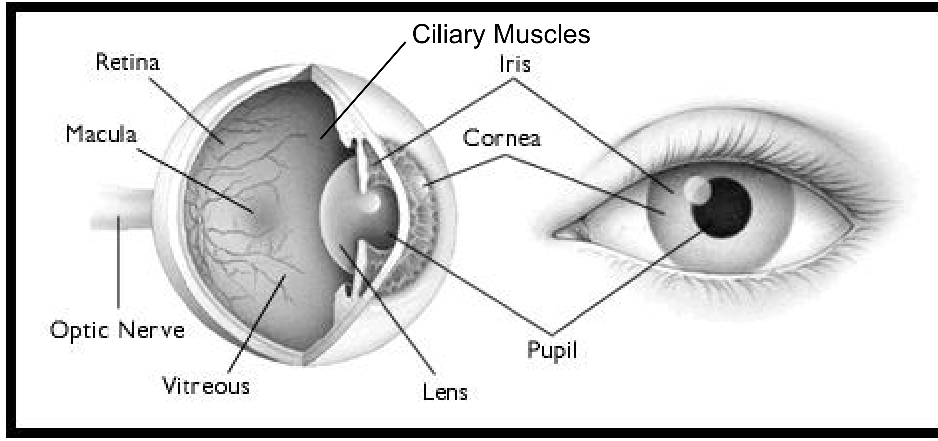
Lens(晶状体) n = 1.4

Vitreous(玻璃体) n = 1.33

Retina(视网膜)

Cones(园锤细胞)

Pupil(瞳孔)



Which part of the eye does most of the light bending?

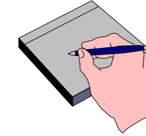
1) Lens 2) Cornea 3) Retina 4) Cones

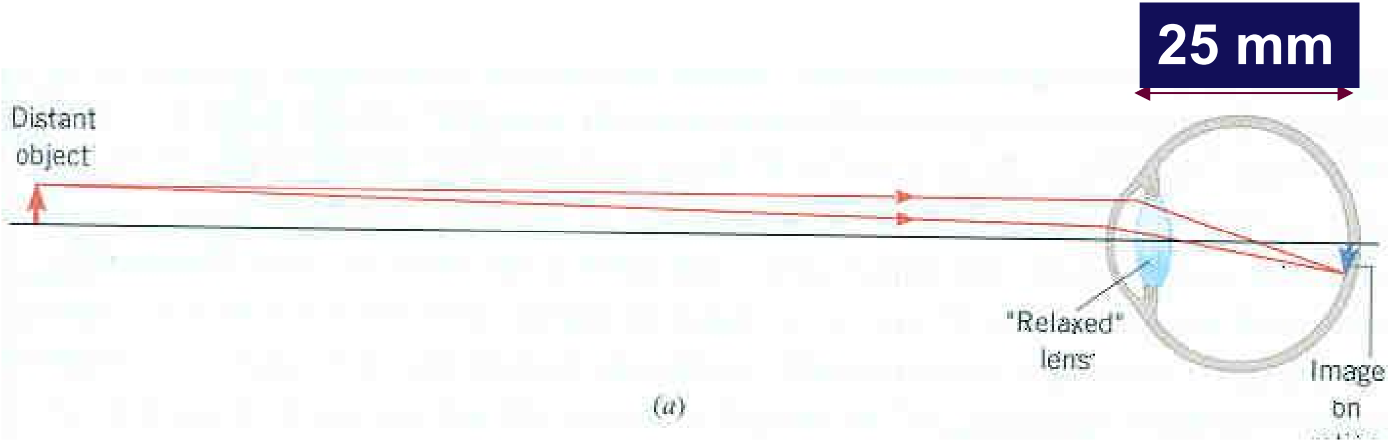
Lens and cornea have similar shape, and index of refraction. Cornea has air/cornea interface 1.38/1, 70% of bending. Lens has Lens/Vitreous interface 1.4/1.33. Lens is important because it can change shape.

