Unit 14

Reflection at Curved Mirrors

This unit online, with its interactives:
science-playground.com/s/11f14

Look into the bowl of a steel spoon: you are upside down. Turn it over and you are the right way up, but tiny. The same piece of polished steel gives two quite different pictures of you, and a single formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, tells you exactly where each one is and how big.

This unit is about curved mirrors: the shaving mirror that enlarges your chin, the convex mirror on a hairpin bend of a hill road that shows the bus coming round it, and the great mirrors of telescopes that gather starlight. You will see why a mirror's focus is halfway to its center of curvature, derive the mirror formula, learn a sign convention that turns every case into the same formula, and use magnification to tell how big, and which way up, an image will be.

14.1 Introduction

When light traveling in one medium meets the surface of another, part of it is reflected, part is absorbed and the rest is transmitted. **Reflection** is the turning back of light into the medium it came from when it strikes a surface. It obeys two laws, which you met in earlier grades:

1. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.
2. The angle of reflection equals the angle of incidence.

A smooth, polished surface reflects light in an orderly way and forms images: a plane mirror, a curved mirror, still water, a polished steel plate. Mirrors are inside telescopes, cameras, car headlamps, projectors and the instruments a doctor uses to look into your eyes, and reflection also explains how we see most of the world around us: by light bounced off it.

A STORY FROM SCIENCE

The chemist who made mirrors cheap

Justus von Liebig was born in Darmstadt, Germany, on 12 May 1803, and received his doctorate from the University of Erlangen in 1823, by then studying chemistry in Paris. He became one of the founders of agricultural chemistry: he showed that plants take their nutrients, nitrogen among them, as simple mineral compounds from the soil and the air, which made chemical fertilizers possible, and he made famous the **law of the minimum**: a crop grows only as well as its scarcest nutrient allows. He also built much of the method of analyzing organic compounds.

In 1835 Liebig found a way to coat glass with a thin, even layer of metallic silver by a chemical reaction: silver comes out of a solution of a silver salt onto the clean glass. Before that, mirrors were backed with a mixture of tin and poisonous mercury, and mirror-makers fell ill from the fumes. Liebig's silvering made good mirrors cheap and safe, and the same reaction is still shown in chemistry labs as the "silver mirror test".

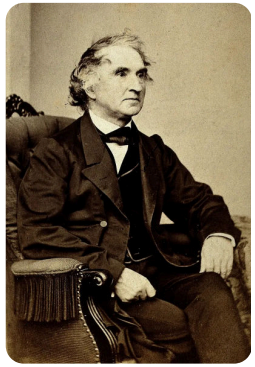


Figure 14.1 *Justus von Liebig (1803–1873), whose silvering process gave us cheap, safe mirrors.*
Photo: Franz Hanfstaengl, Public domain

14.2 Image

When the rays of light from a point of an object, after reflection (or refraction), meet at a point, or seem to come from a point, that point is the **image** of the object point. There are two kinds.

A **real image** is formed where the rays really meet after reflection or refraction. The light actually passes through it, so a real image can be caught on a screen: the picture on a cinema screen, on the retina of your eye, on a camera's sensor.

A **virtual image** is formed where the rays do not meet but only **appear** to meet when they are produced backwards. No light reaches it, so it cannot be caught on a screen. Your face in a plane mirror is virtual: the light never goes behind the glass.

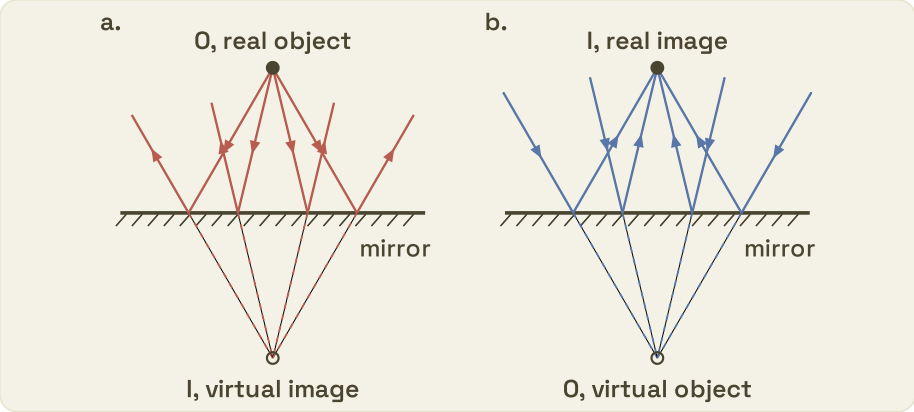


Figure 14.2 *Real and virtual at a plane mirror. a. Light spreading from a real object O reflects and keeps spreading; only the dashed lines, produced behind the mirror, meet: a virtual image I, as far behind the mirror as O is in front. b. Light already converging (from a lens, say) towards a point O behind the mirror, a* ***virtual object****, is reflected before it gets there and really meets at I in front: a real image.*

The same two kinds appear with a concave mirror. An object beyond the focus gives a real image in front of the mirror (Figure 14.3); an object between the focus and the mirror gives a virtual one behind it (Figure 14.4). A convex mirror gives a virtual image behind it wherever a real object stands (Figure 14.5).

