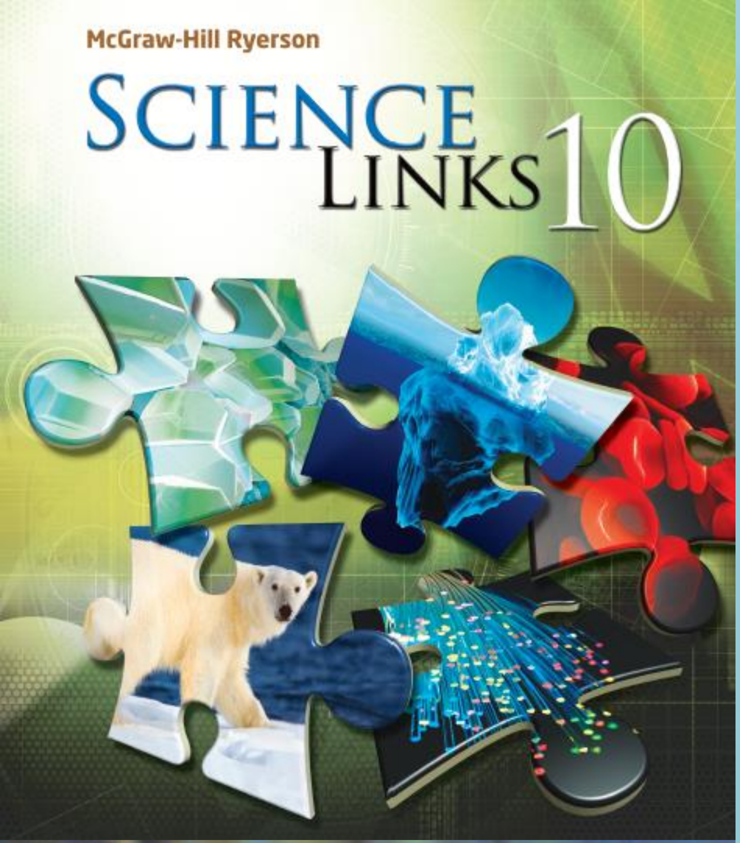


UNIT 4

Light and Applications of Optics

Topic 4.1: *What is light and how is it produced?*

Topic 4.2 : *How does light interact with objects to give them colour?*

Topic 4.3: *How can you mix colours to make different colours?*

Topic 4.4: *What is the law of reflection and how do mirrors form images?*

Topic 4.5: *What is refraction and how can it be used?*

Topic 4.6: *What are lenses and what are some of their applications?*

Topic 4.1 What is light and how is it produced?

(Pages 276-85)

Key Concepts

- Many technologies produce light by converting other forms of energy.
- Light is energy and travels like a wave.

What is light and how is it produced?

Today, light helps carry tens of thousands of messages over vast distances—each is transmitted in milliseconds. This is achieved with laser light pulsed through optical-fibre cables, microwaves beamed between relay towers, and Earth-orbiting satellites.

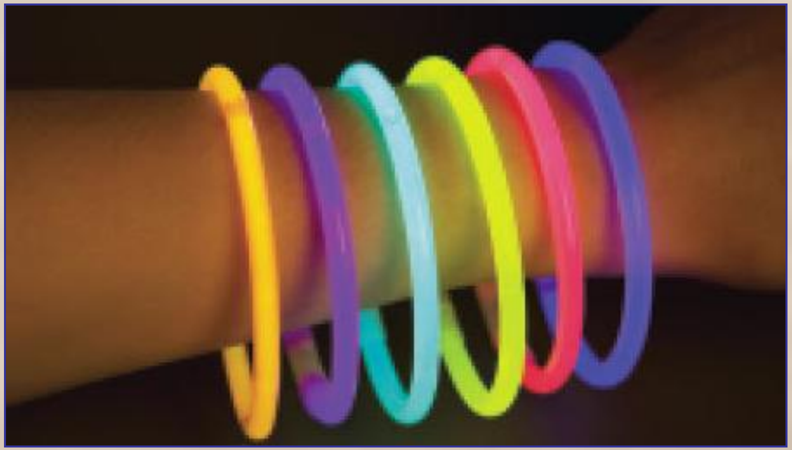
Many technologies produce light by converting other forms of energy.

We use the energy of light to help us communicate. Light is also used to see and to illuminate the world around us.

Light given off by objects when they become very hot is called **incandescence** or **incandescent light**.

Many technologies produce light by converting other forms of energy.

Light given off by objects that have not been heated is called **luminescence** or **luminescent light**.



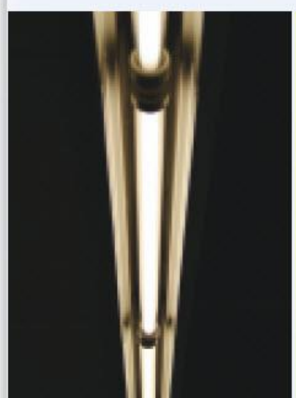
Producing Light by Luminescence

Three examples of light-producing technologies that involve luminescence are shown on this slide and the next.

Examples	Energy Transformation	Type of Luminescence
You have probably seen glow sticks in the form of jewellery. When glass capsules inside the plastic stick are broken, a chemical inside the glass mixes with another chemical inside the plastic. The chemical reaction that results releases light.	chemical energy to light energy 	*Chemiluminescence* is light that is released during chemical reactions.

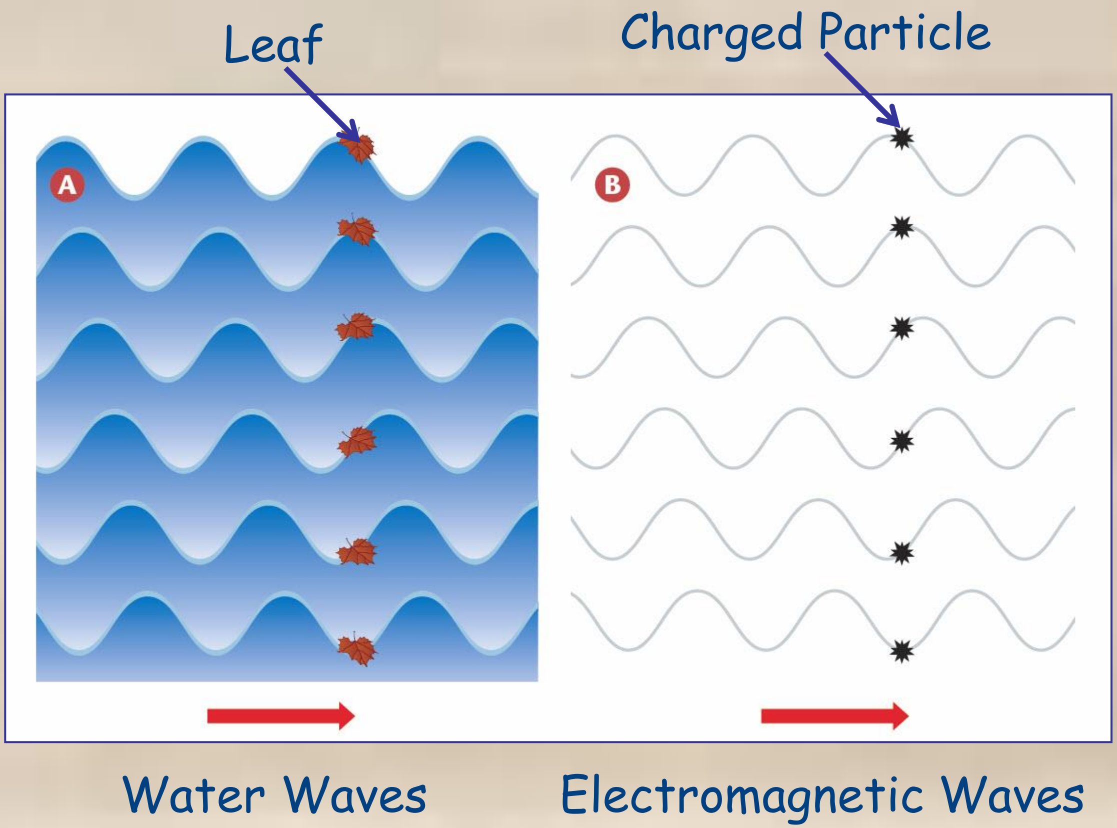
How can you make glow sticks last longer? Why?

Producing Light by Luminescence

Examples	Energy Transformation	Type of Luminescence
Many street lights are electric discharge lights. You might have noticed some street lights that have a slightly yellowish tint. These are called sodium vapour lights. Some sodium and a small amount of mercury are sealed inside the tube. A little heat will cause them to form a vapour, and the electric discharge will cause the vapour to emit light with a yellow colour.	electrical energy to light energy 	*Electric discharge* is carried out in a sealed glass tube. One or more gases are sealed in the glass. An electrode at one end emits high-energy electrons, and an electrode at the other end attracts them. As the energetic electrons collide with particles of gas, they transfer energy to them. The gases release the energy as light.
For many years, long tubular fluorescent lights were used in schools and businesses. More recently, small compact fluorescent bulbs have come into use in homes. Because these bulbs produce light without becoming very hot, they are more efficient than incandescent bulbs. Thus, they conserve energy.	electrical energy to light energy  	*Fluorescence* is a form of electric discharge. However, the gases emit ultraviolet light. The inner walls of the glass tube are covered with a substance called a phosphor. The ultraviolet light transfers energy to the phosphor, which then releases the energy as light.

Light is energy and travels like a wave.

Light is related to certain other forms of energy such as microwaves, ultraviolet waves, and X rays. These forms of energy are all classified as **electromagnetic waves**, which are waves that carry electrical and magnetic energy.

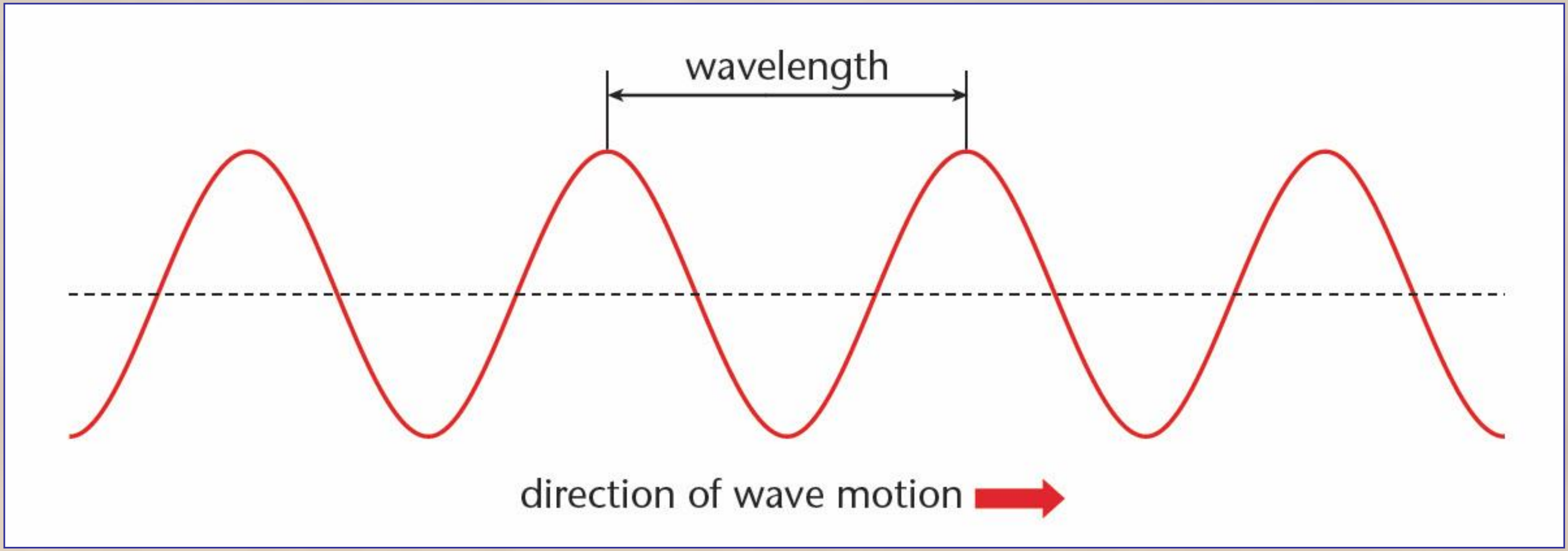


In image **A**, the energy in the water wave is moving to the right with the waves. The water (and the leaves) move up and down, not along the energy's flow.

In image **B**, charged particles move up and down with the electromagnetic wave.

Light is energy and travels like a wave.

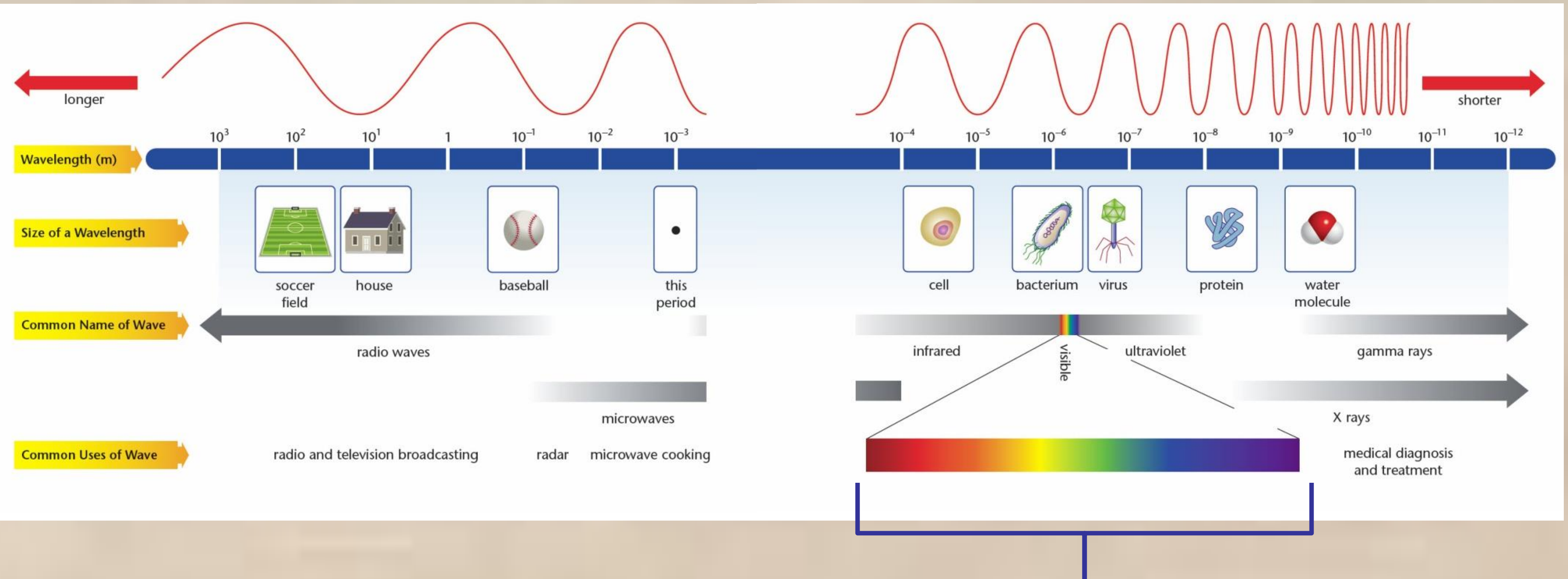
The image below can be used to represent any type of wave. A wave's **wavelength** is the distance between peaks.