Laser eye surgery changes Cornea

Example

Eye (Relaxed)





Determine the focal length of your eye when looking at an object far away.

Object is far away: $d_o = \infty$

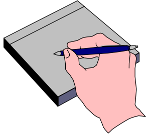
$$\frac{1}{\infty} + \frac{1}{25\text{ mm}} = \frac{1}{f}$$

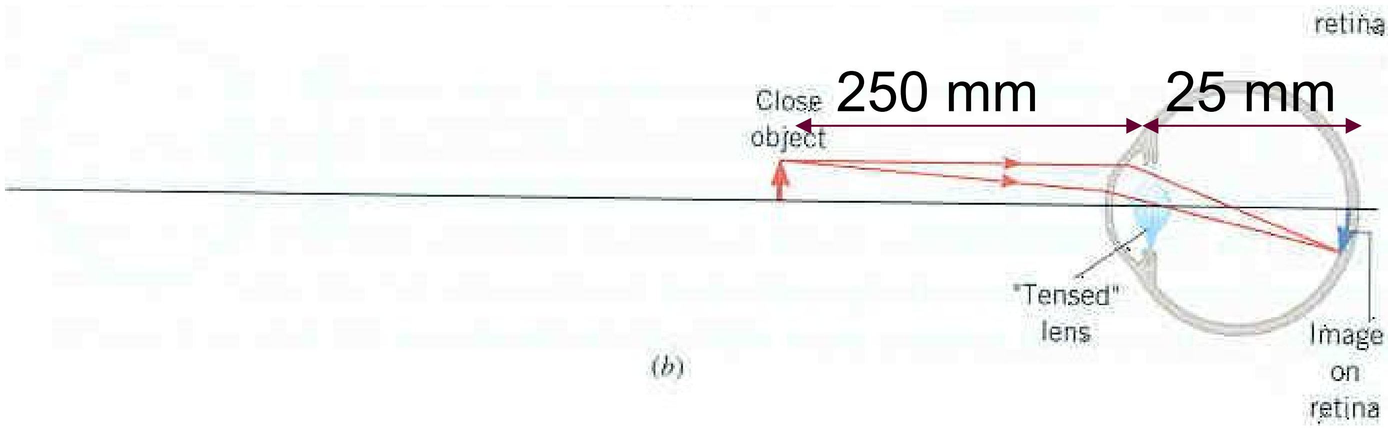
Want image at retina: $d_i = 25mm$

$$f_{relaxed} = 25\text{ mm}$$

Example

Eye (Tensed)





Determine the focal length of your eye when looking at an object up close (25 cm).

$$f = f' = \frac{1}{(n_L - 1)(\frac{1}{r_1} - \frac{1}{r_2})}$$

Object is up close:

$$d_o = 25cm = 250mm$$

Want image at retina:

$$d_i = 25mm$$

$$\frac{1}{250\text{ mm}} + \frac{1}{25\text{ mm}} = \frac{1}{f}$$

$$f_{tense} = 22.7\text{ mm}$$

$$f_{relaxed} = 25\text{ mm}$$

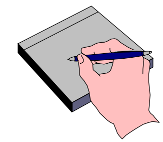
Near Point, Far Point

- Eye's lens changes shape (changes *f*)
  - Object at any d_o can have image be at retina (d_i = approx. 25 mm)
- Can only change shape so much
- "Near Point"
  - Closest d_o where image can be at retina
  - Normally, ~25 cm (if far-sighted then further)
- "Far Point"
  - Furthest d_o where image can be at retina
  - Normally, infinity (if near-sighted then closer)