24. A pole 4 m long lies along the principal axis of a convex mirror of focal length 1 m, as in the figure. The end of the pole nearer the mirror is 2 m from it. Find the length of the image of the pole.

25. An object is 40 cm from a convex mirror. A plane mirror is put between them, 32 cm from the object, facing the object, and the images in the two mirrors coincide. What is the focal length of the convex mirror?

A companion to your textbook, not a replacement for it: study from the book your school uses, and where the two differ, follow your teacher. Found a mistake? Please tell us.

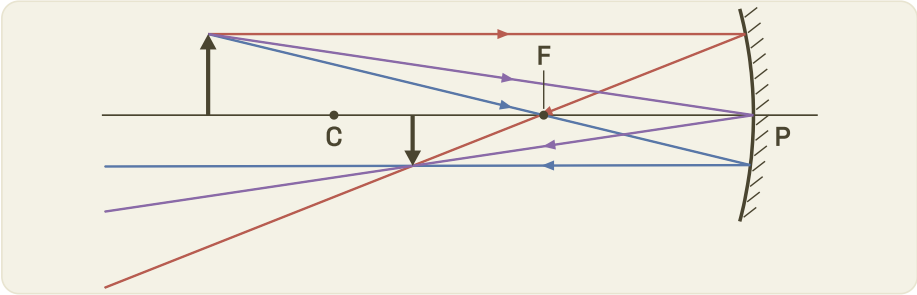


Figure 14.3 A concave mirror, object beyond C: the reflected rays really cross in front of the mirror, between C and F. The image is real and inverted, and could be caught on a card held there.

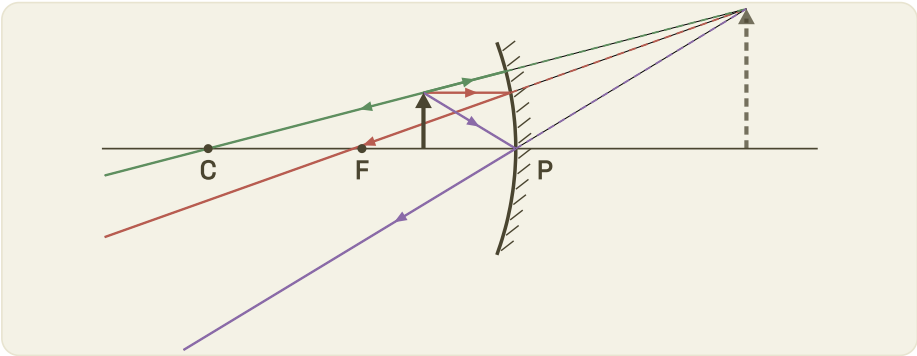


Figure 14.4 The same mirror, object between F and P: the reflected rays spread out. Produced back (dashed), they meet behind the mirror: a virtual, upright, enlarged image, the one you see in a shaving mirror.

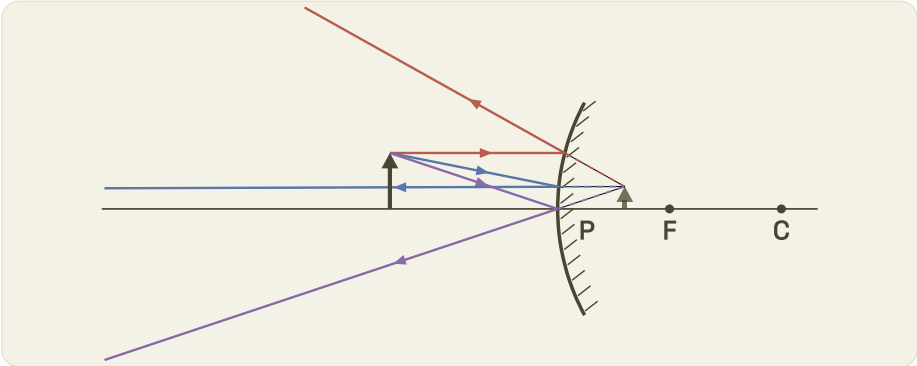


Figure 14.5 A convex mirror: the ray parallel to the axis leaves as if from F, the ray aimed at F leaves parallel to the axis, and the ray to the pole leaves at an equal angle. They spread out, and only produced back (dashed) do they meet, between P and F behind the mirror: a virtual, upright, smaller image.

Real and virtual images compared

	Real image	Virtual image
How it forms	the rays really meet (converge) at it	the rays only seem to meet, when produced

	Real image	Virtual image
		backwards
On a screen	can be caught on a screen	cannot be caught on a screen
Which way up (for a real object)	inverted	upright (erect)
Examples	a camera's picture, the image on the retina, a cinema picture	the image in a plane mirror, in a convex mirror, in a magnifying glass

The "inverted" and "upright" row holds for a **real object**, the usual case. With a virtual object the rule turns round: in Worked example 3 below, a convex mirror gives a real image that is upright.

