Optical Instruments I

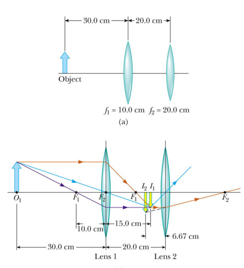
Combinations of Optical Elements

- An optical element is an instrument that changes the path of light: mirrors and lenses of all types.
- When two optical elements are combined, the **image** of the **first element** becomes the **object** of the **second element**.

Simulation:
http://webphysics.davidson.edu/applets/optics4/default.html

Example

Two convex lenses of focal lengths $f_1 = 10.0\ \mathrm{cm}, f_2 = 20.0\ \mathrm{cm}$. The two lenses are separated by $20.0\ \mathrm{cm}$. An object is placed 30.0 cm to the left as shown. Where is the final image relative first lens?



Lens Power

- The lens power is just the reciprocal of the lens's focal length P (measured in m^{-1} or Diopters):

$$P \equiv \frac{1}{f}$$

- If two lenses are placed in contact, their combined power P_{combo} is:

$$P_{combo} = P_1 + P_2 \Leftrightarrow \frac{1}{f_{combo}} = \frac{1}{f_1} + \frac{1}{f_2}$$

- Notice that our former equation for f (also known as the Len's maker's equation) directly gives power:

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

- This time we have included the index of refraction n' of the medium containing the lens
- Convention for sign of R: if it's convex to the touch it's positive, if it's concave to the touch it's negative.

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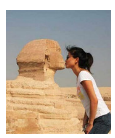
Angular Size

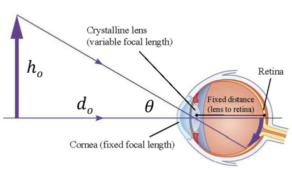
$$\tan\theta \approx \theta(\mathrm{rad}) = \frac{h_o}{d_o}$$



Recall: $1\ \mathrm{rad} = \frac{180}{\pi}{}^{\circ}$

$$\theta_{max} = \frac{h_o}{d_{o,\min}} = \frac{h_o}{N}$$

- where $N = d_{o,\min}$ is called the near point and it's usually about $25.0\ \mathrm{cm}$



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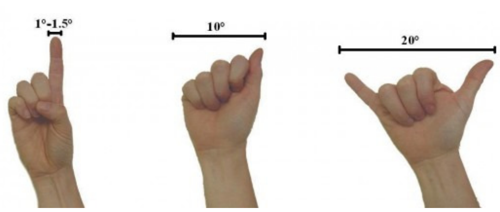

If you extend your hand to arm's length…

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Quickuiz

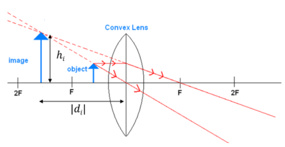
Simple Magnifier

- We've seen the unaided eye perceives a maximum angular size of $\theta_{\max} = h_o/N$
- Using a simple convex lens we can form a virtual magnified image
- Angular magnification

$$m_{ang} = \frac{\theta'}{\theta_{\max}} = \frac{N(f + |d_i|)}{|d_i| f}$$

- Angular size of virtual image:

$$\theta' = \frac{h_i}{|d_i|} = \frac{h_o m_{lat}}{|d_i|} = \frac{h_o(|d_i| + f)}{|d_i| f}$$



$$m_{lat} = -\frac{d_i}{d_o}, \quad d_i = \frac{d_o f}{d_o - f}$$

For a virtual image:

$$m_{lat} = \frac{|d_i| + f}{f}$$

Example

$$m_{ang} = \frac{\theta'}{\theta_{\max}} = \frac{N(f + |d_i|)}{|d_i| f}$$

- What is the angular magnification of an object whose image forms at the near point of an eye?

$$m_{ang} = \frac{f + N}{f} = 1 + \frac{N}{f}$$

What if the image forms at infinity (when would this happen?

$$m_{ang} = \frac{N(f + N)}{Nf} \approx \frac{N}{f}$$

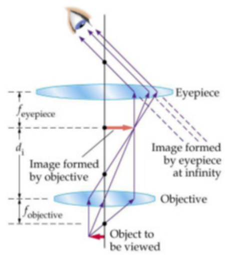
Compound Microscope

- Objective lens forms an enlarged real image of the object at (really, just inside) the focal point of the eyepiece lens, which then acts as a simple magnifier for this image.
- Lateral magnification by objective:

$$m_{lat,obj} = \frac{h_{i,obj}}{h_{o,obj}} = -\frac{d_{i,obj}}{d_{o,obj}} \approx -\frac{d_{i,obj}}{f_{obj}}$$

- Angular magnification of eyepiece:
- $m_{eye} = \frac{N}{f_{eye}}$ (or $m_{eye} = 1 + \frac{N}{f_{eye}}$)
- The total angular magnification:

$$m_{tot} \approx \left(-\frac{d_{i,obj}}{f_{obj}}\right)\left(\frac{N}{f_{eye}}\right)$$



Barrel length: $L = d_i + f_e$

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