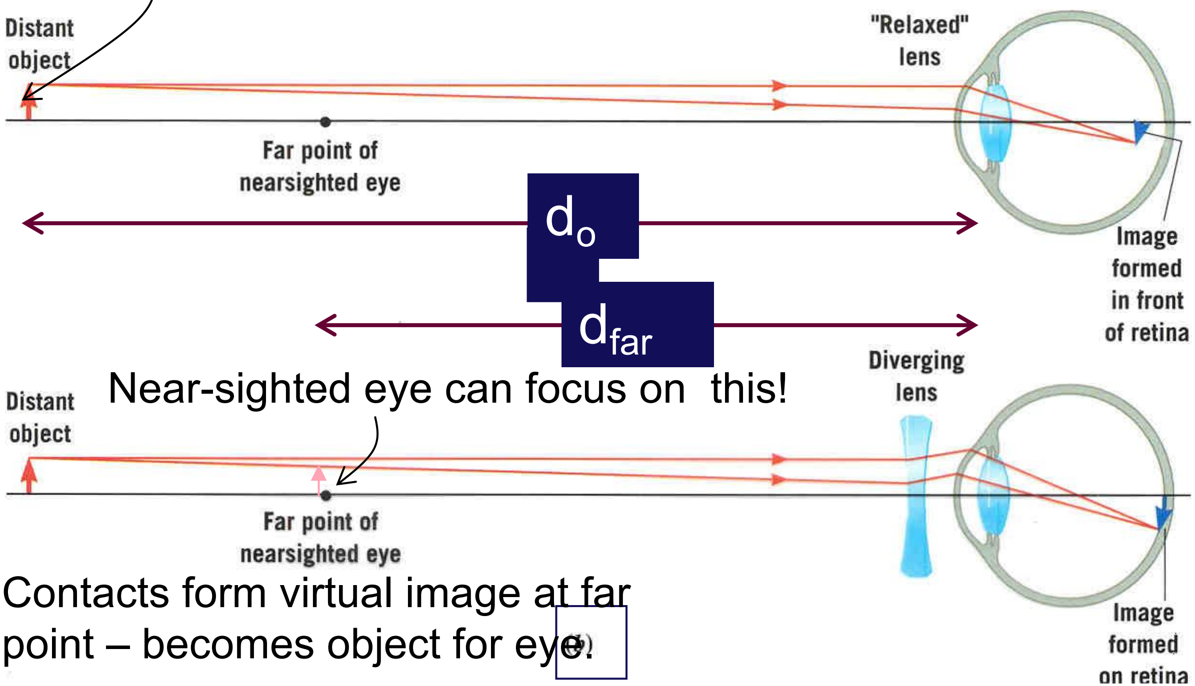
If you are nearsighted(近视眼)...

(far point is too close)

Example



Too far for near-sighted eye to focus



Near-sighted eye can focus on this!

Contacts form virtual image at far point – becomes object for eye!

$$\frac{1}{d_o} + \frac{1}{-d_{far}} = \frac{1}{f_{lens}}$$

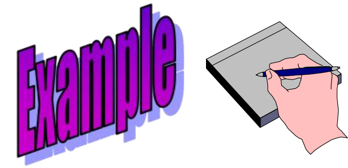
$$\frac{1}{\infty} + \frac{1}{-d_{far}} = \frac{1}{f_{lens}}$$

