Optics
Image formation from Mirrors

Lana Sheridan

De Anza College

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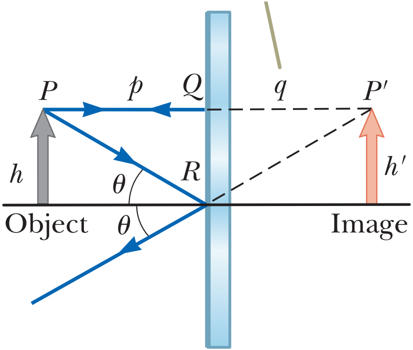
Last time

- dispersion
- total internal reflection
- ray diagrams and terminology

Overview

- image formation from mirrors

Ray Diagram for a Flat Mirror

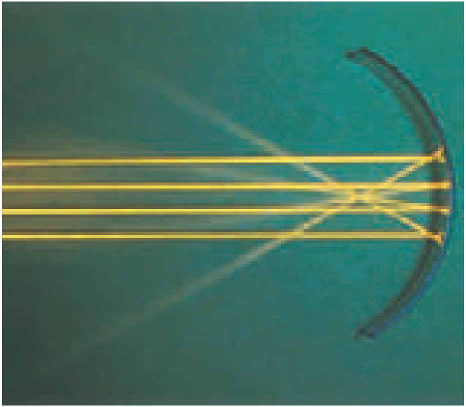


Ray diagrams have the optical device sketched vertically in cross section, the object on the left represented by an arrow pointing up.

The image is also represented by an arrow, but it may be to the left or right, pointing up or down depending on how the image is formed.

We sketch rays with paths we know to find the image.

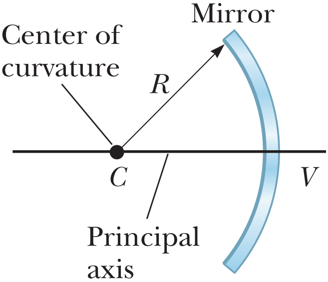
Images formed by Spherical Mirrors: Concave Mirrors

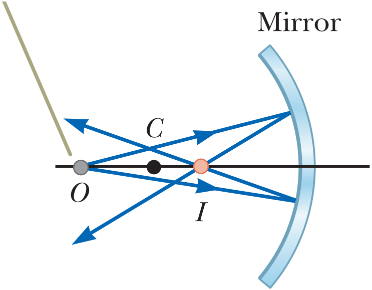


Henry Leap and Jim Lehman

Concave mirrors can focus light.

Images formed by Spherical Mirrors: Concave Mirrors





Assumption: paraxial rays

In studying curved mirrors and thin lenses we assume that all rays are **paraxial rays**.

Paraxial rays are rays close to the principle optical axis of our optical device. (Rays that strike close to the middle.)

For a spherical lens, rays that strike further from the axis are not focused to the same point (spherical aberration).

Mirror Focal Length

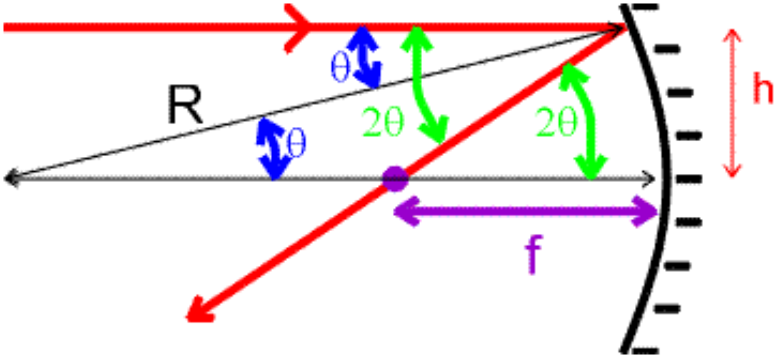
What is the focal length for a spherical mirror?

Spherical Concave Mirrors

The focal point is where the detectors are place on satellite dishes and radio telescopes.

[1]Parkes telescope in Australia.