Check 1

You can catch the image formed by a mirror on a sheet of paper. The image must be:

a virtual
b real
c upright
d behind the mirror

Check 2

Which of these images is virtual?

a the picture on a cinema screen
b the image on the retina of your eye
c your face in a convex rear-view mirror
d the image of the Sun caught on paper by a concave mirror

14.3 Spherical mirrors

A **spherical mirror** is a mirror whose reflecting surface is part of a sphere. Cut a cap off a hollow glass sphere and silver one of its surfaces, and you have one.

- Silver the **outside** of the cap, and light reflects from the inner, hollowed face: a **concave** mirror (it caves in, like the bowl of a spoon).
- Silver the **inside**, and light reflects from the outer, bulging face: a **convex** mirror (like the back of the spoon).

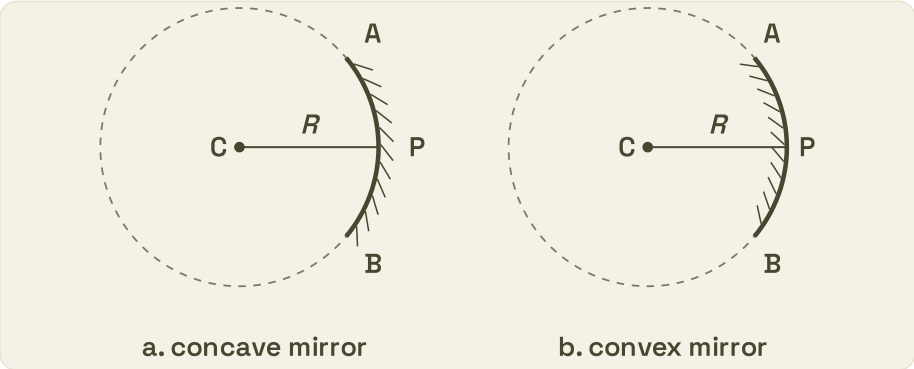


Figure 14.6 *A spherical mirror APB is a cap cut from a sphere of center C and radius R. a. Silvered (hatched) on the outside: a concave mirror. b. Silvered on the inside: a convex mirror.*

18. a. A convex mirror and a concave mirror are fixed on a wall. How can you tell which is which without touching them?
    b. Why does a ray of light falling normally on a mirror retrace its path?

Numerical problems

19. How far from a lamp must a concave mirror of focal length 3 m be placed to throw an image of the lamp on a screen 8 m from the lamp?
20. An object is placed in front of a convex mirror of radius of curvature 20 cm. Its image is formed 8 cm behind the mirror. Find the distance of the object from the mirror.
21. An object is 10 cm from a mirror, and its image is 30 cm from the mirror on the same side as the object. Is the mirror concave or convex? What is its focal length?
22. An object 1 cm high is 1.5 m from a screen. Where must a concave mirror be placed so that it forms an image 2 cm high on the screen? Find the focal length of the mirror.
23. A concave mirror gives a magnification of 0.5 when an object is 60 cm from it. Where should the object be placed to get a virtual image twice the size of the object?

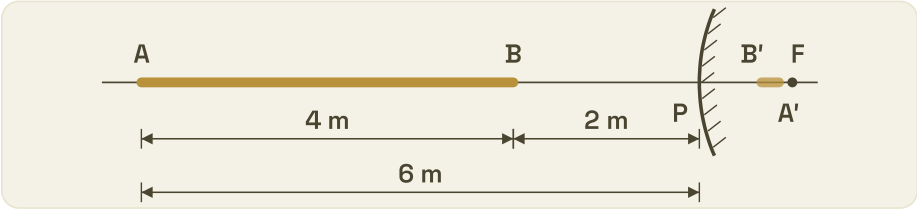


Figure 14.16 *For question 24, drawn to scale.*

Check 15

9. The focal length of a concave mirror is:

a greatest for red light
b greatest for violet light
c greatest for yellow light
d the same for all colors

Check 16

10. An object is 20 cm from a convex mirror of focal length 10 cm. The image is:

a real, 20 cm from the mirror
b virtual, 20 cm from the mirror
c virtual, $\frac{20}{3}$ cm from the mirror
d real, $\frac{20}{3}$ cm from the mirror

Check 17

11. An upright object 1 m tall is placed very far (at infinity) in front of a concave mirror. The image is:

a the same size as the object
b half the size of the object
c twice the size of the object
d a point

Check 18

12. A concave mirror of focal length f forms a real image with magnification m. The object distance is:

a $\frac{m-1}{m}f$
b $\frac{m+1}{m}f$
c $\frac{m-1}{f}$
d $(m+1)f$

Check 19

13. A converging beam of light is heading for a point 12 cm behind a convex mirror. The mirror forms an inverted image of the same size at that same point. The focal length of the mirror is:

a 24 cm
b 12 cm
c 6 cm
d 3 cm

Check 20

14. A spherical mirror forms a real image of a point object. The object and the image are 20 cm and 30 cm from the mirror. The focal length and the type of the mirror are:

a 120 mm, convex
b 60 mm, convex
c 120 mm, concave
d 60 mm, concave

17.

a. Explain how a spherical mirror can behave as a plane mirror, as a special case.

b. A convex mirror is put under water. Will its focal length change?

c. A concave mirror of focal length f in air is put under water. What is its new focal length? Explain.

