

OPTICS

• **Today:**

- Review refraction and lenses
- Fermat's principle
- Optical Instruments

Review: Images

We can use reflection and refraction to do lots of things with light, such as forming images. This is called geometric optics, and is of course the basis for a big industry. Again we have to master some terminology. The key distinction is between *real* and *virtual* images.

REAL IMAGE: The light is *really* brought to a focus, such as when you start a fire using sunlight and a lens.

VIRTUAL IMAGE: The light only *appears* to come from it, as when you seem to see Halley Berry inside your TV set, or your face behind the bathroom mirror.

Optics Review

Formulas for spherical mirrors and thin lenses in the small angle approximation:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} \quad m = -\frac{i}{p}$$

- f = focal length: + = converging, - = diverging
- p = object distance: + = real, - = virtual
- i = image distance: + = real, - = virtual
- m = magnification: + = erect, - = inverted

Three more points

1. Dispersion

Index of refraction depends on wavelength!
Prism spectrometer

2. Circular polarization

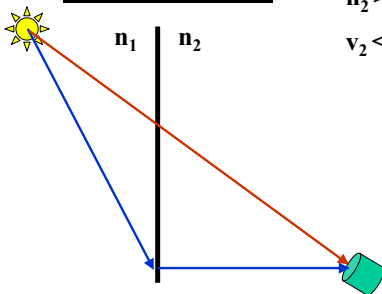
Light can carry angular momentum

3. Fermat's principle of least time

Gives Snell's Law

Fermat's Principle

The path chosen by a light ray will be the one which minimizes the time.



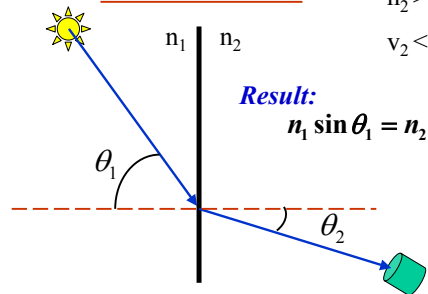
$$v = c/n$$

$$n_2 > n_1$$

$$v_2 < v_1$$

Fermat's Principle

The path chosen by a light ray will be the one which minimizes the time.



Result:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$v = c/n$$

$$n_2 > n_1$$

$$v_2 < v_1$$

The Eye and the Camera

Focus a Camera

Problem 35-37
 $f=5\text{cm}$, $p=1\text{m}$

- Set for infinity, focal point of lens is on the film
- Actually **focal plane**.
- For closer object, **move lens**.
- Which way and how much?

$$\frac{1}{i} = \frac{1}{f} - \frac{1}{p} = \frac{1}{5} - \frac{1}{100} = .20 - .01 = .19$$

$$i = 1/0.19 = 5.26 \text{ cm}$$

$$x = i - f = \underline{2.6 \text{ mm}}$$

Focus the Eye

Problem 35-35
 $f = 2.50 \text{ cm}$, $p = 40.0 \text{ cm}$

- Set for infinity, focal point of lens is on the retina.
- For closer object, **reshape lens**.
- What should be new focal length?

$$\frac{1}{f'} = \frac{1}{p} + \frac{1}{i} = \frac{1}{40} + \frac{1}{2.5}$$

$$= .025 + .400 = .425$$

$$f' = 1/.425 = \underline{2.35 \text{ cm}}$$

Systems of Lenses

For a system of two or more lenses, treat the lenses one at a time. The **image** formed by the first acts as the **object** for the second. Note that this can result in a **virtual object** ($p < 0$).

Example: Problem 35-26

Diverging lens followed by converging lens.

$f_1 = -15 \text{ cm}$, $f_2 = +12 \text{ cm}$, $p_1 = +10 \text{ cm}$

Locate and describe the final image.

$f_1 = -15 \text{ cm}$, $f_2 = +12 \text{ cm}$, $p_1 = +10 \text{ cm}$

First the principal rays for lens 1:

Image looks to be virtual, erect, and reduced.

$$\frac{1}{i_1} = \frac{1}{f_1} - \frac{1}{p_1}$$

$$= -\frac{1}{15} - \frac{1}{10} = -\frac{1}{6}$$

$$i_1 = -6 \text{ cm}$$

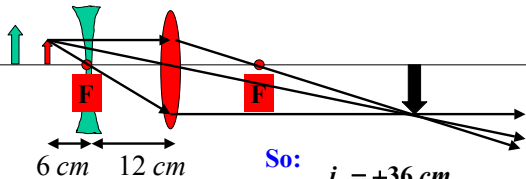
$$m_1 = -(-6)/10 = 0.6$$

$$f_1 = -15 \text{ cm}, \quad f_2 = +12 \text{ cm}, \quad p_1 = +10 \text{ cm}$$

$$i_1 = -6 \text{ cm}, \quad m_1 = 0.6, \quad \underline{p_2 = +18 \text{ cm}}$$

Now do the principal rays for lens 2:

Final image is real and inverted.



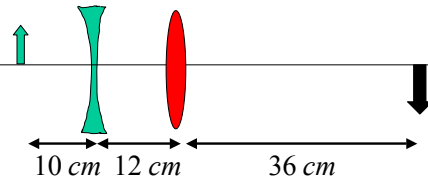
$$\frac{1}{i_2} = \frac{1}{f_2} - \frac{1}{p_2} = \frac{1}{12} - \frac{1}{18} = \frac{1}{36}$$

So: $i_2 = +36 \text{ cm}$
 $m_2 = -36/18 = -2$

Overall magnification of two-lens system:

$$m_{tot} = m_1 m_2 = (0.6)(-2) = \underline{-1.2}$$

Final image is real, inverted, enlarged.