The **wavelength** of an electromagnetic wave determines how it can be used and whether you can see it.

The Electromagnetic Spectrum

There are many types of electromagnetic waves. The main difference among them is their wavelength.



The only waves of the electromagnetic spectrum that you can see are those of **visible light** (a very small part of the electromagnetic spectrum).

Topic 4.1 Review

Key concepts to be reviewed:

- *Many technologies generate light by converting other forms of energy.*
- *Light is energy and travels like a wave.*

Topic 4.2 How does light interact with objects to give them colour?

(Pages 286-93)

Key Concepts

- Light can be reflected, absorbed, or transmitted by objects.
- Objects can absorb some colours and reflect or transmit others.

How does light interact with objects to give them colour?

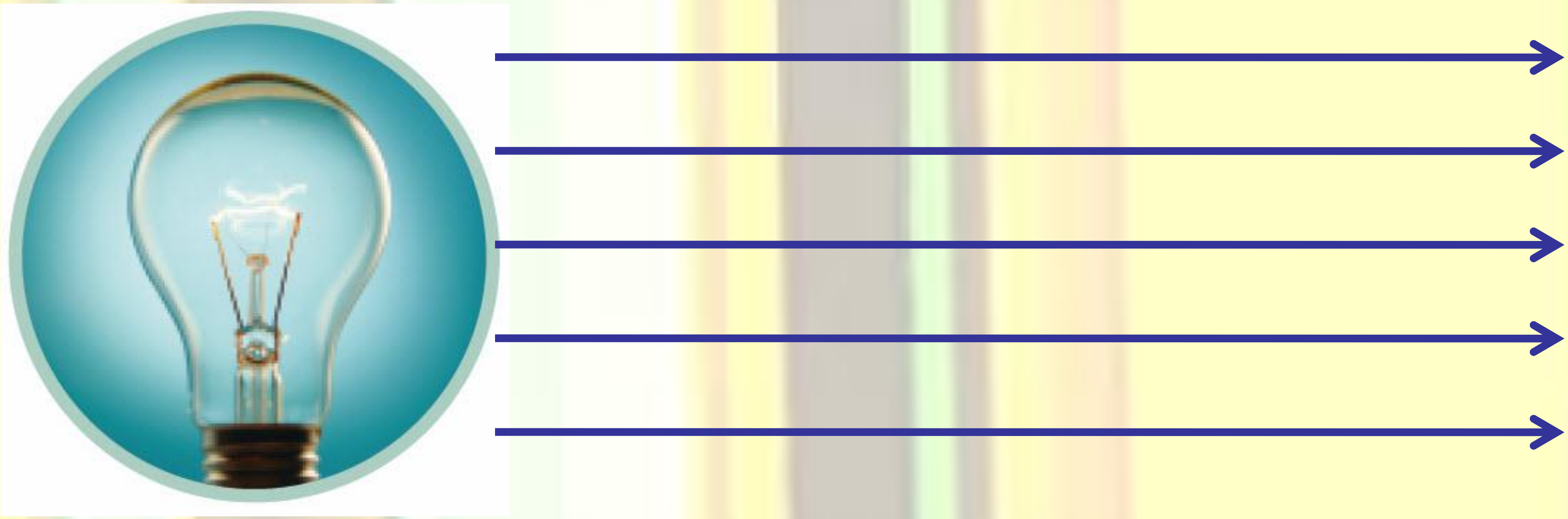
When sunlight passes through stained glass, colours are projected throughout a room.

What is the source of the colours projected into the room?

Light can be reflected, absorbed, or transmitted by objects.

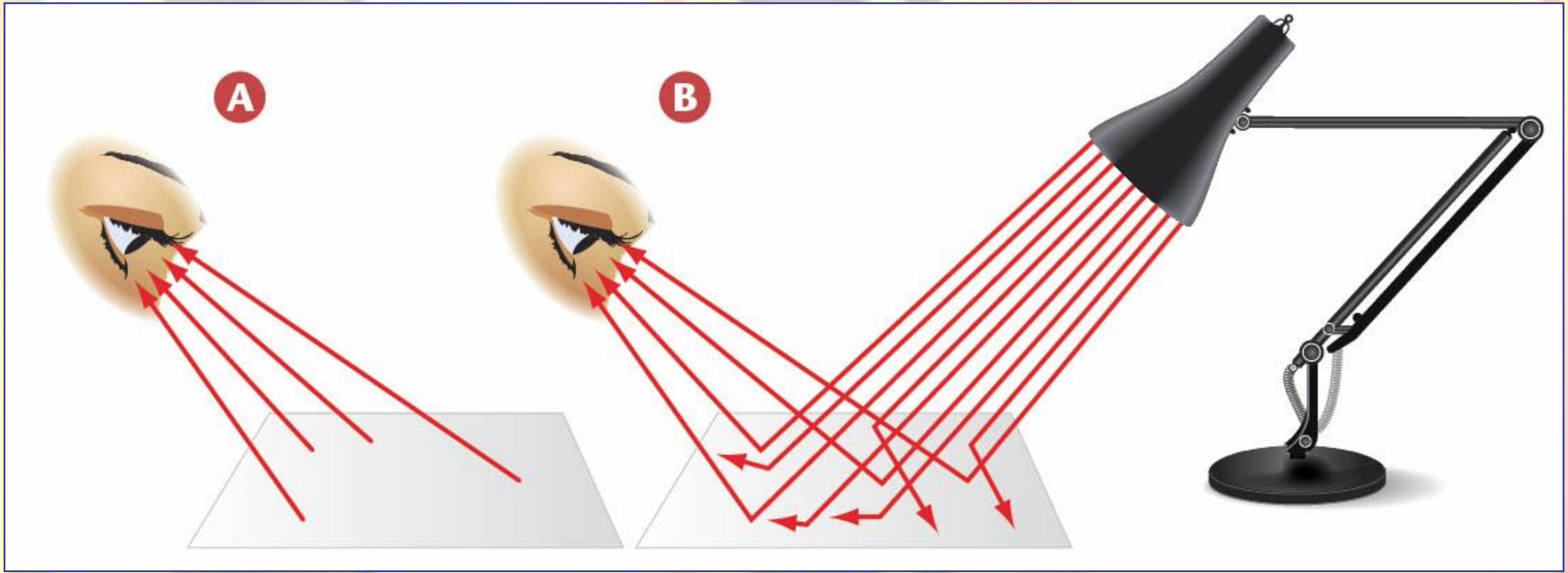
A **ray** is an arrow that shows the direction in which light is travelling.

Scientists use diagrams called **ray diagrams** to help them understand and make predictions about how light behaves.



Reflection — Light Changes Direction

Reflection is the process in which light "bounces off" the surface of an object and travels in another direction.



In **A** the person sees the object because light travels to their eyes. **B** shows that light must travel from a source (the lamp) and then **reflect** off the object toward the eye.

Absorption – Light Is Converted to Heat

Absorption is the process in which light energy remains in the object that it hits, and the light energy is converted into heat.

The “**E**” in the image above appears black because the ink absorbs all of the light that hits it. No light reaches your eyes from the printed “**E.**”

Reviewing Reflection and Absorption

Click the "Start" button to review the reflection and absorption of light.

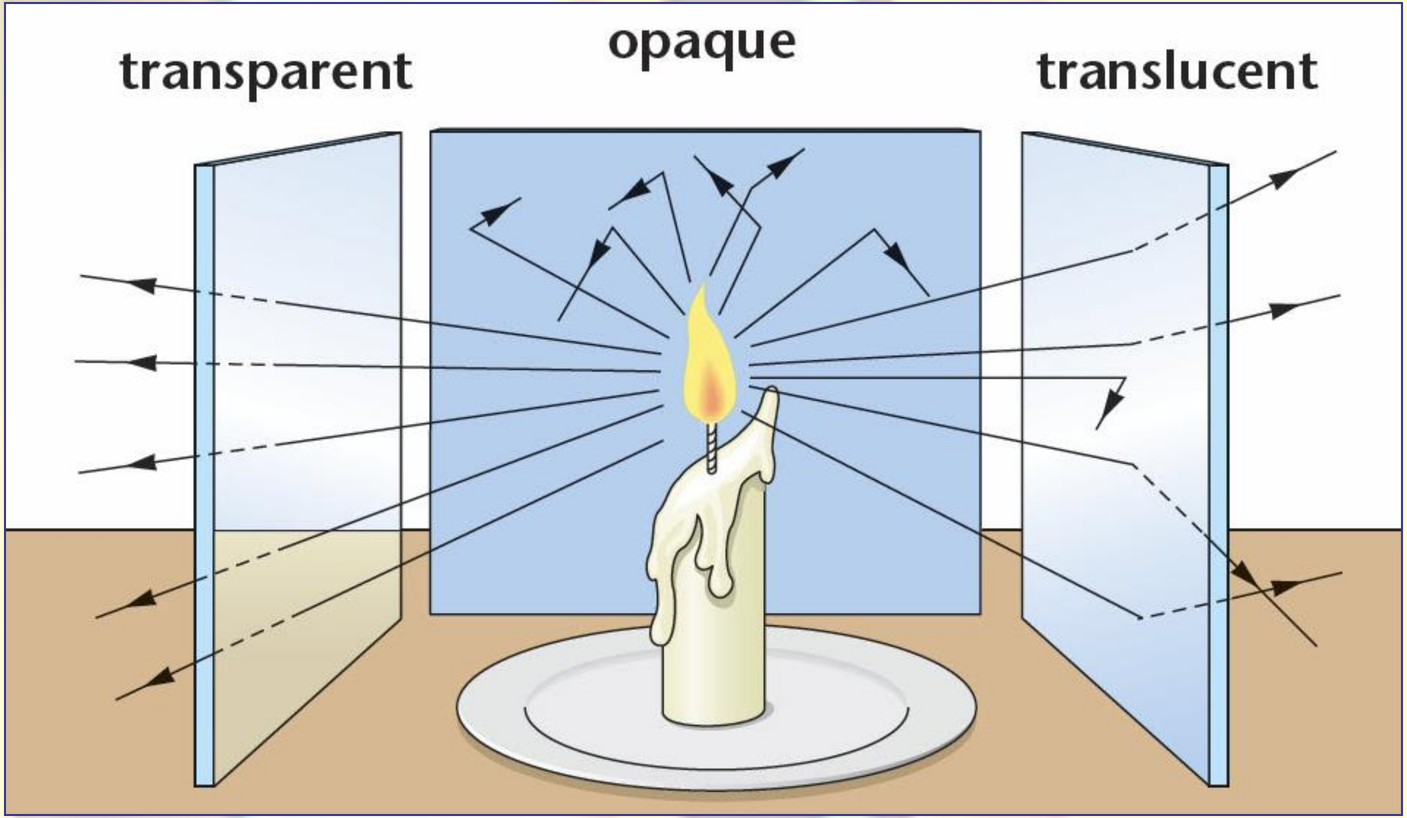
Transmission – Light Travels Through

Transmission is the process in which light travels through an object and continues travelling. Clear glass and plastic transmit most of the light that hits them. Light that is not transmitted by an object is either reflected or absorbed.

The coloured windows shown above allow only certain colours to be transmitted. The other colours are reflected or absorbed.

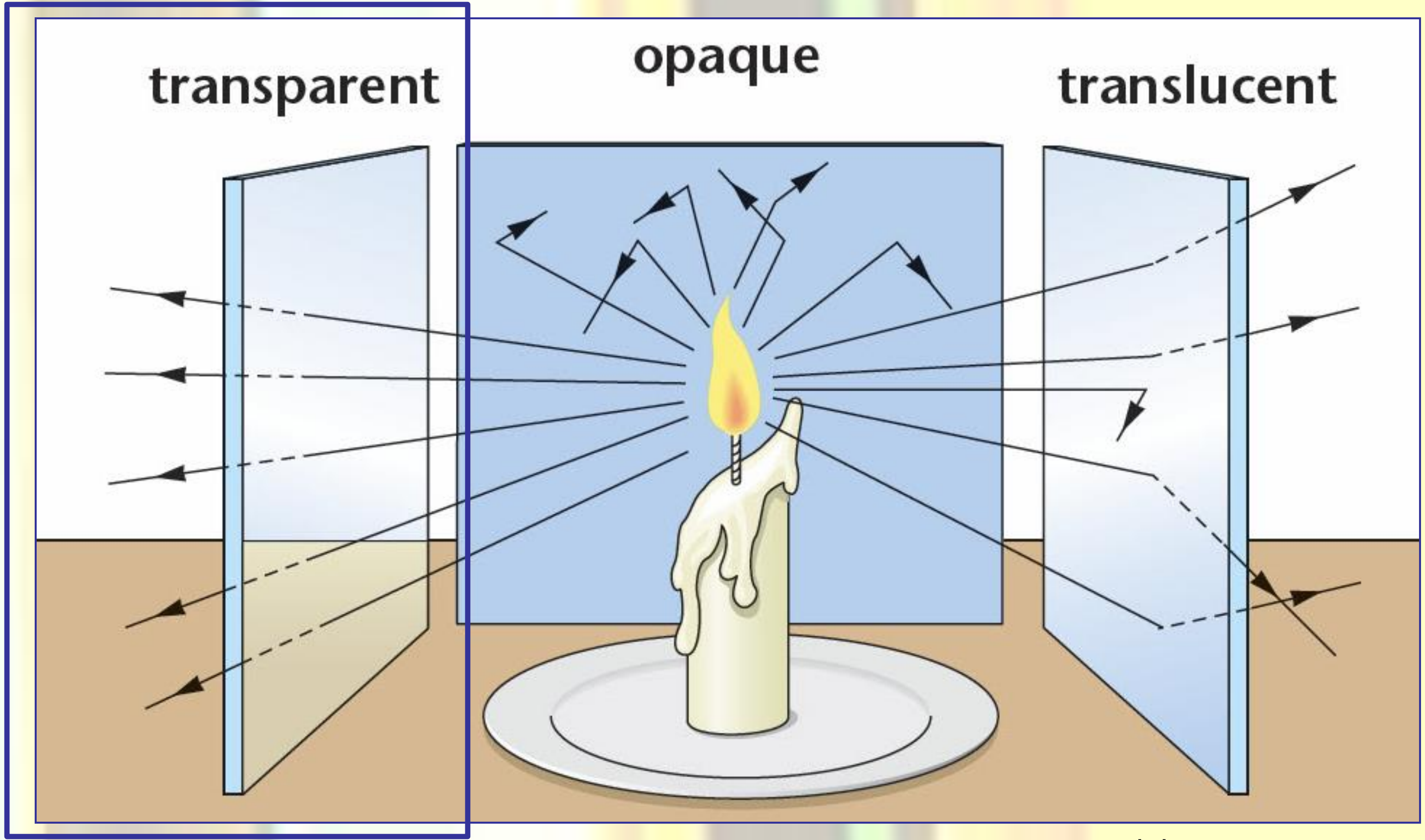
Transparent, Translucent, and Opaque Objects

Objects or materials are considered to be **transparent**, **translucent**, or **opaque** depending on how light behaves when it hits them.