The words used with spherical mirrors:

- **Pole (P):** the middle point of the mirror's surface.
- **Center of curvature (C):** the center of the sphere the mirror is part of. In front of a concave mirror, behind a convex one.
- **Radius of curvature (R):** the radius of that sphere, the distance CP.
- **Principal axis:** the straight line through P and C.
- **Aperture:** the width of the mirror's surface, the diameter of its rim (AB).
- **Principal focus (F):** the point on the axis where rays parallel to the axis, close to it, meet after reflection from a concave mirror (a **real** focus, in front), or from which they seem to come after reflection from a convex mirror (a **virtual** focus, behind).
- **Focal length (f):** the distance PF from the pole to the principal focus.

The normal to a spherical mirror at any point is the radius through that point: a line from C. That single fact is the key to everything in this unit.

14.4 Relation between f and R

For a spherical mirror of small aperture, the focal length is half the radius of curvature:

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

For a concave mirror

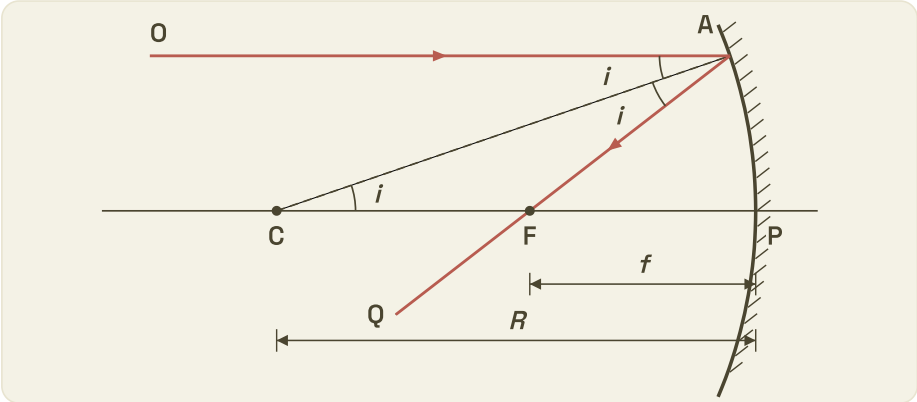


Figure 14.7 *A ray OA parallel to the axis meets a concave mirror at A. The radius CA is the normal there, so the angle of incidence OAC = i, and the reflected ray AQ makes the same angle with it, crossing the axis at F. The angle ACP is also i.*

A ray OA, parallel to the principal axis, meets the mirror at A (Figure 14.7) and is reflected through F.

1. CA is a radius, so it is the normal at A. The angle of incidence is $\angle OAC = i$, and by the law of reflection the angle of reflection is $\angle CAF = i$.
2. OA is parallel to the axis CP, and CA cuts both, so $\angle ACF = \angle OAC = i$ (alternate angles).
3. So in triangle FAC, the angles at A and at C are both i: the triangle is isosceles, and $FA = FC$.
4. For a mirror of small aperture, A is very close to P, so $FA \approx FP$. Then $FP = FC$: F is halfway between P and C.

5. $FP = f$ and $CP = R$, so $f = \dfrac{R}{2}$.

For a convex mirror

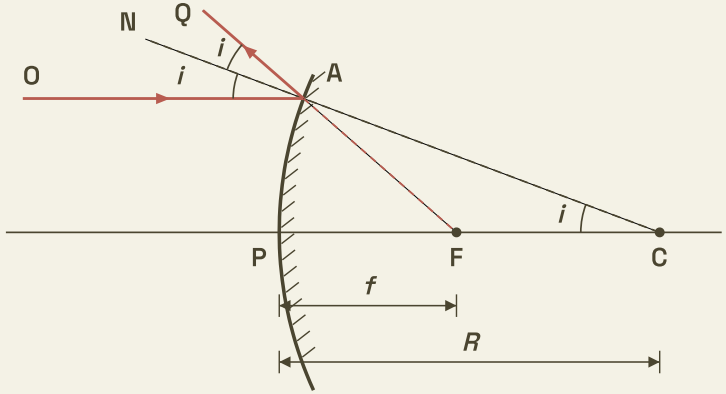


Figure 14.8 *A ray OA parallel to the axis meets a convex mirror at A. The normal is the radius CA produced to N. The reflected ray AQ, produced back behind the mirror, passes through F, halfway between P and C.*

1. The normal at A is the radius CA, produced outwards to N (Figure 14.8). The angle of incidence is $\angle OAN = i$, and the reflected ray AQ makes $\angle NAQ = i$.
2. Produced back, QA passes through F behind the mirror. $\angle FAC = \angle NAQ = i$ (vertically opposite angles).
3. OA is parallel to the axis, so $\angle ACF = \angle OAN = i$ (corresponding angles).
4. Triangle FAC has equal angles at A and C, so $FA = FC$. For a small aperture $FA \approx FP$, so $FP = \frac{1}{2}CP$, that is $f = \dfrac{R}{2}$.

