

Optics

- **Last time:** Reflection and refraction
- **Today:** Image formation by lenses and mirrors
- **Quiz Thursday:** Chs. 33, 34

Optics Quiz on Thursday

- **Ch. 33, Light waves.**
 - Review waves: $f\lambda = v$, $y = y_m \sin \omega t$
 - Refraction: $n = c/v = \lambda_0/\lambda$
 - Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
- **Ch. 34, Thin lenses, spherical mirrors.**
 - Real and virtual images
 - Principal rays
 - Image location: $1/p + 1/i = 1/f$
 - Magnification: $m = -i/p$

IMAGES

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

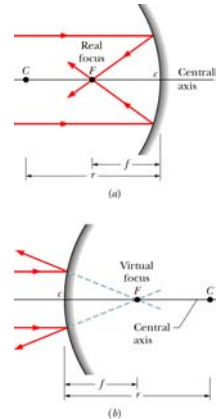
In formulas the image distance i is *positive*.

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

In formulas the image distance i is *negative*.

Spherical Mirrors

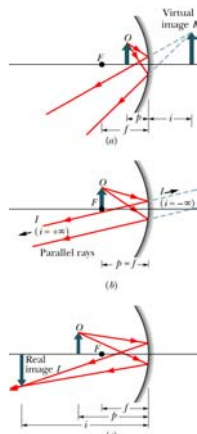
- Focal point
- Focal distance
- Concave mirror is *converging*: $f > 0$.
- Convex mirror is *diverging*: $f < 0$.



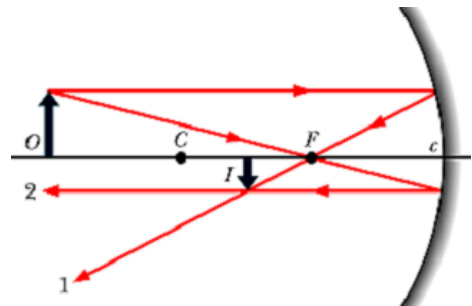
Images in Concave Mirrors

Let p = object distance,
let i = image distance.

Let p, i be positive for
real, negative for virtual.

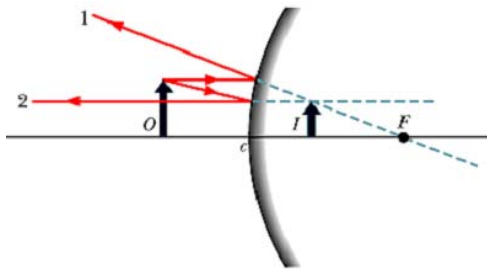


Locating the Images Principal Rays for concave mirror



Locating the Images

Principal Rays for convex mirror

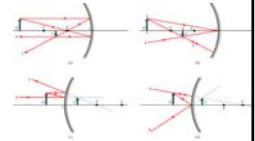


Equations for the Images

** Small-angle Approximation **

Summarize Results:

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



Also: let *magnification m* be defined as *image size divided by object size*. Then:

$$m = -\frac{i}{p}$$

Negative *m* means *inverted image!*

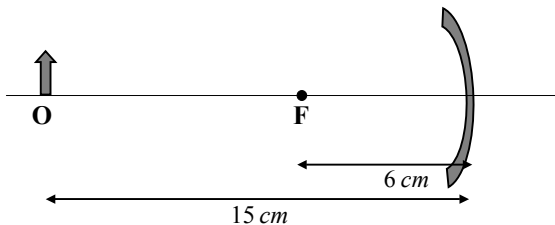
Spherical mirror example 1

An object is placed 15 cm in front of a concave mirror with focal length 6 cm. Describe the resulting image.