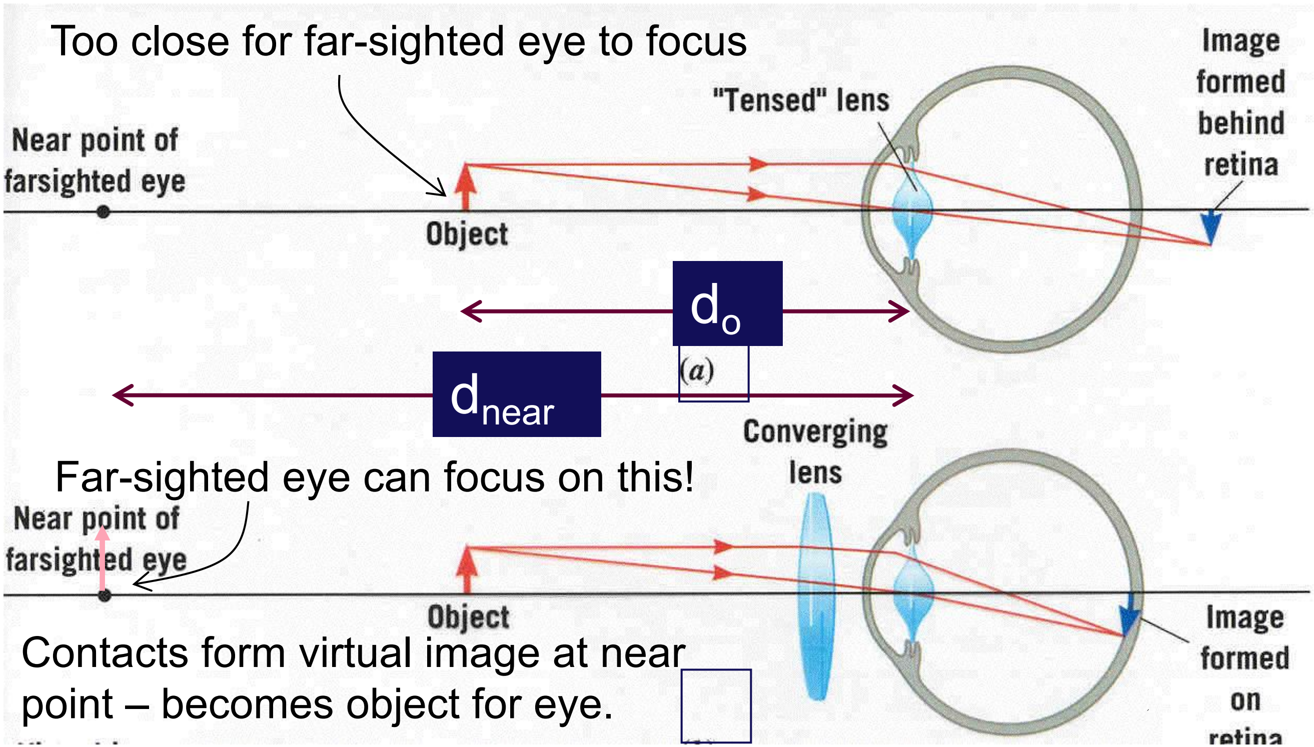
$$f_{lens} = -d_{far}$$

Want to have (virtual) image of distant object, $d_o = \infty$, at the far point, $d_i = -d_{far}$.

If you are farsighted(远视,老花)...

(near point is too far)





$$\frac{1}{d_o} + \frac{1}{-d_{near}} = \frac{1}{f_{lens}}$$

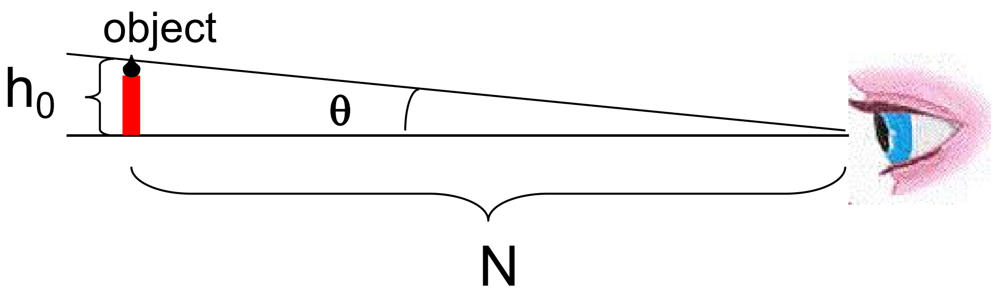
When object is at d_o, lens must create an (virtual) image at $-d_{near}$.

$$\frac{1}{25\text{ cm}} + \frac{1}{-50\text{ cm}} = \frac{1}{f}$$

$$f = 50\text{ cm}$$

Unaided Eye (裸眼)

How big the object looks with unaided eye.