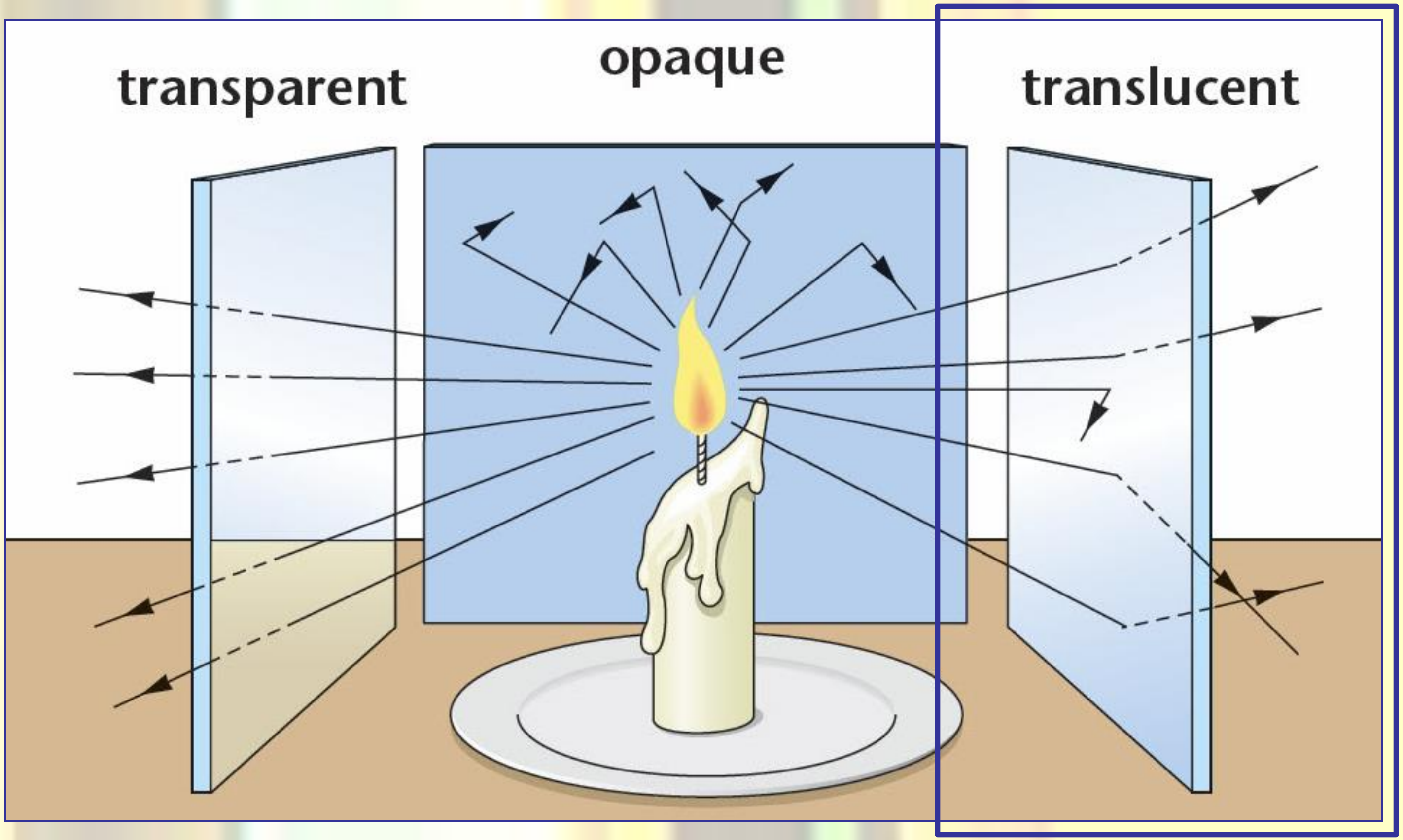
Transparent, Translucent, and Opaque Objects

Transparent materials allow light to penetrate or pass through them, making it possible to see objects from the other side.



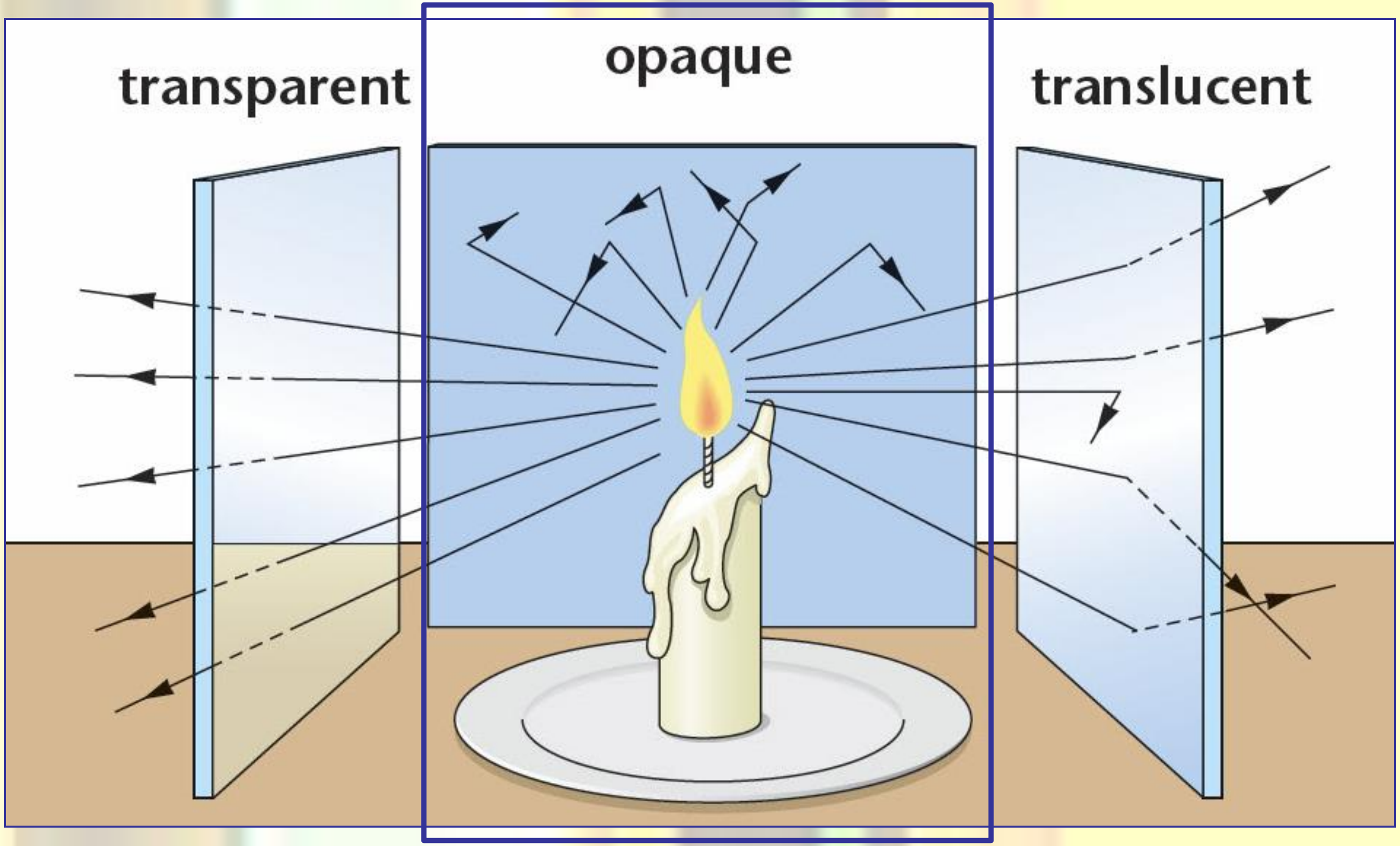
Transparent, Translucent, and Opaque Objects

Translucent materials allow light to pass through but scatters it in different directions.

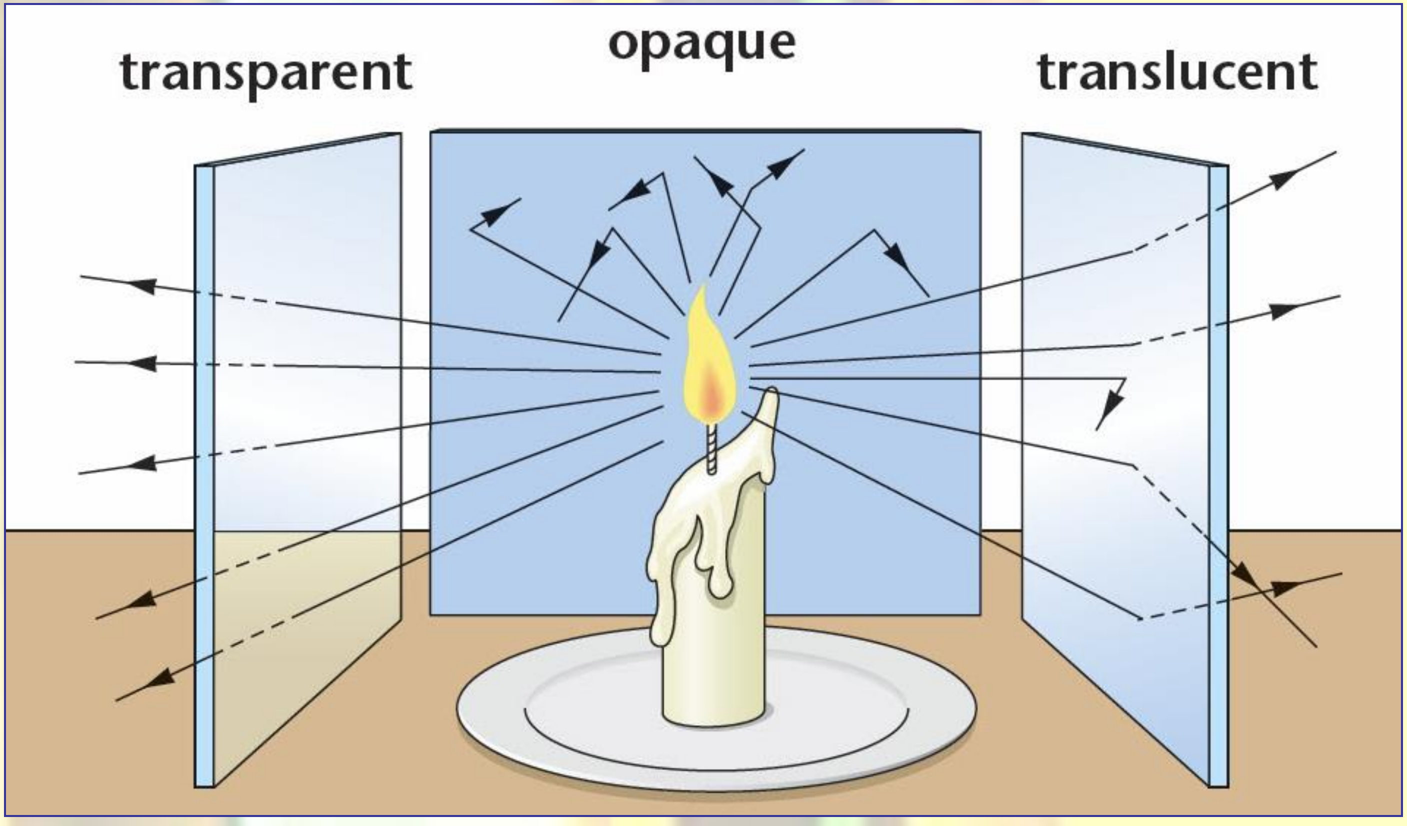


Transparent, Translucent, and Opaque Objects

Opaque materials do not allow any light to penetrate them. All light is either absorbed or reflected.



Transparent, Translucent, and Opaque Objects

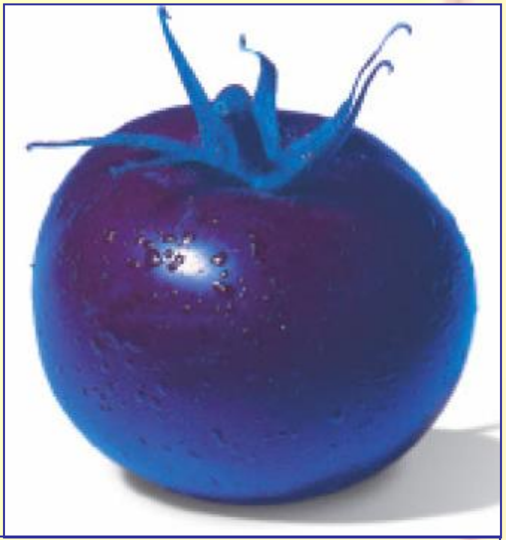


What examples of **transparent**, **translucent**, and **opaque** materials or objects can you think of?

Objects can absorb some colours and reflect or transmit others.

Opaque objects either absorb or reflect light. The colour an object appears to be is determined by the colours (or wavelengths) of light that are reflected by its surface and the colours that are absorbed by the object.

Under white light, the tomato appears to be red because only the red wavelength is reflected.

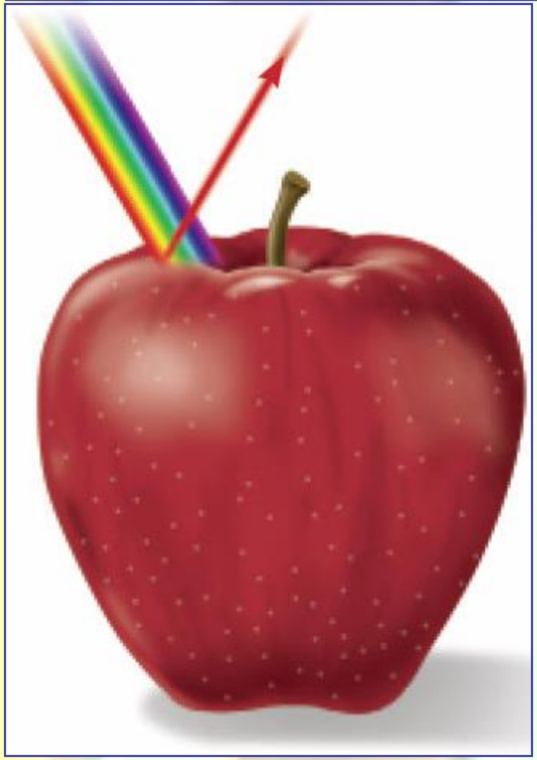


Under blue light, the tomato appears to be blue.

Objects can absorb some colours and reflect or transmit others.

The colour of an object is determined by which colours (or wavelengths) of light are reflected by its surface and which colours are absorbed by the object.

