Last Time...

Reflection and refraction

Total internal reflection

Light rays and images

- Each point on object reflects light
- Light propagates out, represented by rays perpendicular to wavefront.
- Lens in our eye does some ‘imaging’ so that we identify origin of light rays.

Question

Does the fish appear

A. Closer than actual
B. Farther than actual
C. Same as actual

How do you ‘see’ this?

- Lens bends (refracts) light rays—forms image on retina
- Sensors on retina report to brain.
  - Color information, intensity information

Making a real image

- Lens: Refracts light so that rays originating from a point are focused to a point on the other side.

How a lens works

Position surfaces to bend light rays in just the right way. Spherical surfaces are very close to the right ones.
1) Rays parallel to optical axis pass through focal point.
2) Rays through center of lens are not refracted.
3) Rays through F emerge parallel to optical axis.

Here is the image real, inverted, enlarged.

**Quick Quiz**

I project a focused image onto a screen 2 meters away. I now want to make the image bigger without changing the lens. I should

A. Move screen farther away only
B. Move screen closer only
C. Move screen closer and object toward lens
D. Move screen farther and object toward lens
E. Move screen farther and object away from lens

**Making an image**

Object distance \( s \)

Image distance \( s' \)

How are all these related?

\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} 
\]

**Image size vs object size: Magnification**

\[
\text{Magnification } M = \frac{s'}{s} = \frac{\text{image distance}}{\text{object distance}}
\]

**Your eye can change focal length**

Object at infinity:

\[
\frac{1}{25\text{ cm}} + \frac{1}{1.7\text{ cm}} = \frac{1}{f} \Rightarrow f = 1.7\text{ cm}
\]

Object at near point:

\[
\frac{1}{1.7\text{ cm}} + \frac{1}{f} = \frac{1}{2.5\text{ cm}} \Rightarrow f = 1.59\text{ cm}
\]

Very limited range
Question

- At what object distance does image size equal object size (magnification=1)?

A. Object distance = f
B. Object distance = 2f
C. Object distance = f/2
D. Object distance = infinity
E. Object distance = 0

Virtual images

- Objects closer to a converging lens than the focal length form a virtual image

- Virtual image
  - Can’t be recorded on film
  - Can’t be seen on a screen.
- But rays can be focused by another lens
  - E.g., lens in your eye (focus on retina)
  - E.g., lens in a camera (focus on film plane)

Magnifying glass

- Object at the near point - this is the biggest it will appear and be in focus

- Object closer than focal point
  - Lens produces virtual image
- Light rays appear to originate from virtual image
- Virtual image is used as object for eye lens.
- Have moved object ‘closer’, while permitting eye to focus
Lens combinations

- Image of one lens acts as object for next.
- Rays originate from image, whether real or virtual
- Can then directly apply

\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}
\]

Far away objects

The moon is 3.8×10^8 m away, and 3.5×10^6 m diameter. I use a 1 m focal length lens to make an image of the moon. About what diameter is this image of the moon?

A. 0.5 cm
B. 1 cm
C. 2 cm
D. 10 cm
E. 1 m

Not a very big image. How can it be made ‘bigger’?

Telescope: object far away

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Nearsightedness

I can’t focus on this

This, I can see

Fixing nearsightedness