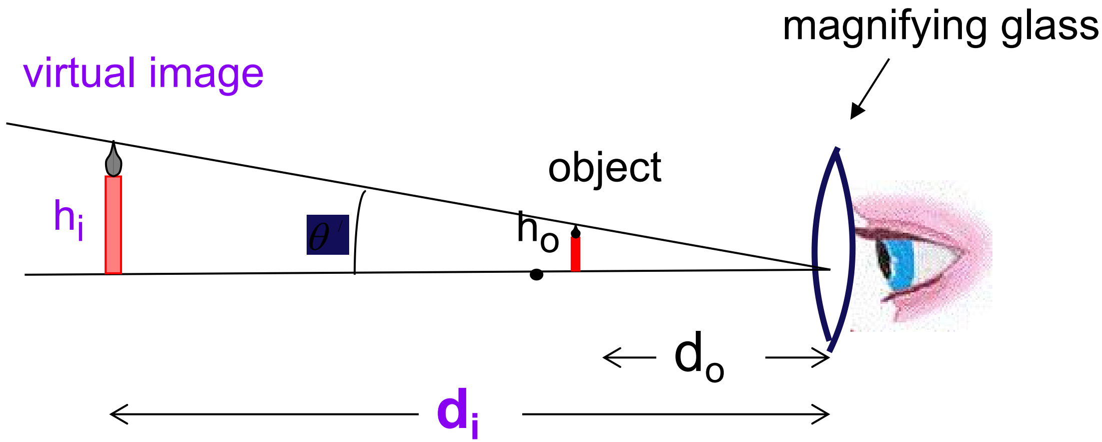


Bring object as close as possible (to near point N)

$$\tan(\theta) = \frac{h_o}{N} \quad \longrightarrow \quad \boxed{\theta \approx \frac{h_o}{N}}$$

**If θ is small and expressed in radians.

Magnifying Glass



Magnifying glass produces virtual image behind object, allowing you to bring object to a closer d_o: and larger θ'

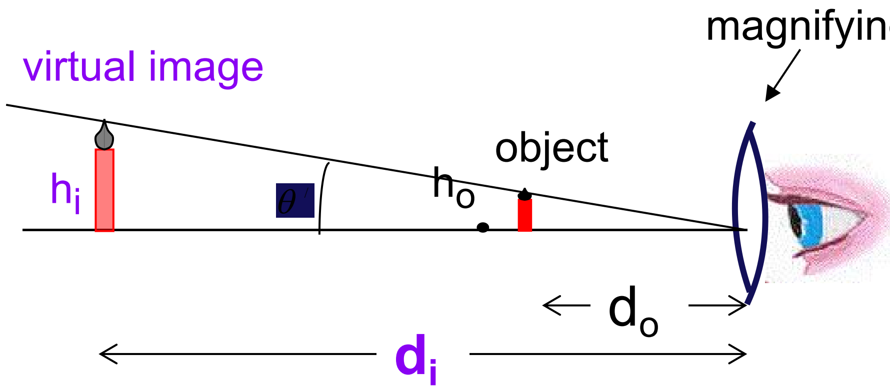
Compare to unaided eye: [redacted] :

$$\theta' = \frac{h_i}{d_i} = \frac{h_o}{d_o}$$

Ratio of the two angles is the angular magnification M:

$$M = \frac{\theta'}{\theta} = \frac{h_o/d_o}{h_o/N} = \frac{N}{d_o}$$

Angular Magnification $M=N/d_o$



(N = near point distance from eye.)

$$\text{For the lens: } \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \Rightarrow \frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i}$$

For max. magnification, need image at N:

$d_i < -N$

so set $d_i = -N$:

$$\frac{1}{d_o} = \frac{1}{f} + \frac{1}{N}$$

$\therefore$ M lies between $\frac{N}{f}$ and $\frac{N}{f}+1$ and the shorter the focal length, the greater the magnification M.

$M = 25/10 + 1 = 3.5$

Homework

- Exercises Page 934, 17, 20,
- Problem Page 937, 5, 7, 12