Step 4 in each proof is where “small aperture” matters. A ray far from the axis crosses it nearer the mirror than F (the angle at A is large and FA is clearly longer than FP). So a wide spherical mirror has no single sharp focus, a blur called **spherical aberration**. That is why a car’s headlamp or a satellite dish is shaped as a **paraboloid**, not a piece of a sphere: a parabola sends every ray parallel to its axis, near or far, through one point.

Check 3

A concave mirror has a radius of curvature of 40 cm. Its focal length is:

a 80 cm
b 40 cm
c 20 cm
d 10 cm

CAREFUL

Concave and convex, which is which?

A **con-cave** mirror caves in, like the inside of a spoon or a dish. A **convex** mirror bulges out. Concave mirrors converge parallel light to a real focus; convex mirrors diverge it, from a virtual focus behind them.

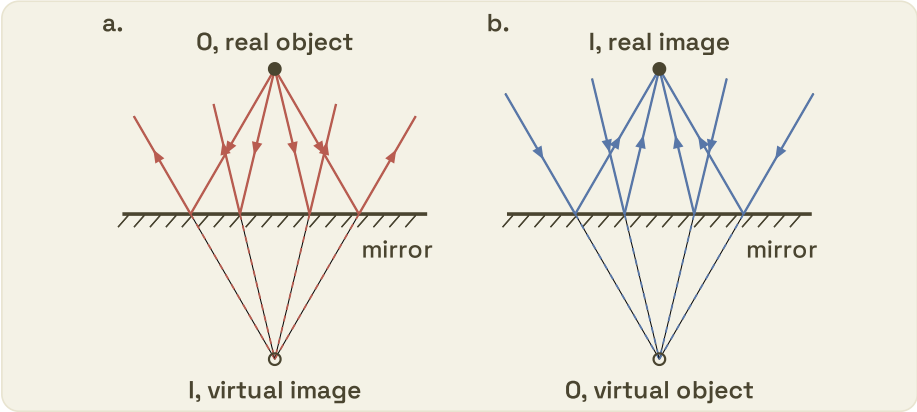


Figure 14.15 *For question 4.*

Check 10

4. What can you conclude from these figures?

a A plane mirror can form only a virtual image.
b A plane mirror can form only a real image.
c A plane mirror forms both kinds of image in every case.
d A plane mirror usually forms a virtual image, but for a virtual object it forms a real image.

Check 11

5. A convex mirror receives light converging towards a point between its pole and its focus (a virtual object between P and F). The image is:

a inverted
b diminished
c virtual
d real

Check 12

6. Which mirror is used for shaving?

a concave
b bifocal
c convex
d convex cylindrical

Check 13

7. The image formed by a convex mirror (of a real object) is:

a real and virtual
b virtual and upright
c real and enlarged
d virtual and enlarged

Check 14

8. A concave mirror of focal length f in air is put under water (refractive index 4/3). Its focal length becomes:

a f
b $\dfrac{4f}{3}$
c $\dfrac{3f}{4}$
d $\dfrac{7f}{3}$

Exercise

Choose the correct option

Check 7

1. Which of these mirrors has the widest field of view?

a plane mirror
b concave mirror
c convex mirror
d cylindrical mirror

Check 8

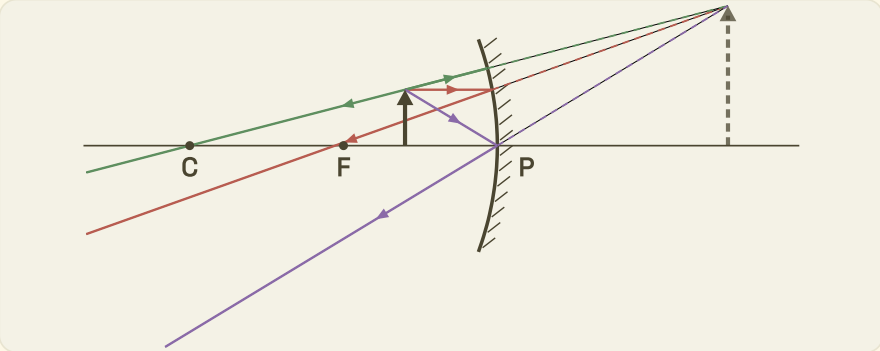


Figure 14.13 *For question 2.*

2. What is the nature of the image formed in the figure above?

a virtual, upright and enlarged
b real, upright and enlarged
c virtual and inverted
d virtual, upright and diminished