Spherical Concave Mirrors Focal Length



$$h = R\sin\theta = f\tan(2\theta)$$

For paraxial rays, $\sin\theta \approx \theta$, $\tan(2\theta) \approx 2\theta$, and so, for a spherical concave mirror of radius R

$$f = \frac{R}{2}$$

Mirror Equation and Thin Lens Equation

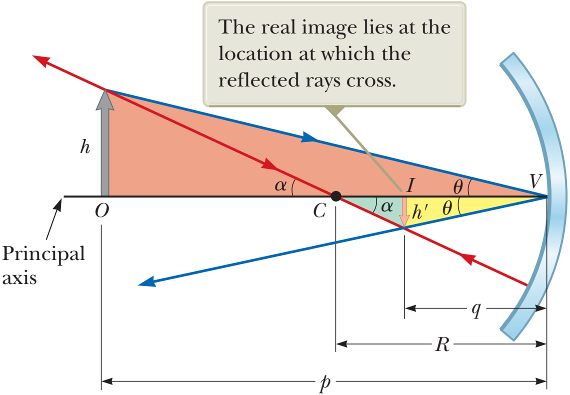
The same equation can help us to find the location and magnification of the image that will be formed by curved mirrors and thin lenses!

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

We will now prove this for concave mirrors.

Concave Mirrors and the Mirror Equation

Simple geometry shows why the mirror equation is true for a concave mirror.



We will use this ray diagram.

Ray Diagrams for Spherical Mirrors

For a ray diagram: draw at least two rays that you know the path of accurately.

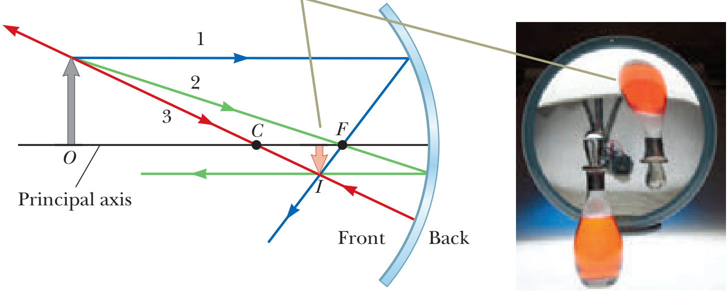
For Spherical mirrors:

1. Draw a ray from the top of the object parallel to the principle axis reflected through the focal point F.
2. Draw a ray from the top of the object through the focal point and reflected parallel to the principal axis.
3. Draw a ray from the top of the object through the center of curvature C and reflected back on itself.

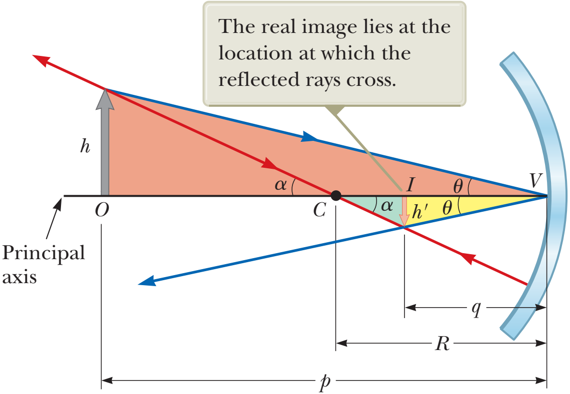
Where the lines meet, an image is formed.

Examples of Ray Diagrams

When the object is located so that the center of curvature lies between the object and a concave mirror surface, the image is real, inverted, and reduced in size.



Concave Mirrors and the Mirror Equation



The angles of incidence and reflection are the same magnitude, θ.