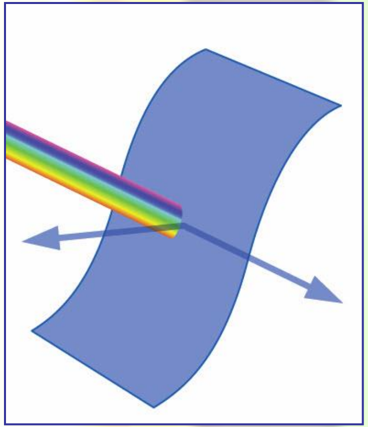
The apple reflects only red light.

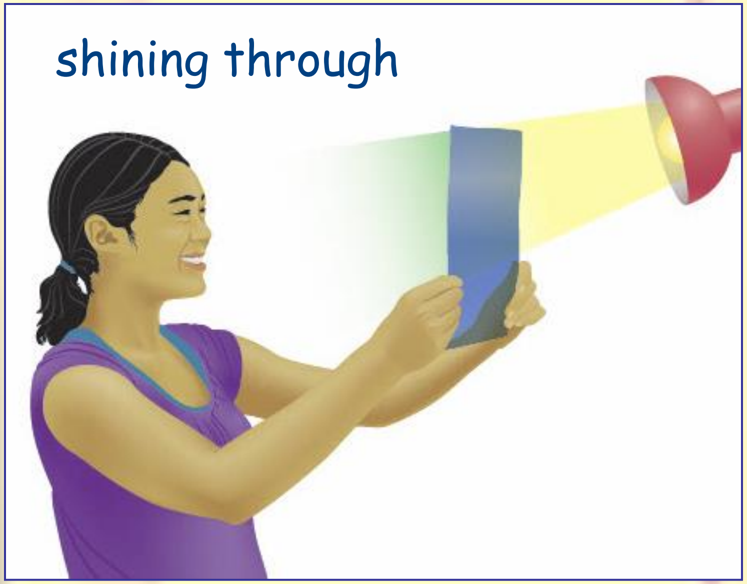


The pepper reflects only green light.

The Colour of a Transparent or Translucent Object

For a transparent or translucent object to have a certain colour, it must absorb all other colours of light and transmit and reflect only the colour that is its particular colour.





The cellophane pictured above looks blue whether light is shining on it or through it.

Topic 4.2 Review

Key concepts to be reviewed:

- Light can be reflected, absorbed, or transmitted by objects.
- Objects can absorb some colours and reflect or transmit others.

Topic 4.3 How can you mix colours to make different colours? (Pages 294-303)

Key Concepts

- Colours can be added together to form a variety of colours.
- Pigments can subtract colours from light.

How can you mix colours to make different colours?

The millions of colours on a computer monitor or TV screen are produced with only three colours. Your eyes have three types of colour-receiving cone cells that respond to colours of light.

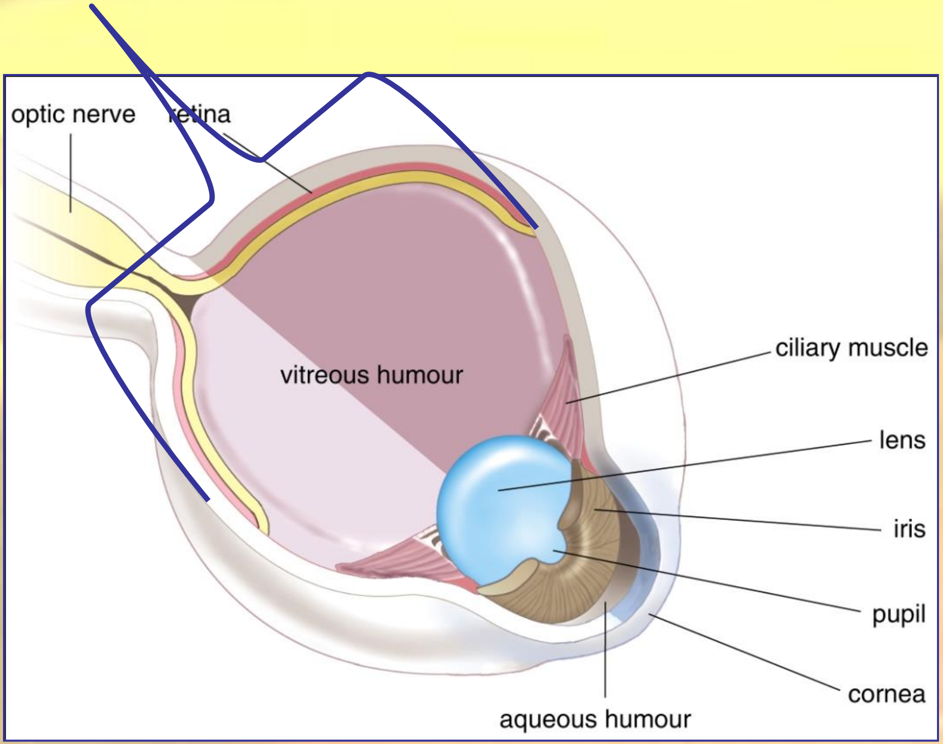
How can so many colours be produced from just **3** colours?

Colours of light can be added together to form a variety of colours.

In nature, there are thousands of different compounds, called pigments, that absorb different colours (wavelengths) of light.

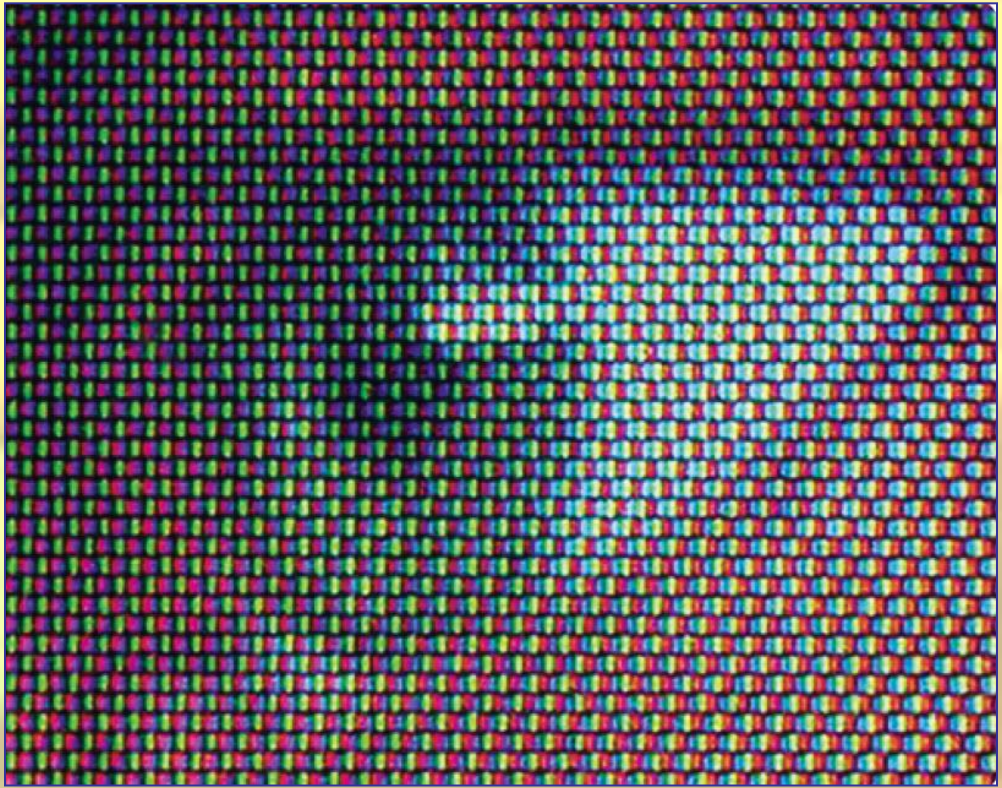
Light-sensitive cells in the retina

Each of the three types of cells in your eyes that are sensitive to colour respond to a group of wavelengths. Your brain combines the information to "see" the correct colour.



Mixing Colours

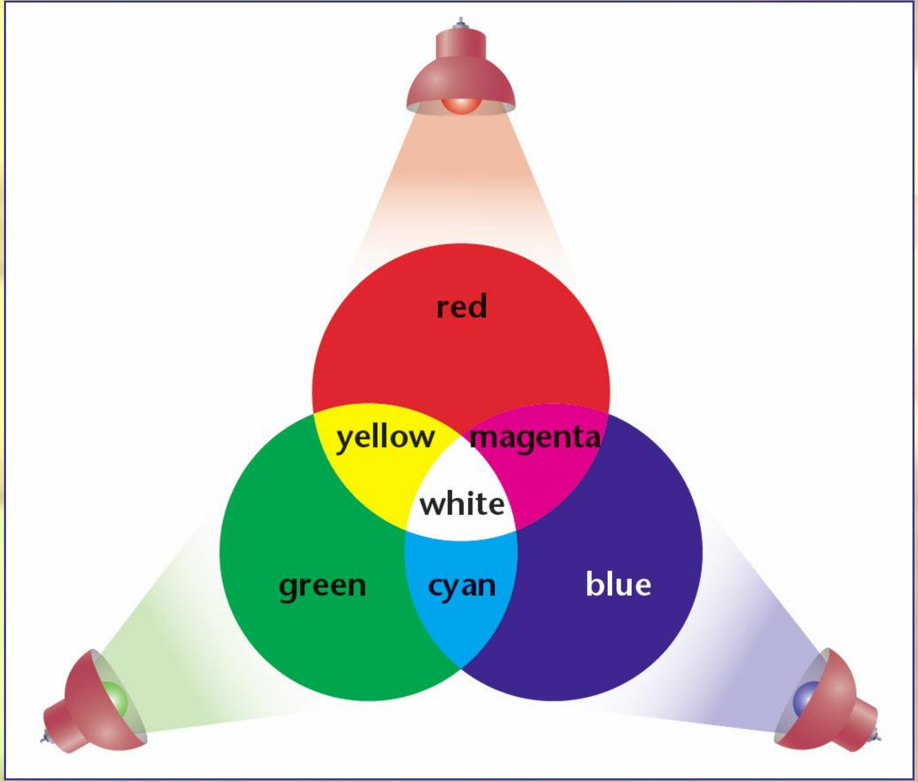
A system of three **primary colours** can create the effect of many different colours. The **primary colours** are three colours that, when combined in different amounts, can generate any other colour. Primary colours can be *additive* or *subtractive* (they can be added together or taken apart).



The enlarged picture of an LCD image lets you see individual pixels. As you get farther away from the picture, your eyes "mix" the colours in the pixels and you see an image.

Additive Primary Colours

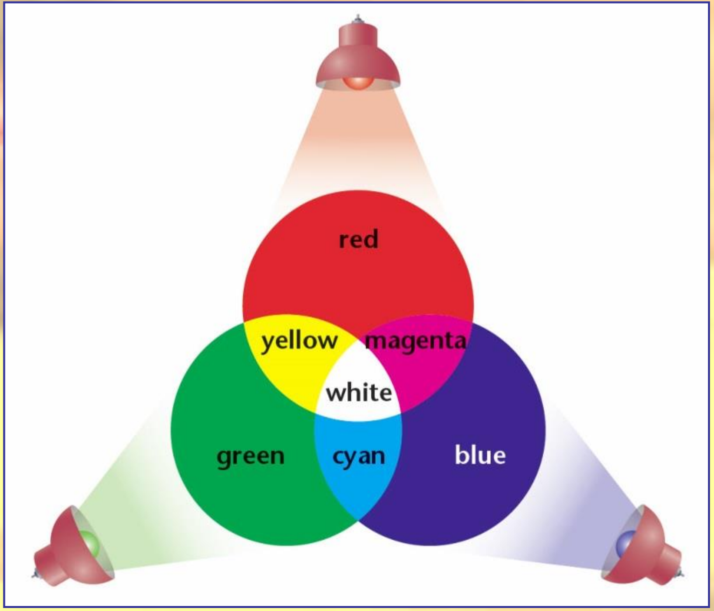
To add colours, you need sources of coloured light that can reach an observer's eyes. The light can go straight to the observer's eyes, or it can shine on a screen that reflects all colours.



The image to the left shows what happens if you shine the **additive primary colours** (red, green, and blue) on a reflective screen, and the lights overlap.

Additive Primary Colours

When the three **additive primary colours** (red, green, and blue) are shone together on a reflective screen, **white light** is produced where the three overlap. Where only two of the additive primary colours overlap, you see new colours, known as additive secondary colours.



Combining Additive Primary Colours

red + green + blue = white

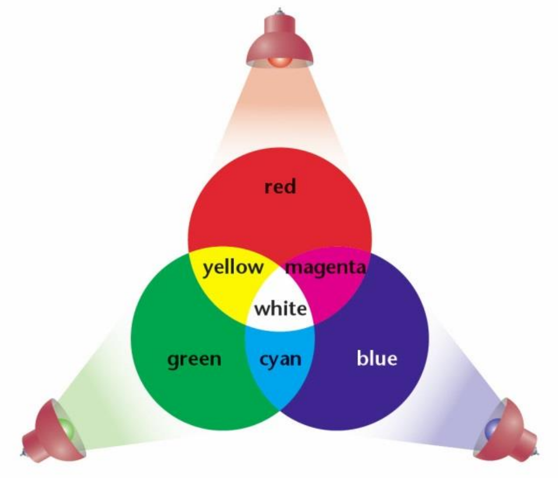
R + G + B = W

Additive Primary Colours

The additive **secondary colours** generated by combining two additive primary colours are **cyan**, **magenta**, and **yellow**.

red + green = yellow	red + blue = magenta	green + blue = cyan
R + G = Y	R + B = M	G + B = C

Complementary colours are a primary colour and the secondary colour created by mixing the other two primary colours. In the configuration on the right, complementary colours are opposite each other.



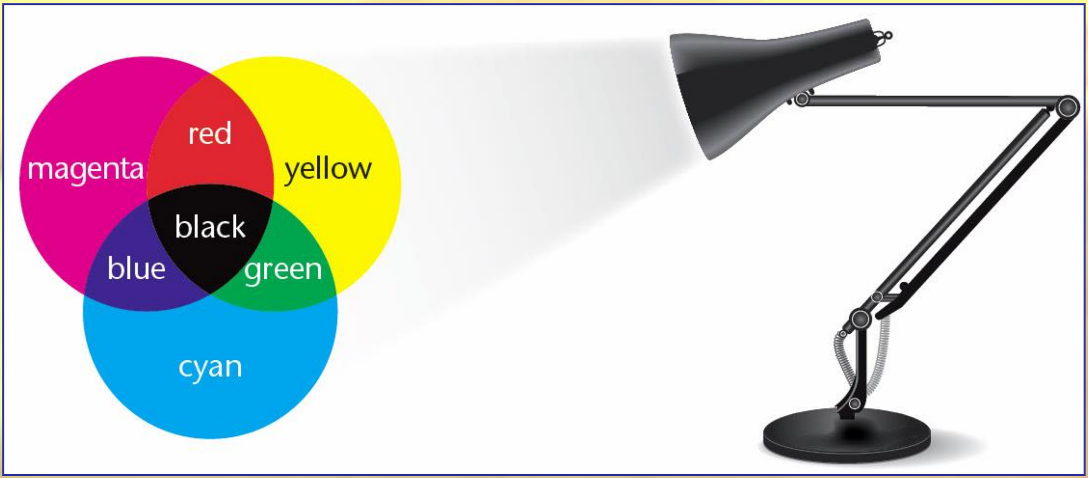
Complementary Colours

red—cyan green—magenta blue—yellow

Pigments can subtract colours from light.