Check 9

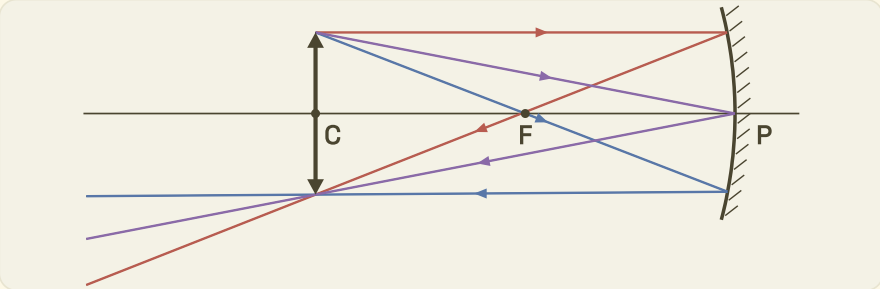


Figure 14.14 *For question 3.*

3. What can you conclude from the ray diagram above?

a The image is the same size as the object.
b The object is larger than the image.
c The object is smaller than the image.
d The image is the same size as the object only when the object is beyond C.

Answer these questions

14.5 Mirror formula

The **mirror formula** relates the object distance u, the image distance v and the focal length f of a mirror:

$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$

It holds for concave and convex mirrors, and for a plane mirror too, as long as each distance is given its proper sign.

Assumptions

1. The aperture of the mirror is small.
2. The rays make very small angles with the principal axis (they are **paraxial** rays).
3. The object is a small object (or a point) on the principal axis.

Sign convention: real is positive

1. All distances are measured from the pole of the mirror.
2. Distances of **real** objects and **real** images are positive; distances of **virtual** objects and **virtual** images are negative.
3. The focal length and radius of curvature of a **concave** mirror are positive (its focus is real); those of a **convex** mirror are negative (its focus is virtual).

CAREFUL

Two sign conventions

Some books measure every distance as a coordinate from the pole, with distances against the direction of the incoming light negative (the "new Cartesian" convention). There the object distance is negative and the formula is written $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ with those signs, and a concave mirror's focal length is negative. Both conventions give the same answers if each is used with its own signs; never mix the formula of one with the signs of the other. This unit, like the Grade 11 curriculum's textbook, uses **real is positive** throughout. Say which you use in an exam answer.

Deriving the mirror formula

Take a concave mirror and an object AB beyond C, so that the image A′B′ is real (Figure 14.9). Two rays from B fix the image:

- BL, parallel to the axis, is reflected through F to B′;
- BP, to the pole, is reflected at the same angle on the other side of the axis, to B′.

Similar triangles at the pole. The angles at A and A′ are right angles, and $\angle BPA = \angle B'PA'$ (the angle of incidence at P equals the angle of reflection, both measured from the axis, which is the normal at P). So triangles ABP and A′B′P are similar, and

$$\frac{A'B'}{AB} = \frac{PA'}{PA} \tag{14.1}$$

Similar triangles at the focus. In triangles LNF and B′A′F, the angles at N and A′ are right angles, and $\angle LFN = \angle B'FA'$ (vertically opposite). So

$$\frac{A'B'}{LN} = \frac{FA'}{FN}$$

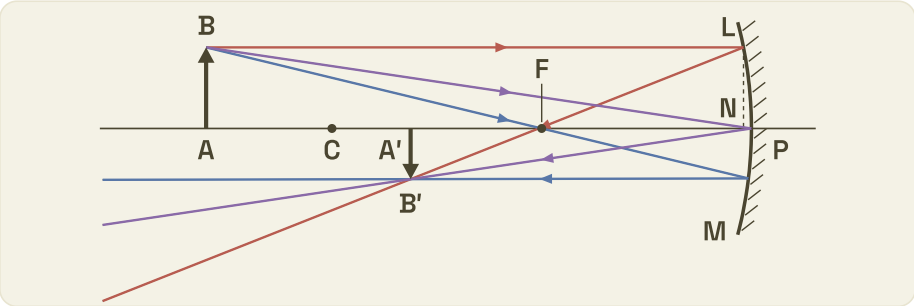


Figure 14.9 *The derivation's ray diagram, drawn to scale: object AB beyond C, image A′B′. BL is parallel to the axis and is reflected through F; BP meets the pole and is reflected at an equal angle; LN is perpendicular to the axis. (The third ray, through F, is reflected parallel to the axis and meets the others at B′ too.)*

The small-aperture step. LN = AB (BL is parallel to the axis), and for a small aperture N is very close to P, so $FN \approx FP$:

$$\frac{A'B'}{AB} = \frac{FA'}{FP} = \frac{PA' - PF}{PF} \tag{14.2}$$

Put the two together. The left sides of (14.1) and (14.2) are equal, so

$$\frac{PA'}{PA} = \frac{PA' - PF}{PF}$$

Insert the distances. The object and the image are real, so with the sign convention $PA = u$, $PA' = v$, $PF = f$, all positive:

$$\frac{v}{u} = \frac{v - f}{f} \quad \Rightarrow \quad vf = uv - uf \quad \Rightarrow \quad uv = uf + vf$$

Dividing every term by uvf:

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \tag{14.3}$$

The same steps for a virtual image, or for a convex mirror, give the same formula once the virtual distances are put in as negative numbers. That is the whole point of the sign convention: one formula for every case.