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

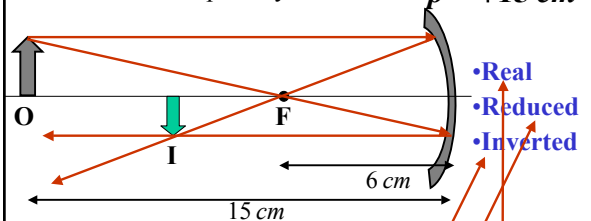
$$f = +6 \text{ cm}$$

$$p = +15 \text{ cm}$$



Example 1 solution

Method 1: Principal Rays



Method 2: $\frac{1}{i} = \frac{1}{6} - \frac{1}{15} = \frac{5}{30} - \frac{2}{30} = \frac{1}{10}$ so $i = +10 \text{ cm}$

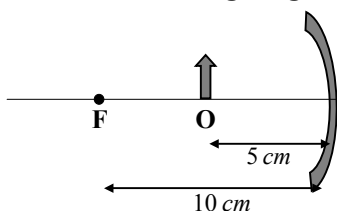
$$m = -i/p = -10/15 = -2/3$$

Spherical mirror example 2

An object is placed 5 cm in front of a concave mirror with focal length 10 cm. Describe the resulting image.

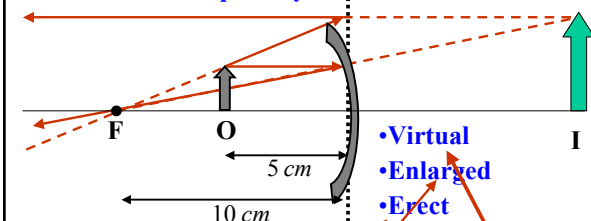
$$f = +10 \text{ cm}$$

$$p = +5 \text{ cm}$$



Example 2 Solution

Method 1: Principal Rays

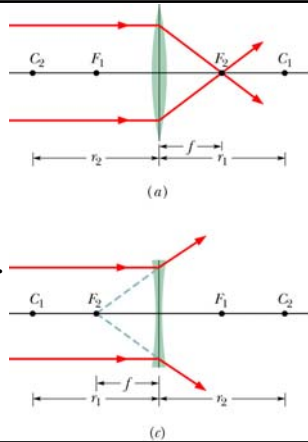


Method 2: $\frac{1}{i} = \frac{1}{10} - \frac{1}{5} = \frac{1}{10} - \frac{2}{10} = -\frac{1}{10}$ so $i = -10 \text{ cm}$

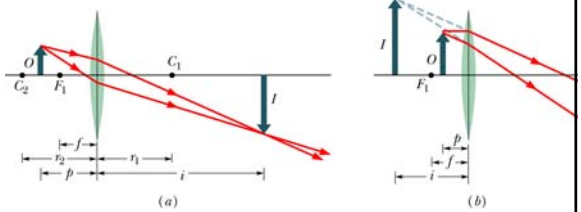
$$m = -i/p = -(-10)/5 = +2$$

Thin Lenses

- Focal point
- Focal distance
- Convex lens is *converging*: $f > 0$.
- Concave lens is *diverging*: $f < 0$.



Images in Thin Lenses

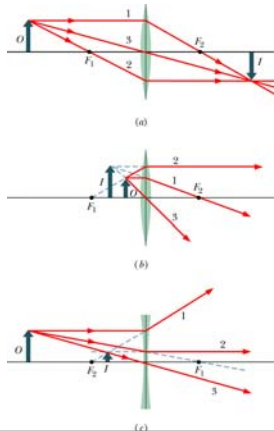


Let p = object distance,
let i = image distance.

Let p, i be positive for
real, negative for virtual.

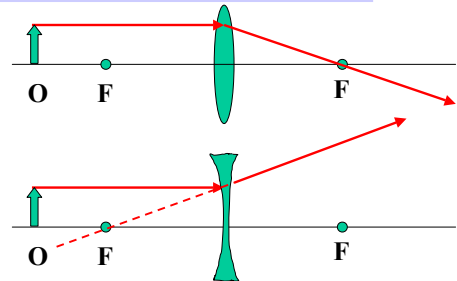
Locating the Images

Just as with the mirrors, follow the *principal rays* to locate image graphically.