When an object absorbs a colour, it removes (or subtracts) it from the beam of light. The colours of most of the objects that you observe every day are the result of subtracting colours.

There are three **subtractive primary colours: cyan**, **magenta**, and **yellow**. A variety of combinations of these three colours can subtract light from white light to produce nearly any colour.



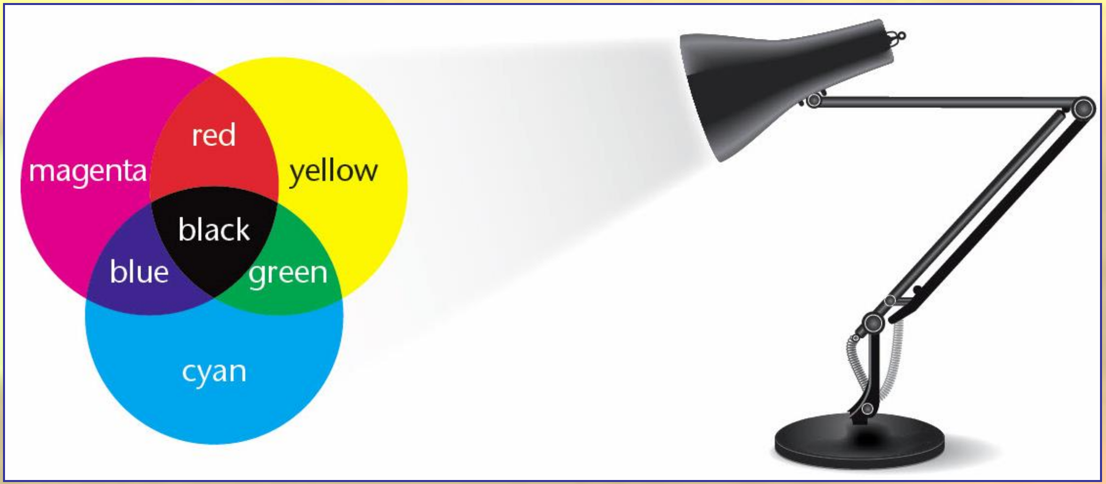
Magenta, cyan, and yellow films subtracting colours from white light. What do you see when these three overlap?

Pigments can subtract colours from light.

The colours produced by subtracting equal amounts of two of the three subtractive primary colours are called **subtractive secondary colours**.

white – (cyan + magenta) = blue	white – (cyan + yellow) = green	white – (magenta + yellow) = red
W – (C + M) = B	W – (C + Y) = G	W – (M + Y) = R

The **subtractive secondary colours** are the same as the three **additive primary colours** (red, green, and blue).



Pigments can subtract colours from light.

When the three **subtractive primary colours** are added together and subtracted from white light, you get **black**. The “code” for black is **K** so as not to be confused with blue.

Combining Subtractive Primary Colours

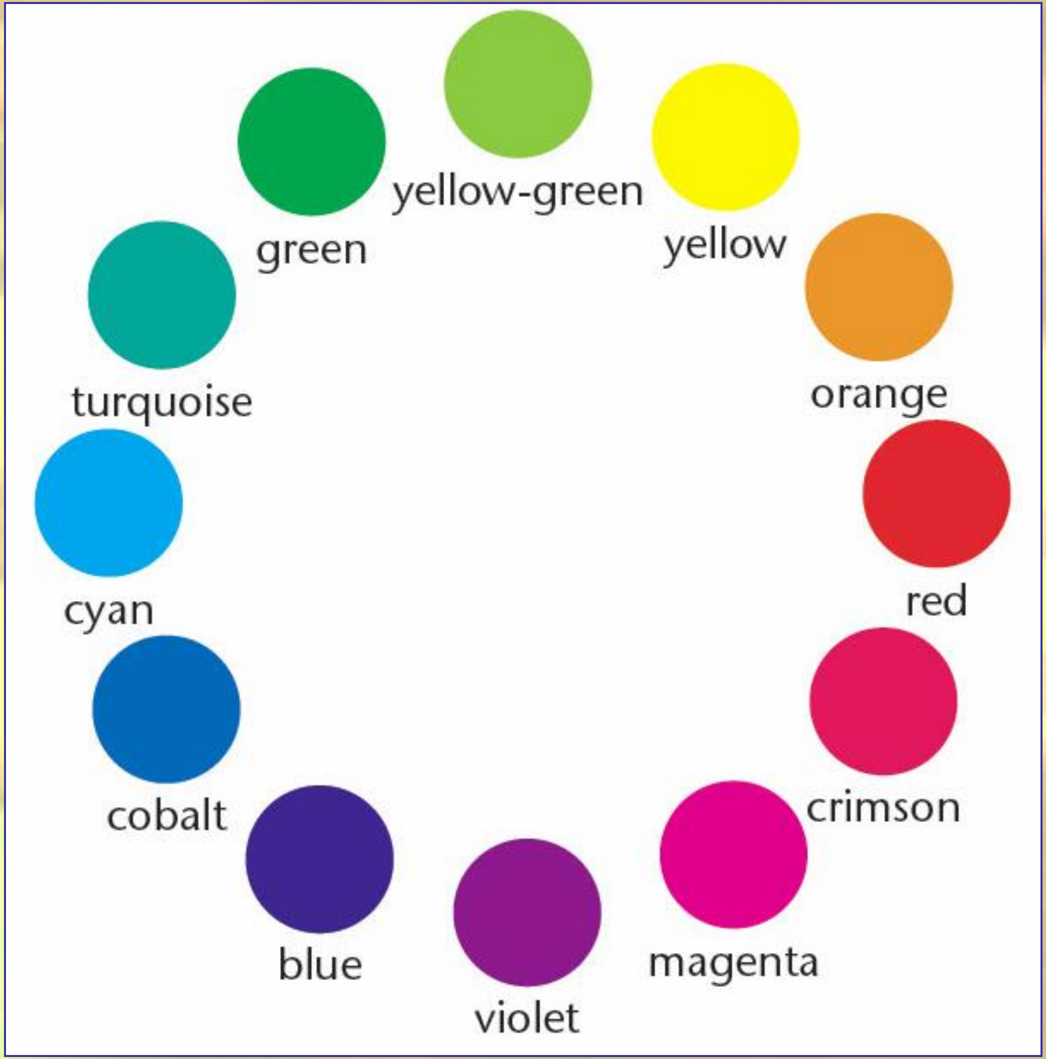
white – (cyan + magenta + yellow) = black

W – (C + M + Y) = K

Pigments can subtract colours from light.

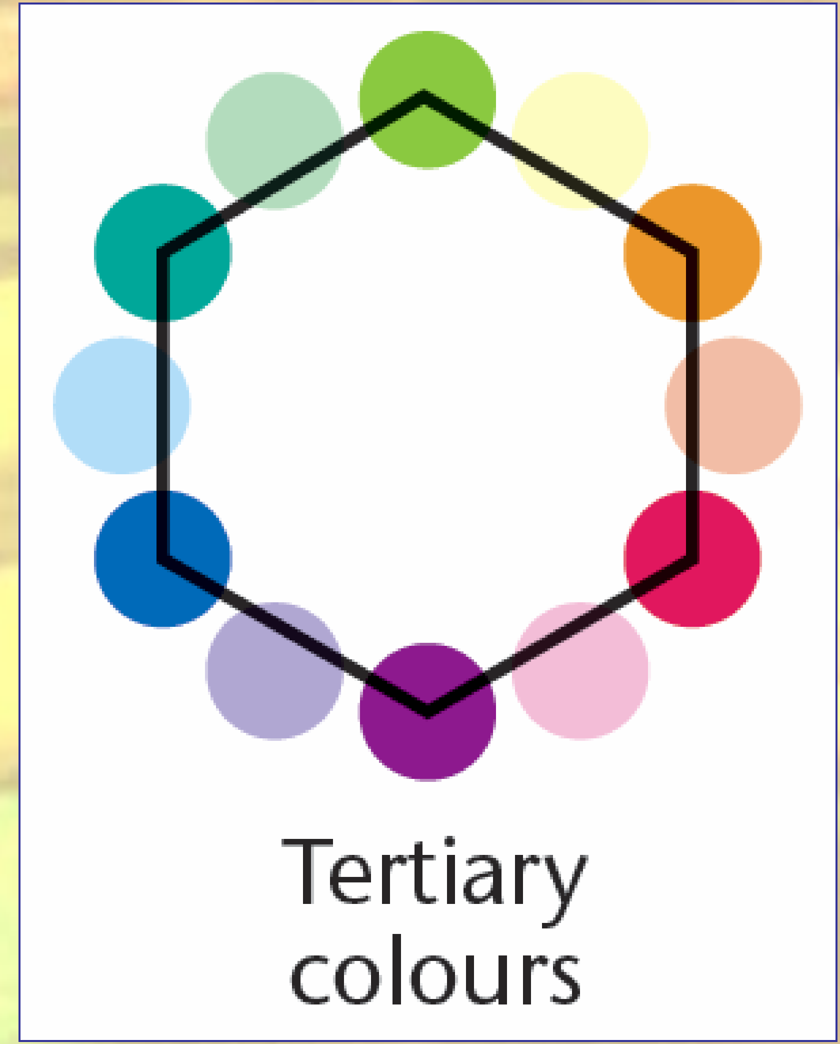
When reproducing colours on paper, most printers use only the three pigment colours cyan, magenta, and yellow, plus black. These three **subtractive primary colours** can make almost any other colour.

Colour Wheel



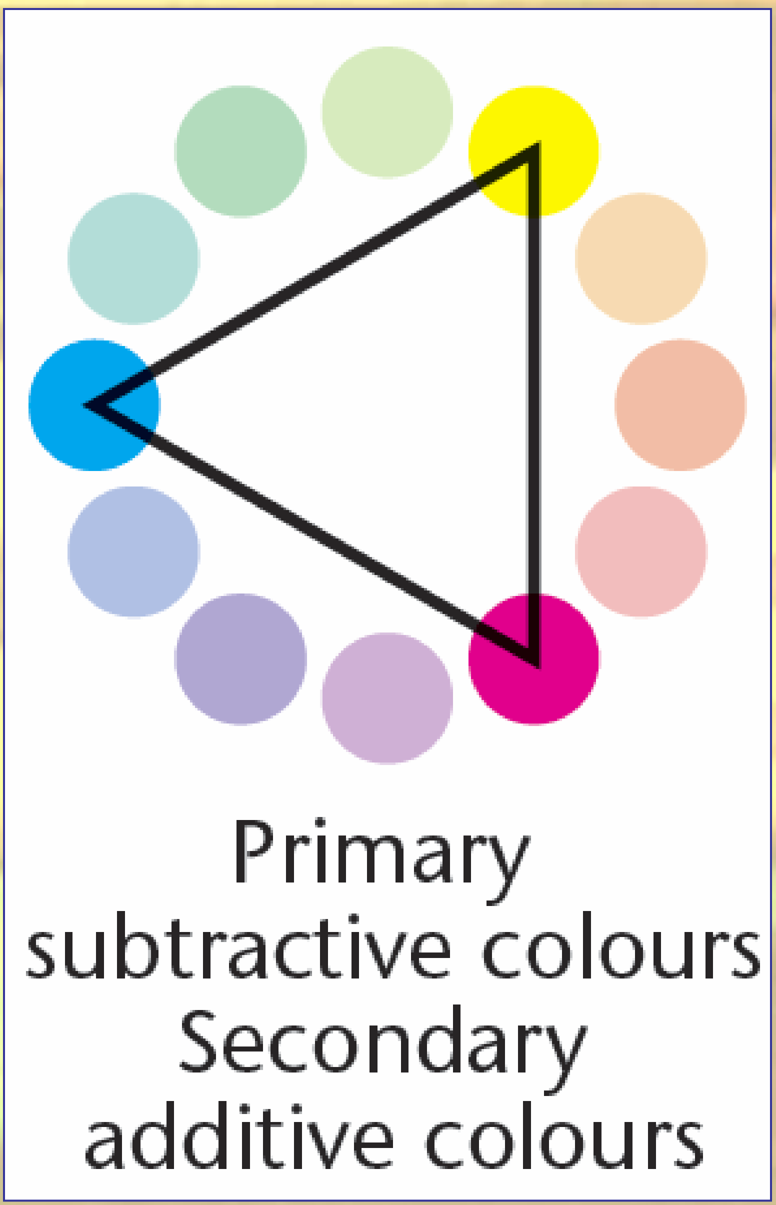
The **colour wheel** summarizes the relationships among additive and subtractive primary, secondary, and complementary colours. In addition, it includes tertiary colours.

Colour Wheel



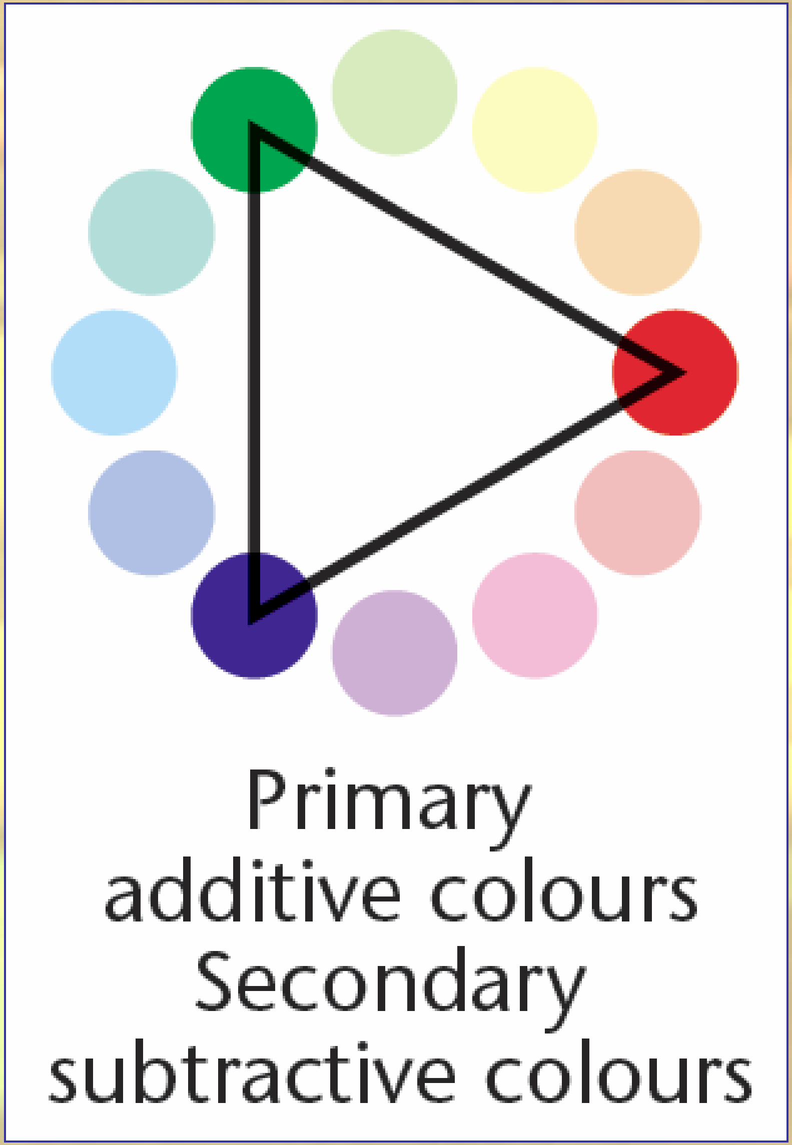
Tertiary colours are formed by mixing the secondary colours. The resulting colours are **yellow-green**, **orange**, **crimson**, **cobalt**, and **turquoise**.