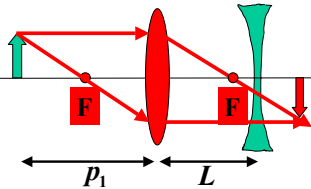
Example 2

$$f_1 = +3 \text{ cm}$$

$$f_2 = -4 \text{ cm}$$

$$L = 4 \text{ cm}$$

$$p_1 = 6 \text{ cm}$$



Find image due to lens 1:

$$i_1 = 6 \text{ cm} \quad m_1 = -1$$

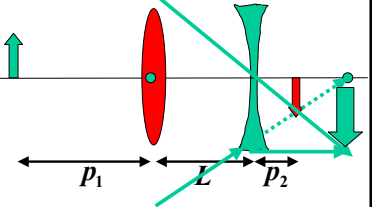
Real image due to lens 1.
 Virtual object for lens 2.

$$\underline{p_2 = -(i_1 - L) = -2 \text{ cm}}$$

Example 2

$$f_2 = -4 \text{ cm}$$

$$p_2 = -2 \text{ cm}$$



Find image due to lens 2:

$$i_2 = +4 \text{ cm} \quad m_2 = +2$$

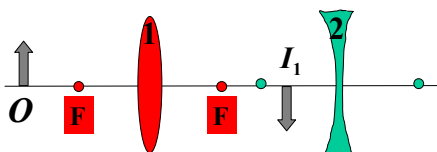
Real image due to lens 2.

$$m_{TOT} = m_1 \times m_2 = -2$$

Final result is real, inverted and enlarged.

Q.35-3

We have a real image formed by a converging lens 1 as shown. Now a diverging lens 2 is added as shown.

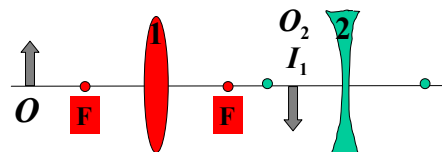


Will lens 2 have a real or virtual object?

- (1) Real (2) Virtual

Q.35-3

We have a real image formed by a converging lens 1 as shown. Now a diverging lens 2 is added as shown.

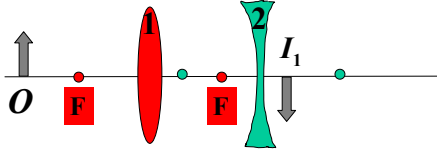


Will lens 2 have a real or virtual object?

- (1) Real** (2) Virtual

Q.35-4

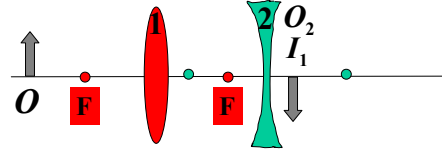
We have a real image formed by a converging lens 1 as shown. Now a diverging lens 2 is added as shown.



Will lens 2 have a real or virtual object?
 (1) Real (2) Virtual

Q.35-4

We have a real image formed by a converging lens 1 as shown. Now a diverging lens 2 is added as shown.



Will lens 2 have a real or virtual object?
 (1) Real (2) Virtual

Astronomical Telescopes

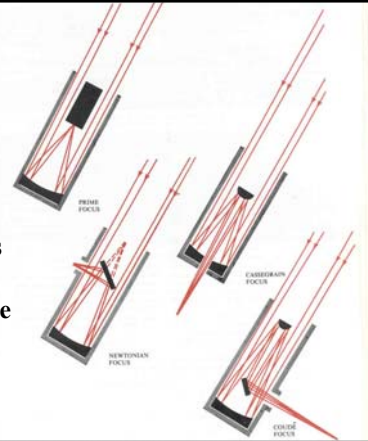
Ritter Observatory



Ritter 1-meter reflector

Styles of Reflectors

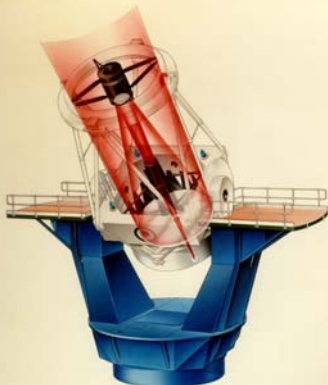
Goal: Collect as much light as possible, with the fewest possible reflections.



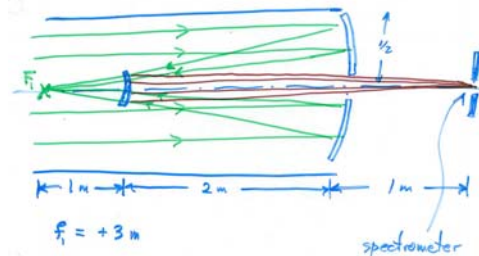
Herschel Telescope

European 4-meter reflector on the Canary Islands

Collects 16 times as much light as we do at Ritter.

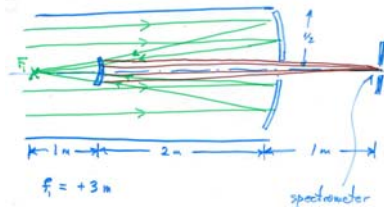


Ritter 1-meter Reflector



• **Problem:** What do we need for f_2 , the focal length of the secondary mirror?

Solution



Mirror 1: Image formed at focus F_1

Mirror 2: Virtual object $p = -1\text{m}$, real image $i = 3\text{m}$.

$$\frac{1}{f_2} = \frac{1}{p_2} + \frac{1}{i_2} = \frac{1}{-1} + \frac{1}{3} = -\frac{2}{3} \quad f_2 = -\frac{3}{2} = \underline{\underline{-1.5\text{m}}}$$

So we want a diverging mirror with $f = 1.5\text{m}$.

Optics Review

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