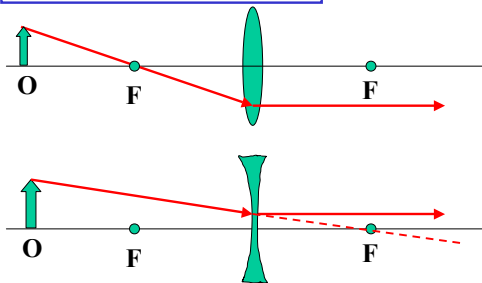
Finding Images: Principal Rays

1. In parallel to axis: out through F.



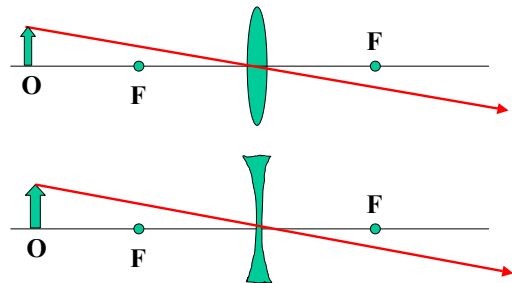
Finding Images: Principal Rays

2. In through F, out parallel



Finding Images: Principal Rays

3. Straight through center



Equations for the Images

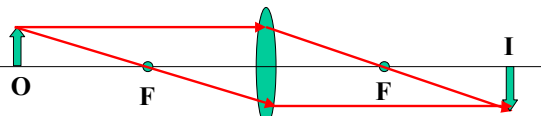
Results in small-angle approximation:

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

Same equations as for spherical mirrors!

Thin-Lens Example 1

Given $f=+20\text{cm}$, $p=+40\text{cm}$, find i , m



$$\frac{1}{i} = \frac{1}{f} - \frac{1}{p} = \frac{1}{20} - \frac{1}{40} = \frac{1}{40} \quad \text{so } i = +40\text{cm}$$

$$m = -\frac{i}{p} = -\frac{40}{40} = -1$$

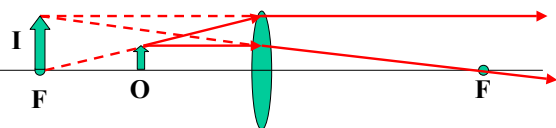
Image is:

- Real
- Inverted
- Same size as object

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Example 2

Given $f=+20\text{cm}$, $p=+10\text{cm}$, find i , m



$$\frac{1}{i} = \frac{1}{f} - \frac{1}{p} = \frac{1}{20} - \frac{1}{10} = -\frac{1}{20} \quad \text{so } i = -20\text{cm}$$

$$m = -\frac{i}{p} = -\frac{(-20)}{10} = +2$$

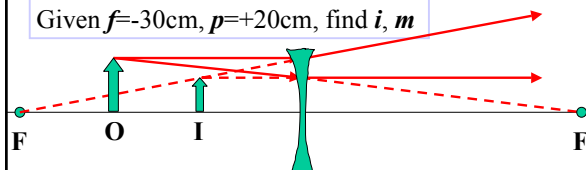
Image is:

- Virtual
- Erect
- Enlarged

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Example 3

Given $f=-30\text{cm}$, $p=+20\text{cm}$, find i , m



$$\frac{1}{i} = \frac{1}{f} - \frac{1}{p} = \frac{1}{(-30)} - \frac{1}{20} = -\frac{5}{60} \quad \text{so } i = -12\text{cm}$$

$$m = -\frac{i}{p} = -\frac{(-12)}{20} = +0.6$$

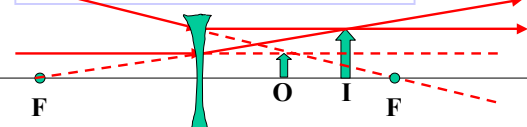
Image is:

- Virtual
- Erect
- Reduced

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Example 4

Given $f=-10\text{cm}$, $p=-4\text{cm}$, find i , m



$$\frac{1}{i} = \frac{1}{f} - \frac{1}{p} = \frac{1}{(-10)} - \frac{1}{(-4)} = +\frac{3}{20} \quad \text{so } i = +6.7\text{cm}$$

$$m = -\frac{i}{p} = -\frac{20/3}{(-4)} = +\frac{20}{12} = +1.7$$

Image is:

- Real
- Erect
- Enlarged

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

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

Definitions and sign conventions:

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