Colour Wheel Relationships



The **subtractive primary colours** cyan, magenta, and yellow are the same as the **additive secondary colours**.

Colour Wheel Relationships



The **additive primary colours** red, green, and blue are the same as the **subtractive secondary colours**.

Colour Wheel Relationships

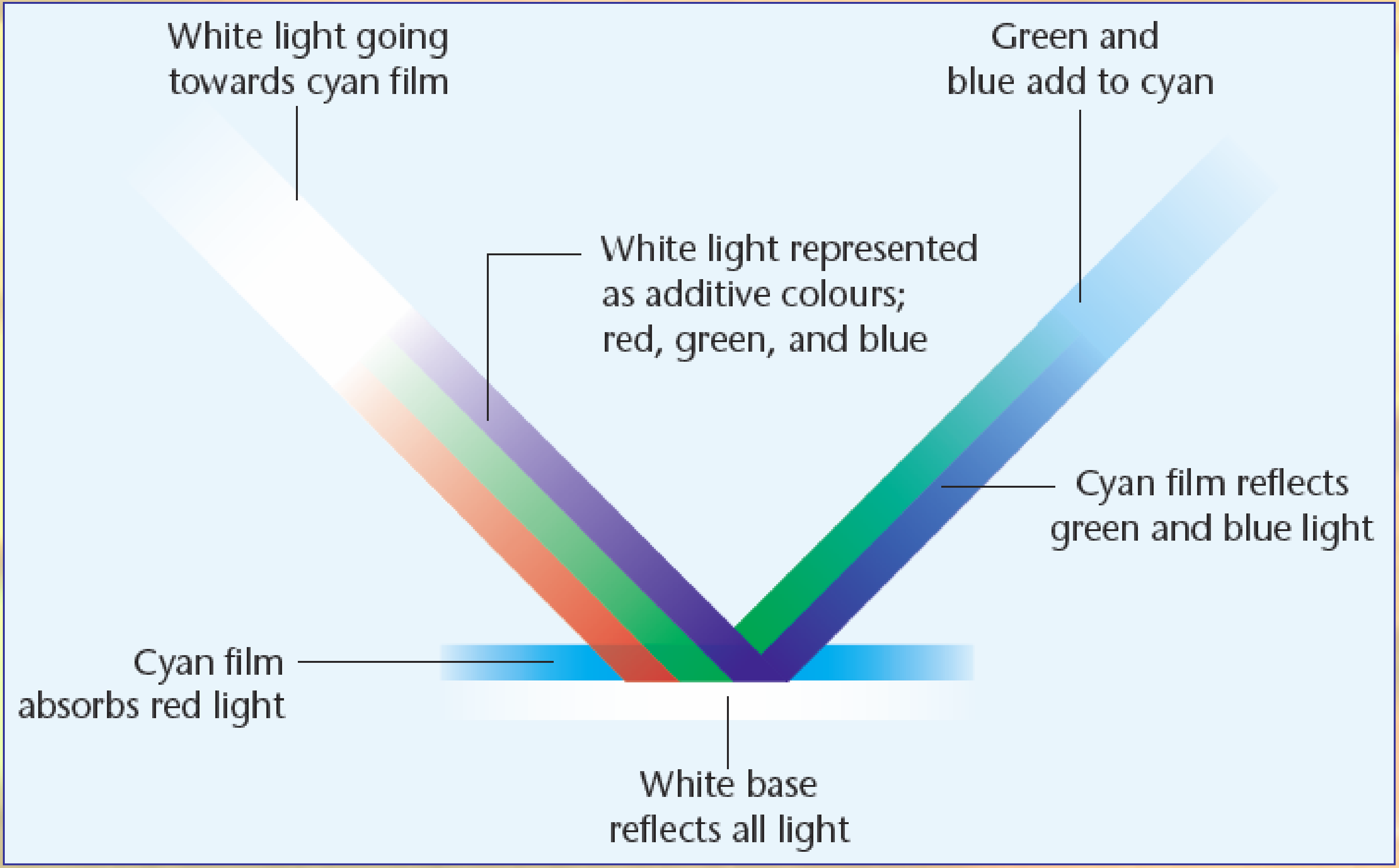
The colours that are directly across from each other on the colour wheel are **complementary colours**.

When you **add** complementary colours, the result is **white**.

When you **subtract** complementary colours, the result is **black**.

Using Diagrams to Illustrate Subtracting Colours

Diagrams can be used to show how colours are subtracted from white light when it hits a film of a certain colour.



Topic 4.3 Review

Key concepts to be reviewed:

- *Colours of light can be added together to form a variety of colours.*
- *Pigments can subtract colours of light.*

Topic 4.4 What is the law of reflection? How do mirrors form images?

(Pages 304-31)

Key Concepts

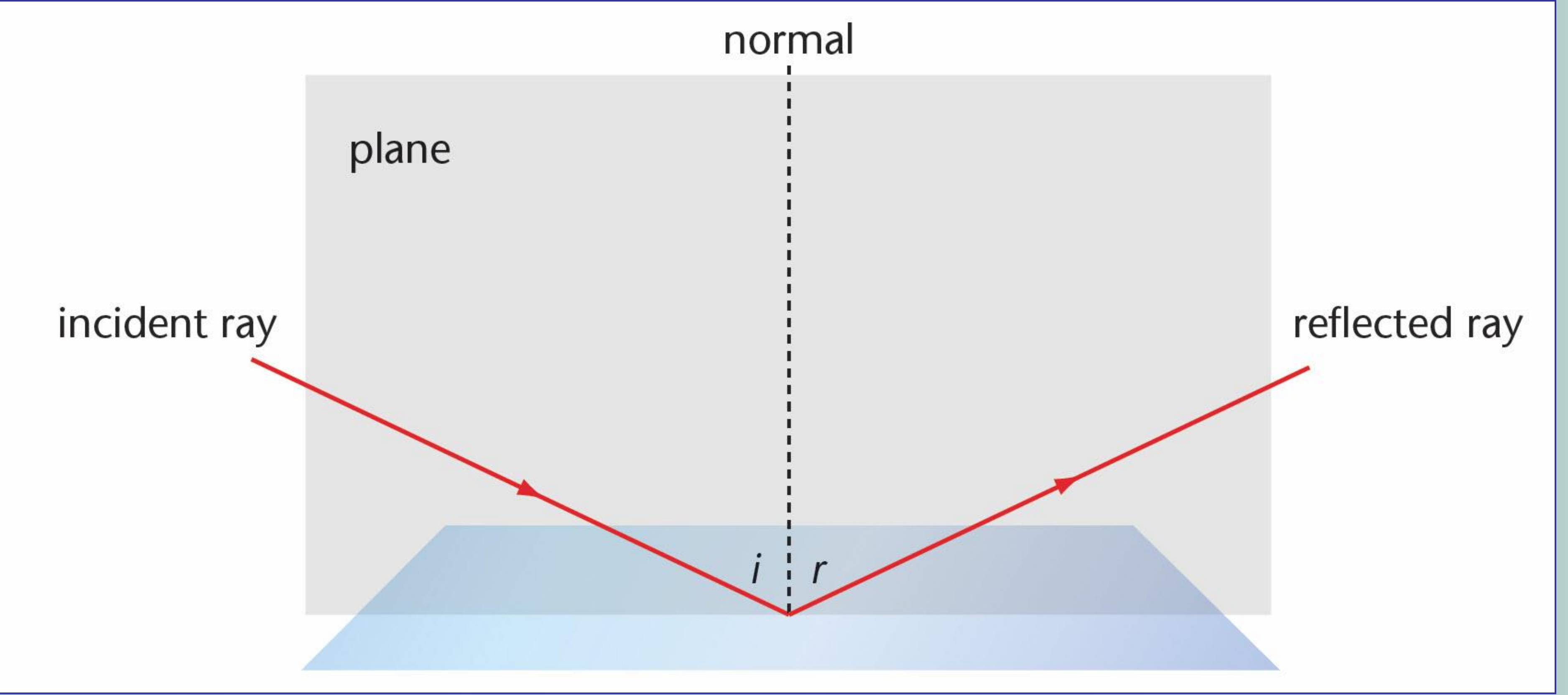
- The angle of reflection is equal to the angle of incidence.
- Plane mirrors form images that are nearly identical to the object.
- Concave mirrors can form real, inverted images.
- Concave mirrors can form upright, virtual images.
- Convex mirrors always form images that are smaller than the object.

What is the law of reflection and how do mirrors form images?

Why does still water reflect a perfect image, but wavy water doesn't?

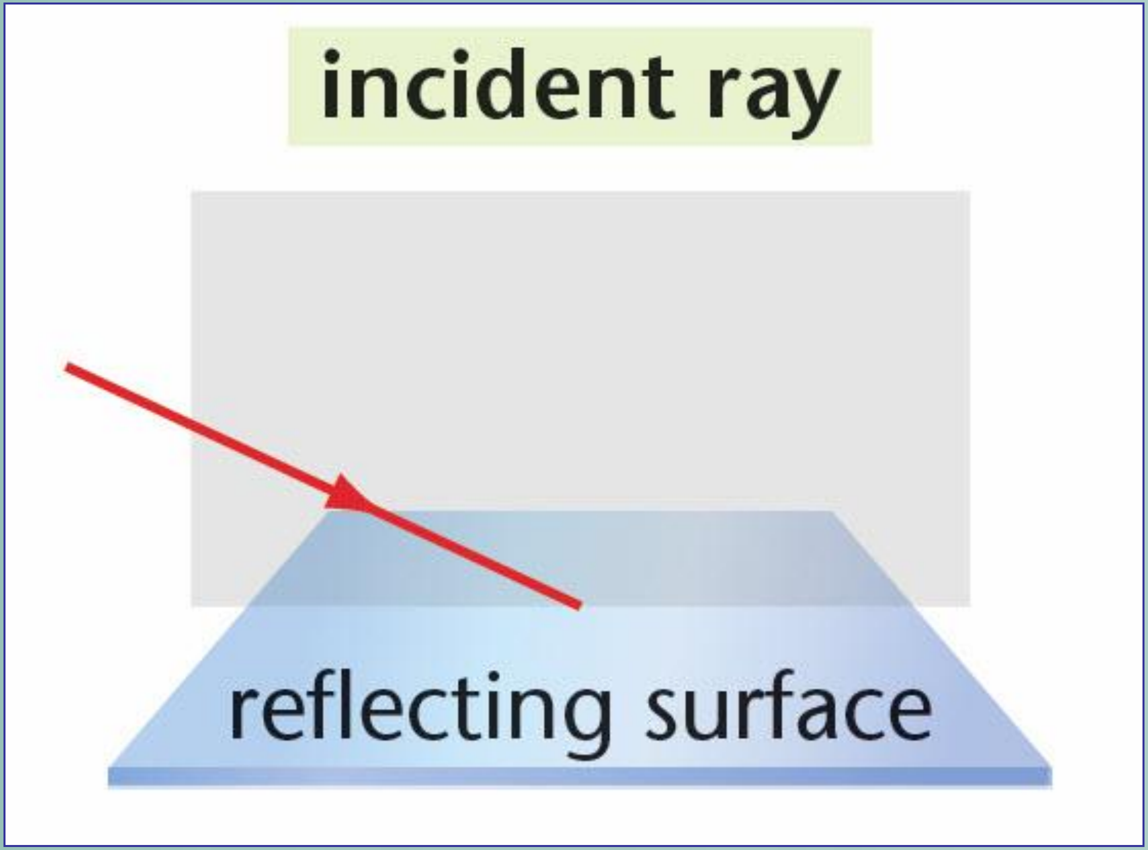
The angle of reflection is equal to the angle of incidence.

Key terms that apply to light rays and reflection are shown in the diagram below. Details are on the slides that follow.



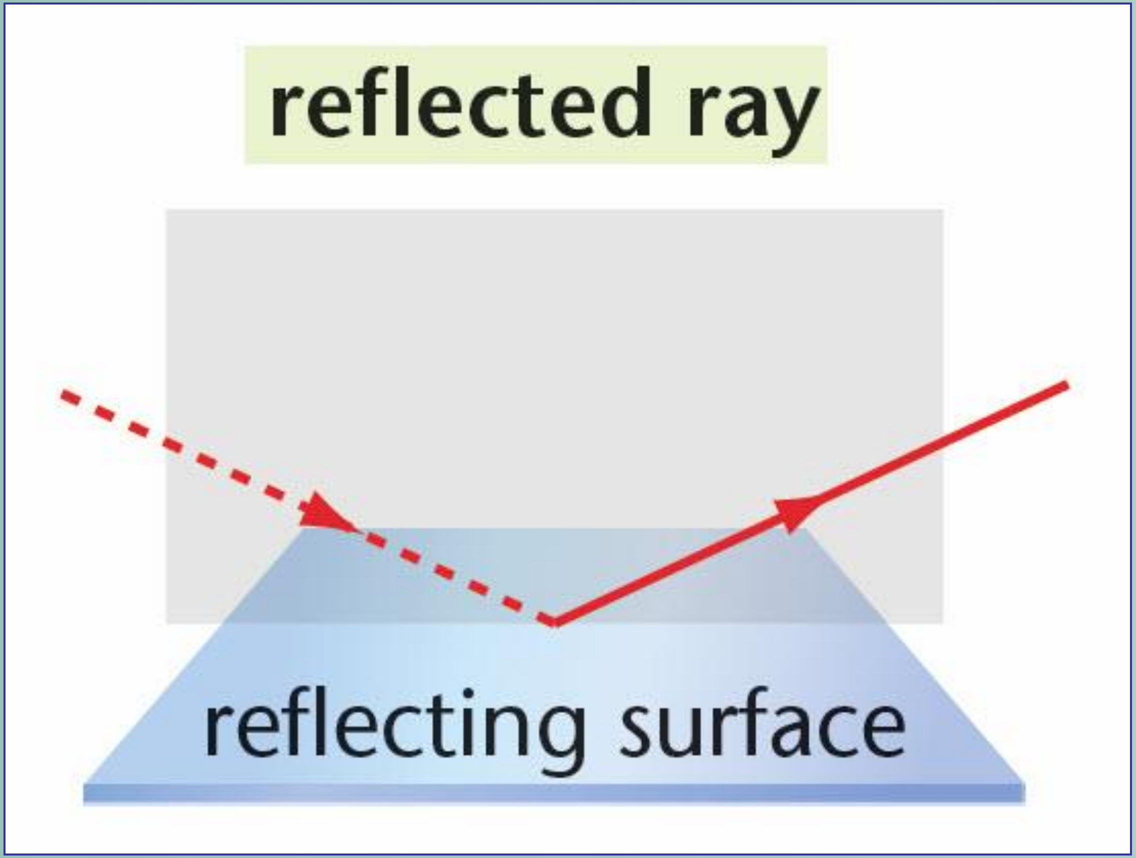
The angle of reflection is equal to the angle of incidence.