So, $\frac{h'}{h} = -\frac{q}{p}$, and

$$M = -\frac{q}{p}$$

Concave Mirrors and the Mirror Equation

Looking at the green triangle and the (small) red triangle with angle α:

$$\frac{-h'}{R-q} = \frac{h}{p-R}$$

which rearranges to

$$\frac{-h'}{h} = -\frac{q-R}{p-R}$$

Using our magnification expression:

$$\frac{q}{p} = -\frac{q-R}{p-R}$$

Concave Mirrors and the Mirror Equation

$$\frac{q}{p} = -\frac{q-R}{p-R}$$

Cross-multiplying and rearranging gives

$$\frac{2}{R} = \frac{1}{p} + \frac{1}{q}$$

However, we already concluded that $f = R/2$, so

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

We have confirmed the mirror equation for spherical concave mirrors, and the convex case also follows from simple geometry.

Cases for Spherical Mirrors

type of mirror	object dist	image		
$f > 0$, converging, concave	$p > 2f$	real	inverted	diminished
	$f < p < 2f$	real	inverted	enlarged
	$p < f$	virtual	upright	enlarged
$f < 0$, diverging, convex	any p	virtual	upright	diminished

Image Cases for Concave Mirror

When the object is located so that the center of curvature lies between the object and a concave mirror surface, the image is real, inverted, and reduced in size.

$\leftarrow \quad p > 2f$

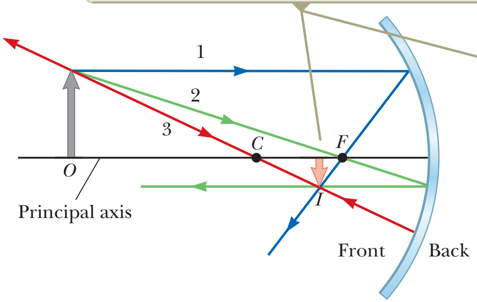


Image Cases for Concave Mirror

When the object is located between the focal point and a concave mirror surface, the image is virtual, upright, and enlarged.

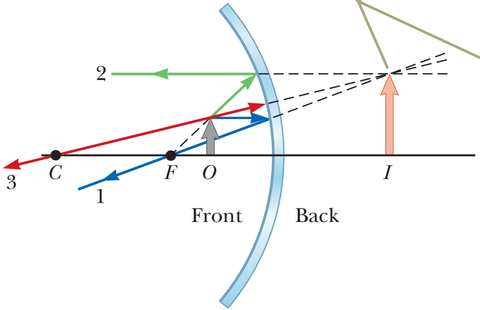
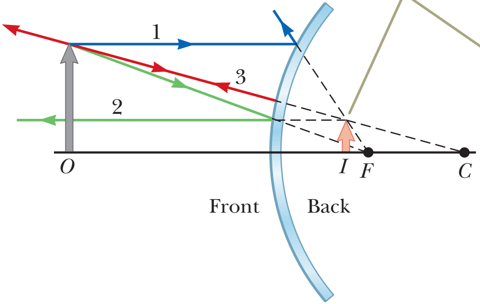


Image Case for Convex Mirror

When the object is in front of a convex mirror, the image is virtual, upright, and reduced in size.



Mirror Question

Quick Quiz 36.3[1] Consider the image in the mirror in shown. Based on the appearance of this image, which of the following should you conclude?

(A) the mirror is concave and the image is real

(B) the mirror is concave and the image is virtual

(C) the mirror is convex and the image is real

(D) the mirror is convex and the image is virtual

NASA

[1] Serway & Jewett, page 1098.

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NASA

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Sign Conventions for Mirrors!

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

Variable	is Positive	is Negative
p	object in front of mirror	—
q	image in front of mirror (real)	image behind mirror (virtual)
h' and M	image upright	image inverted
f and R	concave mirror	convex mirror

Example 36.4: Convex Mirror Image

An automobile rearview mirror shows an image of a truck located 10.0 m from the mirror. The focal length of the mirror is -0.60 m.

Find the position of the image of the truck and the magnification of the image.

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$$q = \underline{-0.57 \text{ m}}$$

Find the magnification of the image.

$$M = -\frac{q}{p} = \underline{+0.057}$$

Summary

- image formation from mirrors

Homework Serway & Jewett:

- Carefully read *all* of Chapter 36. (over the next few days)