Check 4

An object is 30 cm in front of a concave mirror of focal length 20 cm. The image is:

a 12 cm in front, virtual
b 60 cm in front, real
c 60 cm behind, virtual
d 12 cm behind, virtual

14.6 Magnification

The **magnification** m of a mirror is the ratio of the size of the image to the size of the object:

$$m = \frac{\text{size of image}}{\text{size of object}} = \frac{I}{O}$$

Equation (14.1) in the derivation showed that the image and the object are in the same ratio as their distances from the pole, so

$$m = \frac{I}{O} = \frac{v}{u}$$

With the sign convention, m carries a sign as well as a size:

DID YOU KNOW?

"Objects in mirror are closer than they appear"

In many countries a car's convex side mirror carries exactly this warning, etched into the glass. The image is diminished, so your brain, which judges distance partly by apparent size, places the car behind farther away than it is. The inside rear-view mirror is a plane mirror, which shows sizes truly but a narrower view; drivers use both.

Check 6

Which mirror gives the widest field of view?

a plane mirror
b concave mirror
c convex mirror
d none: all the same size of mirror show the same view

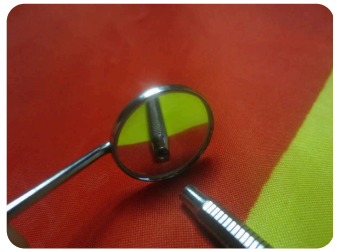


Figure 14.12 *A dentist's mouth mirror. Its small mirror shows the back of the teeth the dentist can't see directly.*

Photo: Daniela Tocan, CC BY-SA 4.0

IN SHORT

Key ideas of Unit 14

- A **real image** is where rays really meet (on a screen; inverted for a real object); a **virtual image** is where they only seem to meet (not on a screen; upright for a real object).
- A spherical mirror is part of a sphere: **concave** (reflects from the hollow side) or **convex** (from the bulging side). Its normal at any point is the radius through C.
- For small aperture, $f = \frac{R}{2}$.
- **Mirror formula:** $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, with **real is positive**: real objects and images positive, virtual ones negative; f positive for concave, negative for convex.
- **Magnification:** $m = \frac{I}{O} = \frac{v}{u}$; positive for a real image, negative for a virtual one; size above 1 enlarged, below 1 diminished.
- Concave: telescopes, shaving and make-up mirrors, ophthalmoscopes, reflectors. Convex: rear-view and road mirrors, for a wide field of view.

3. **Ophthalmoscopes.** A doctor looks into a patient's eye through a small hole in the center of a concave mirror, which throws light into the eye, lighting up the retina.
4. **Reflectors.** A concave mirror behind a lamp sends the light out as a beam: in torches, car headlamps, projectors and searchlights. With the lamp at the focus of a **parabolic** mirror, the beam comes out parallel. Run backwards, the same shape gathers sunlight onto one spot in a solar cooker, or radio waves onto the receiver of a satellite dish.
5. **Dentists' mirrors.** A dentist's small mouth mirror is usually plane, but some are slightly concave, giving an enlarged view of the back of your teeth.
6. **Microscopes.** The small mirror under the stage of a school microscope has a concave side, which gathers the light of a window or a lamp onto the specimen.

Convex mirrors

A **convex mirror** is used as a rear-view mirror on vehicles. Vehicles behind are real objects in front of the mirror, and their images are always virtual, upright and diminished, between the pole and the focus. So a small convex mirror shows a much wider stretch of the road than a plane mirror of the same size: it has a wider **field of view**. Its drawback is that everything looks smaller, and so farther away, than it is, so a driver can't judge the distance and speed of a vehicle coming up behind from it alone.

Convex mirrors are also used on blind bends of roads, at the exits of car parks, and in shops for security, wherever one mirror must show a wide area.

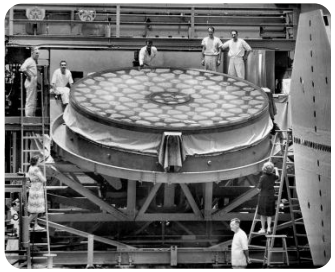


Figure 14.10 *The 5.1 m (200-inch) mirror of the Hale Telescope in California being ground to shape in 1945. Its concave surface had to be correct to about 50 nanometers.*
Photo: Paul Calvert, Los Angeles Times, Public domain



Figure 14.11 *A convex traffic mirror at a blind bend. Nepal's hill roads have them on many hairpin bends, so drivers can see what is coming round the corner.*
Photo: Neil Theasby, CC BY-SA 2.0

- m **positive**: a real image, which (for a real object) is inverted;
- m **negative**: a virtual image, which (for a real object) is upright;
- the **size** of m: equal to 1, the image is the same size as the object; less than 1, smaller (**diminished**); more than 1, larger (**enlarged**).

Magnification has no unit. It is what makes curved mirrors useful: a make-up or shaving mirror and a dentist's mirror give enlarged images of small things close by; a telescope's concave mirror forms a large, bright image of something very far away; and convex mirrors give diminished images, fitting a wide view into a small mirror, for vehicles, for road bends and for security in shops. An enlarged image also helps you take exact readings in an experiment.