The **incident ray** is the light ray travelling toward the mirror or other surface.



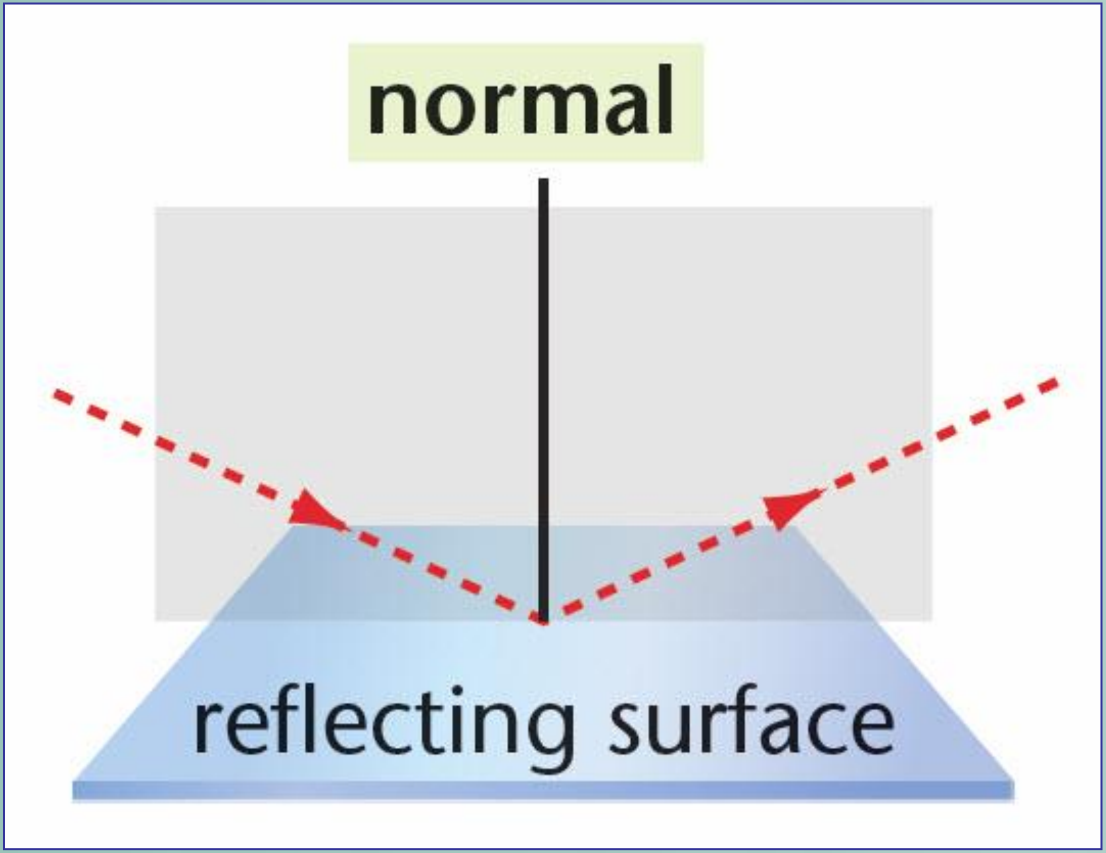
The angle of reflection is equal to the angle of incidence.

The **reflected ray** is the light ray that has "bounced" off a reflecting surface.



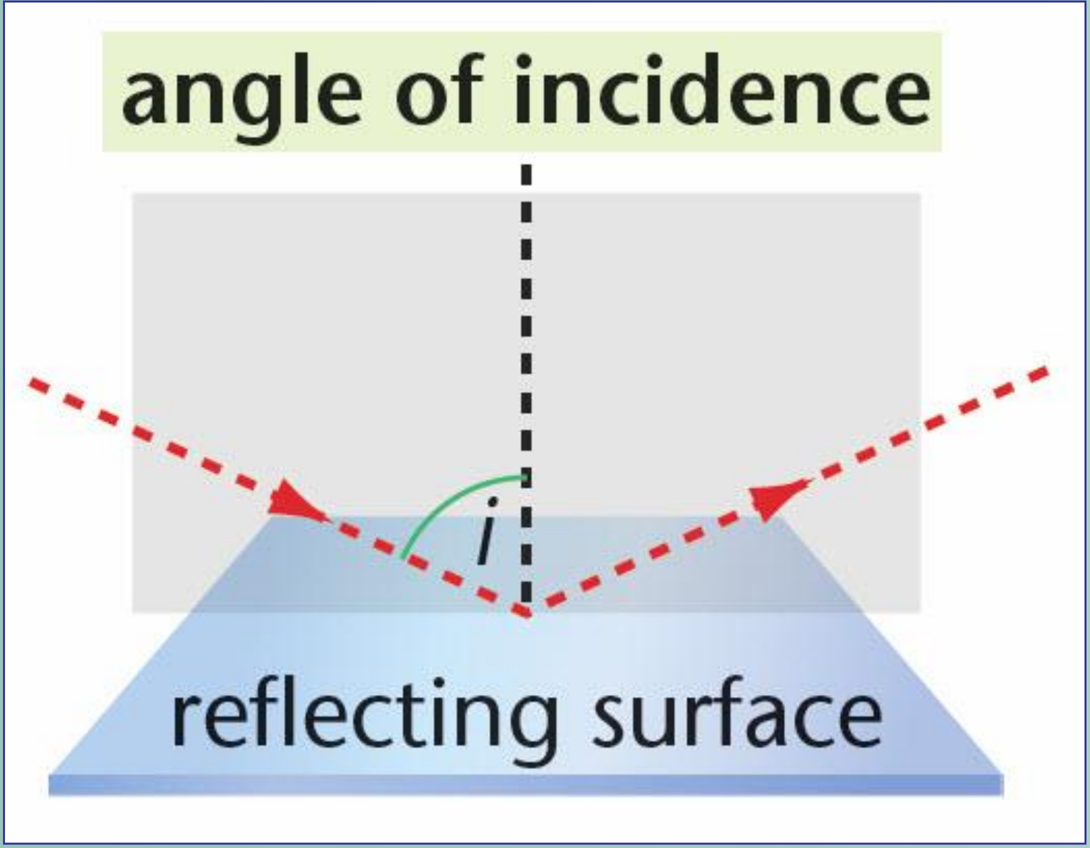
The angle of reflection is equal to the angle of incidence.

The **normal** is a line that is perpendicular to a surface such as a mirror.



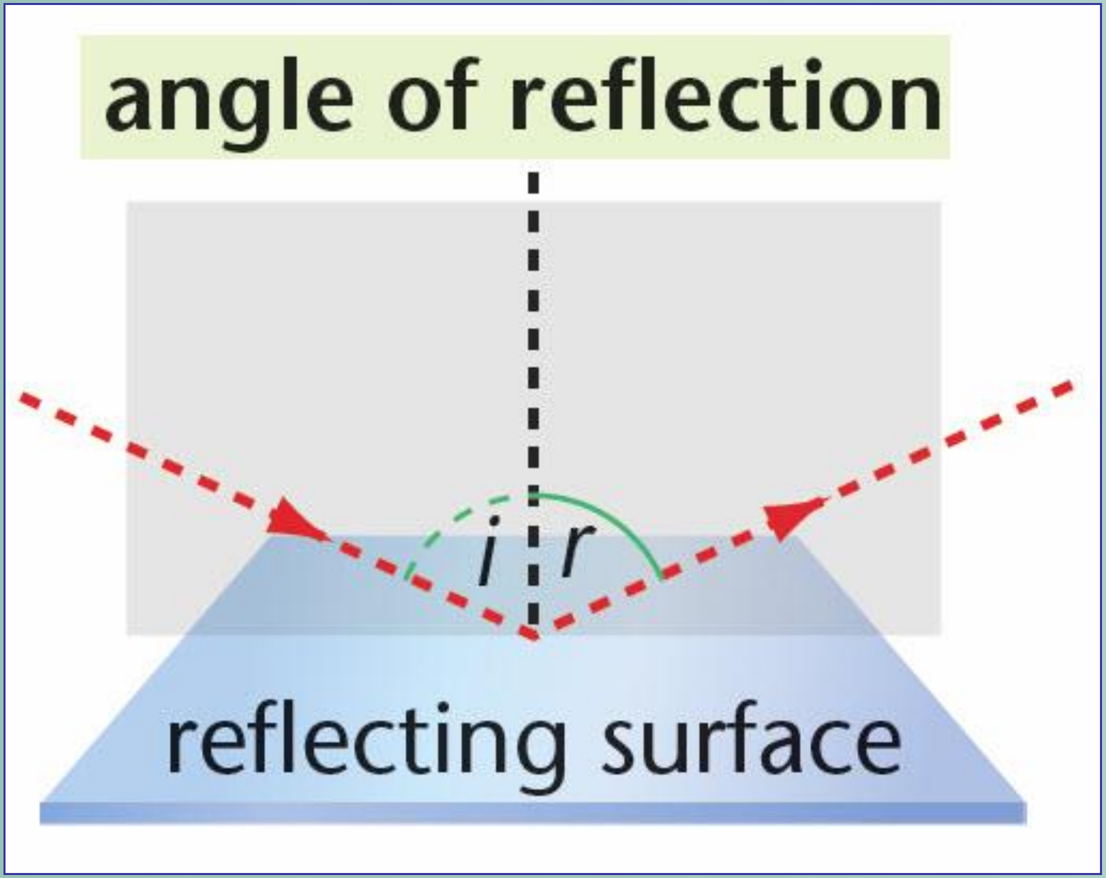
The angle of reflection is equal to the angle of incidence.

The **angle of incidence** (*i*) is the angle between the incident ray and the normal.



The angle of reflection is equal to the angle of incidence.

The **angle of reflection** (*r*) is the angle between the reflected ray and the normal.

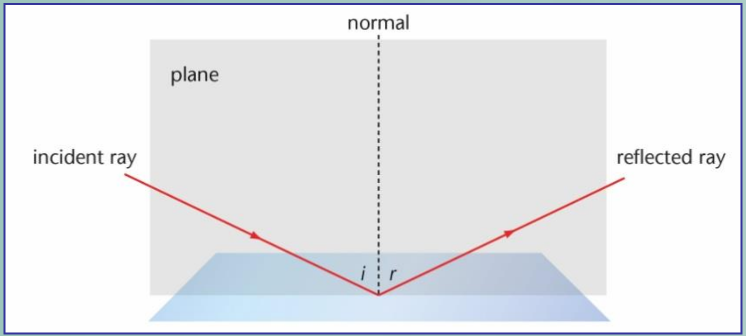


The Law of Reflection

The **Law of Reflection** applies to every reflecting surface.
The word "plane" refers to any flat surface.

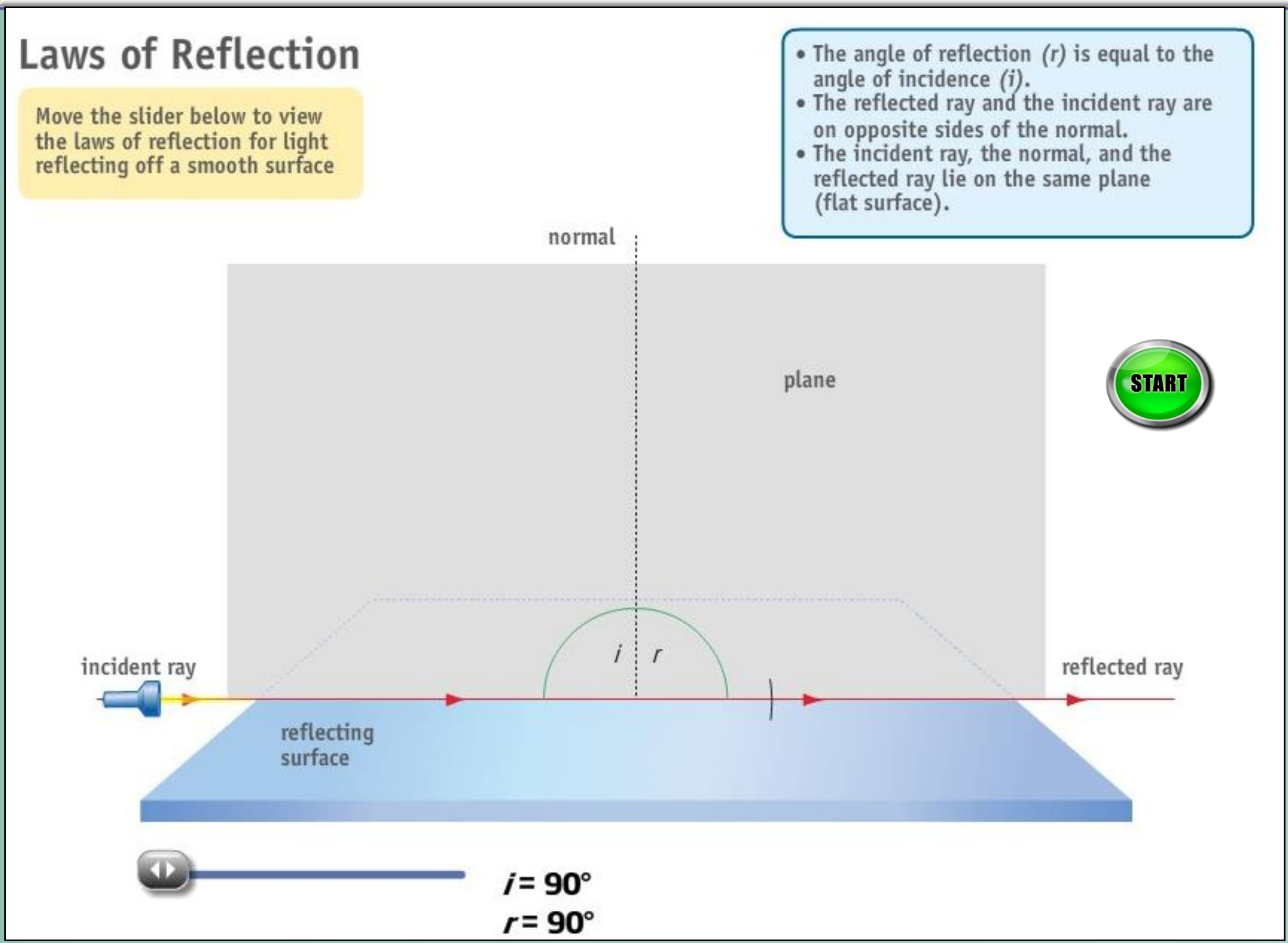
Law of Reflection

- The angle of reflection (r) is equal to the angle of incidence (i).
- The reflected ray and the incident ray are on opposite sides of the normal.
- The incident ray, the normal, and the reflected ray lie on the same plane (flat surface).