Check 5
A mirror forms an image with $m = -0.5$. The image is:

a real, inverted and half the size
b virtual, upright and half the size
c virtual, upright and twice the size
d real, inverted and twice the size

Worked examples

WORKED EXAMPLE

Example 1: A plane mirror's magnification

Why is the magnification of a plane mirror always 1?

Answer

A plane mirror forms an image the same size as the object. From the mirror formula with $f = \infty$, $v = -u$, so $m = \dfrac{v}{u} = -1$: its size is always 1 (the minus sign only says the image is virtual and upright), wherever the object is.

WORKED EXAMPLE

Example 2: An upright image three times as tall

Where should an object be placed in front of a concave mirror of radius of curvature 0.4 m so that an upright image three times as tall is formed?

Answer

$f = \dfrac{R}{2} = \dfrac{0.4}{2} = 0.2$ m (concave, positive).

An upright image from a real object is virtual, so $m = -3$: $\dfrac{v}{u} = -3$, $v = -3u$.

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \;\Rightarrow\; \frac{1}{0.2} = \frac{1}{u} - \frac{1}{3u} = \frac{2}{3u} \;\Rightarrow\; 3u = 2 \times 0.2 \;\Rightarrow\; u = \frac{0.4}{3} = 0.133 \text{ m}$$

The object must be **13.3 cm** in front of the mirror, between F (20 cm) and the pole, as for a shaving mirror.

WORKED EXAMPLE

Example 3: A convex mirror forms a real image

A convex mirror of radius of curvature 30 cm forms a real image 20 cm from its pole. Explain how this is possible, and say whether the image is upright or inverted.

Answer

$R = -30$ cm (convex), so $f = \dfrac{R}{2} = -15$ cm. The image is real: $v = +20$ cm.

$$\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = -\frac{1}{15} - \frac{1}{20} = \frac{-4-3}{60} = -\frac{7}{60} \;\Rightarrow\; u = -\frac{60}{7} = -8.57 \text{ cm}$$

The object distance is negative: the object is **virtual**, 8.57 cm behind the mirror. This happens when light arriving at the mirror is already converging (from a lens, for instance) towards a point 8.57 cm behind it. A real object can never give a real image in a convex mirror; a converging beam can, because the mirror spreads it only a little, and it still meets in front.

$m = \dfrac{v}{u} = \dfrac{20}{-8.57} = -2.33$. The sign is negative, so the image is **upright** (erect) with respect to the object, and 2.33 times as large. (Here u and v have opposite signs, which is what makes the image upright.)

WORKED EXAMPLE

Example 4: The height of an image in a convex mirror

An object 10 cm high stands 30 cm in front of a convex mirror of focal length 20 cm. Find the height of the image.

Answer

$O = 10$ cm, $u = 30$ cm, $f = -20$ cm (convex).

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = -\frac{1}{20} - \frac{1}{30} = -\frac{5}{60} \;\Rightarrow\; v = -12 \text{ cm}$$

(virtual, 12 cm behind the mirror).

$$m = \frac{I}{O} = \frac{v}{u} = \frac{-12}{30} = -0.4 \;\Rightarrow\; I = -0.4 \times 10 = -4 \text{ cm}$$

The image is **4 cm high**; the minus sign says it is virtual and upright.

YOUR TURN

The spoon

The bowl of a steel spoon is a concave mirror of radius of curvature about 6 cm. You hold it 30 cm from your eye. Where is the image of your eye, and how tall is it, if your eye is 3 cm tall?

Answer

$f = 6/2 = 3$ cm. $\dfrac{1}{v} = \dfrac{1}{3} - \dfrac{1}{30} = \dfrac{9}{30}$, so $v = +3.33$ cm: a real image just outside the focus, in front of the spoon.

$m = \dfrac{v}{u} = \dfrac{3.33}{30} = +0.11$: real, **inverted**, about 0.33 cm tall. That is why you see yourself tiny and upside down in a spoon. Turn the spoon over (convex, $f = -3$ cm) and $v = -2.73$ cm, $m = -0.09$: tiny and the right way up.

YOUR TURN

Where to stand

A concave mirror has a focal length of 15 cm. Where should an object be placed to get a real image the same size as the object?

Answer

Same size and real: $m = +1$, so $v = u$. Then $\dfrac{1}{15} = \dfrac{2}{u}$ and $u = 30$ cm $= 2f$: at the center of curvature. The image forms at C too, inverted.

14.7 Applications of spherical mirrors

Concave mirrors

1. **Reflecting telescopes.** The large telescopes of astronomy collect light with a concave mirror, not a lens. A lens meters across can't be made free of defects (its glass would sag under its own weight, and it would split colors), but a mirror can be supported all over its back, and reflection bends every color equally. The largest single mirrors are over 8 m across.
2. **Shaving and make-up mirrors.** With your face between the pole and the focus of a concave mirror, you see an upright, enlarged, virtual image, which shows the fine detail for a close shave or careful make-up.