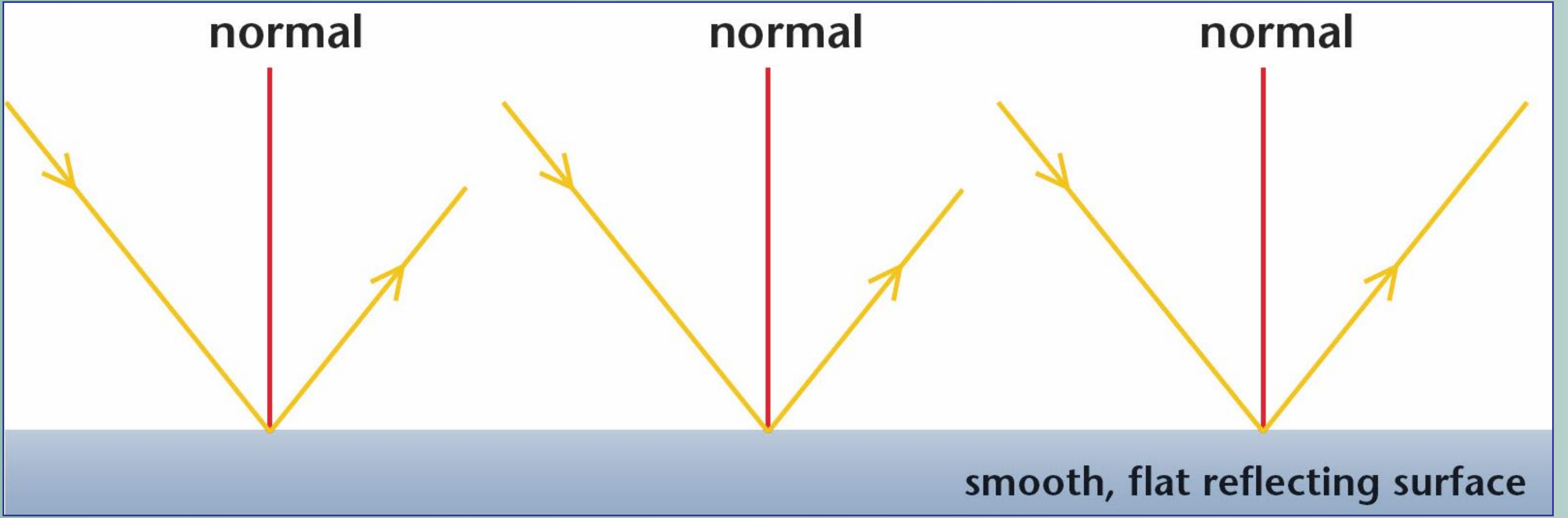
Reviewing the Law of Reflection

Click the “Start” button to review the law of reflection.



How Smooth Reflecting Surfaces Differ from Rough Reflecting Surfaces

The law of reflection applies to every reflecting surface, whether they are smooth or rough.



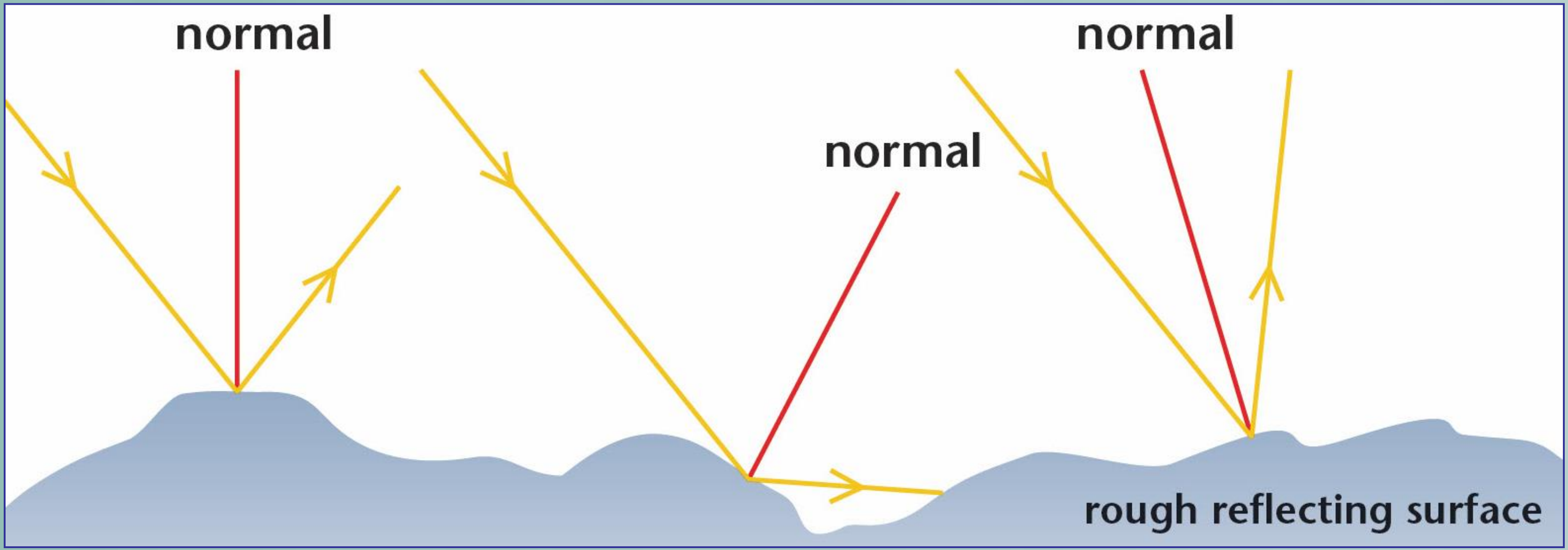
When light reflects off a smooth surface, the normals are all parallel to each other so the reflected rays leave the surface with the same pattern that the incident rays had.

How Smooth Reflecting Surfaces Differ from Rough Reflecting Surfaces

Smooth surfaces result in reflected images that look the same as the original object.

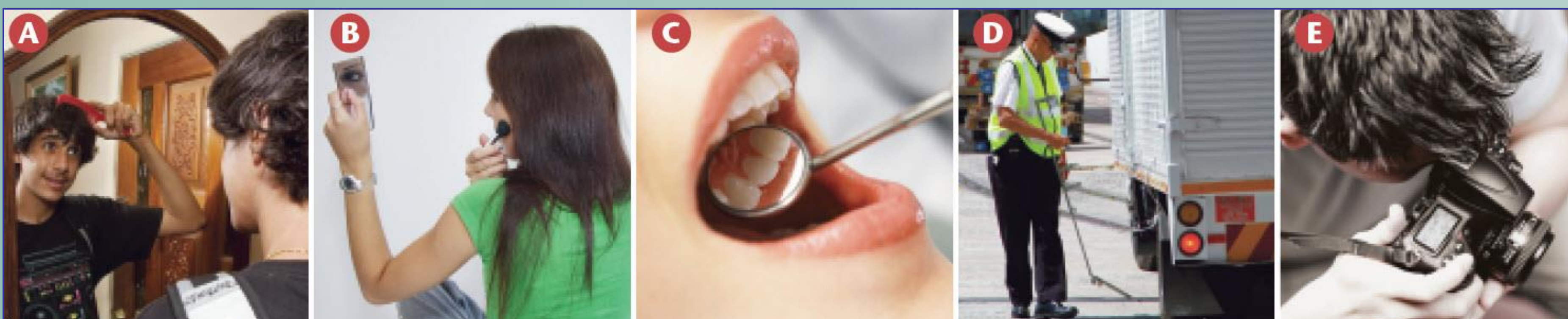
How Smooth Reflecting Surfaces Differ from Rough Reflecting Surfaces

When light reflects off a rough surface, the normals all point in different directions. Although the incident rays are parallel to each other, the angles of incidence are all different. This results in the angles of reflection being different. The reflected rays leave the surface with a totally different pattern than the incident rays had.



Plane mirrors form images that are nearly identical to the object.

Any smooth, flat reflecting surface, such as a mirror, is called a **plane mirror**. Examples of plane mirrors are shown below.

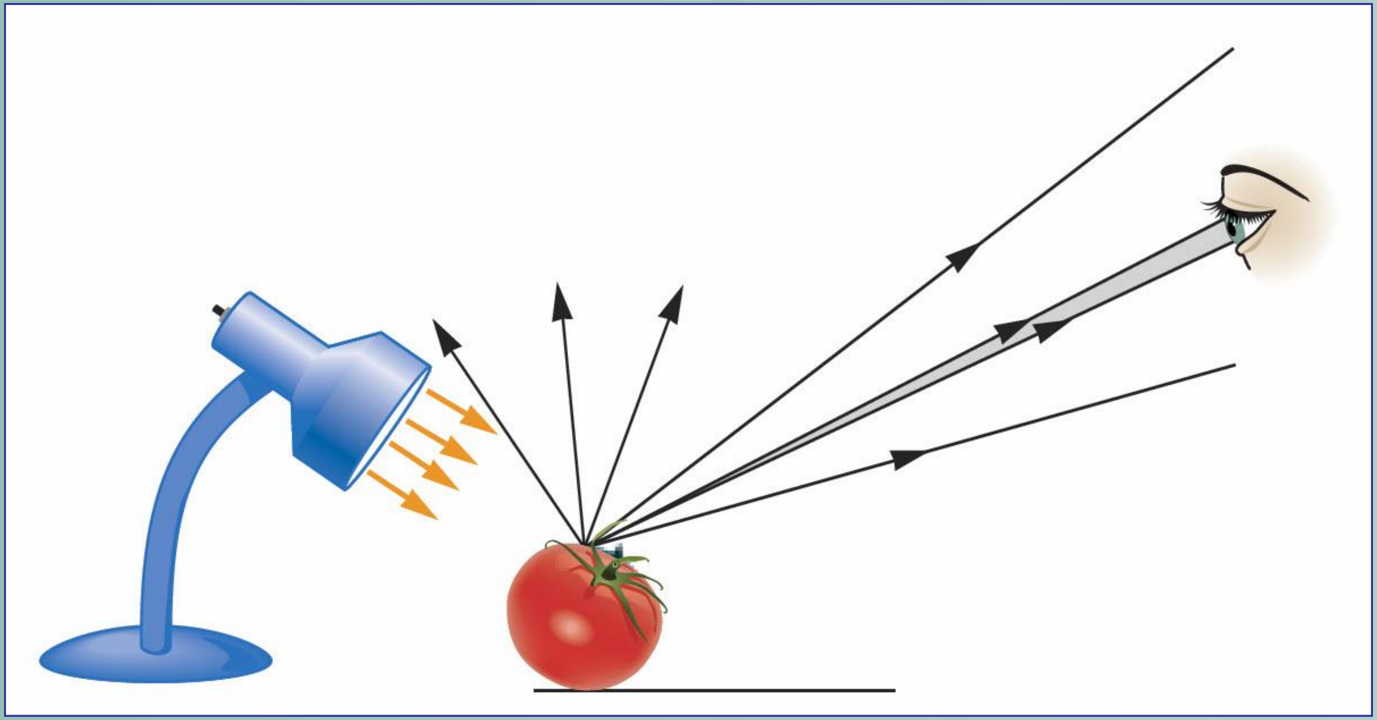


- **A** and **B**, grooming mirrors
- **C**, dentist's mirror
- **D**, security mirror
- **E**, camera viewfinder mirror

What other examples of plane mirrors can you think of?

Seeing Objects

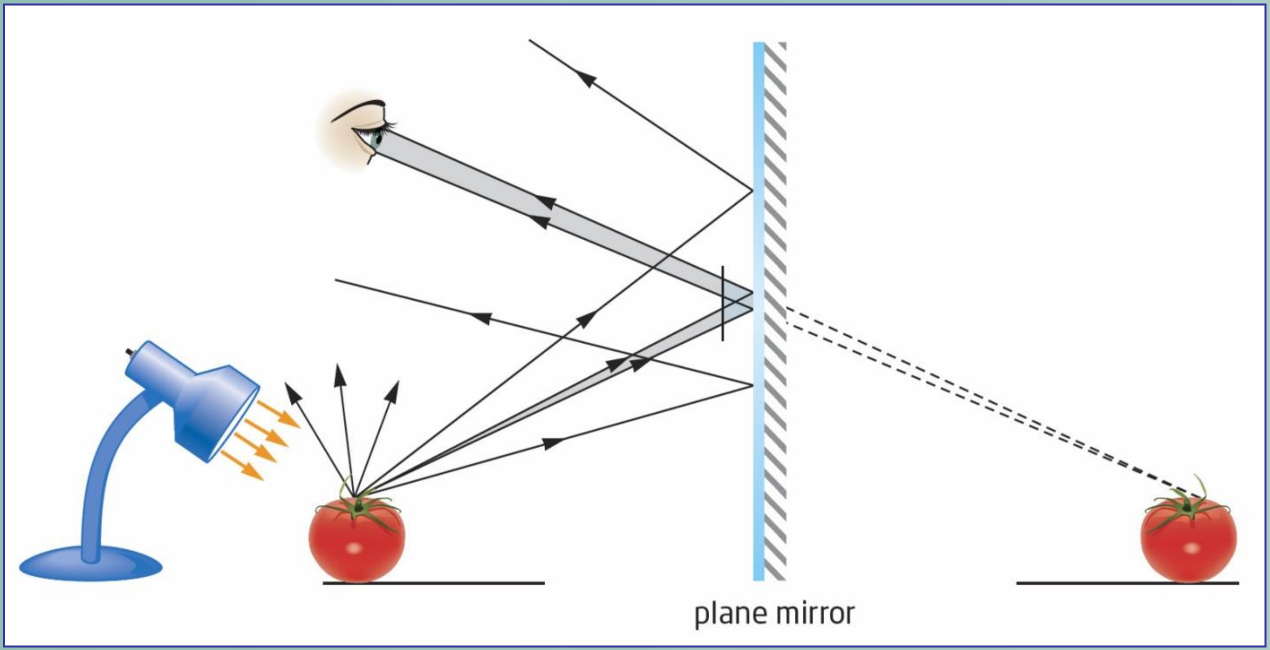
You "see" an entire object because reflected light from every part of the object is reaching your eyes.



The lens of your eye focuses the rays, and your eyes send messages to your brain about the object.

Images in Plane Mirrors

When an object is put in front of a plane mirror, all of the light rays from the object strike the mirror and reflect from it according to the law of reflection.

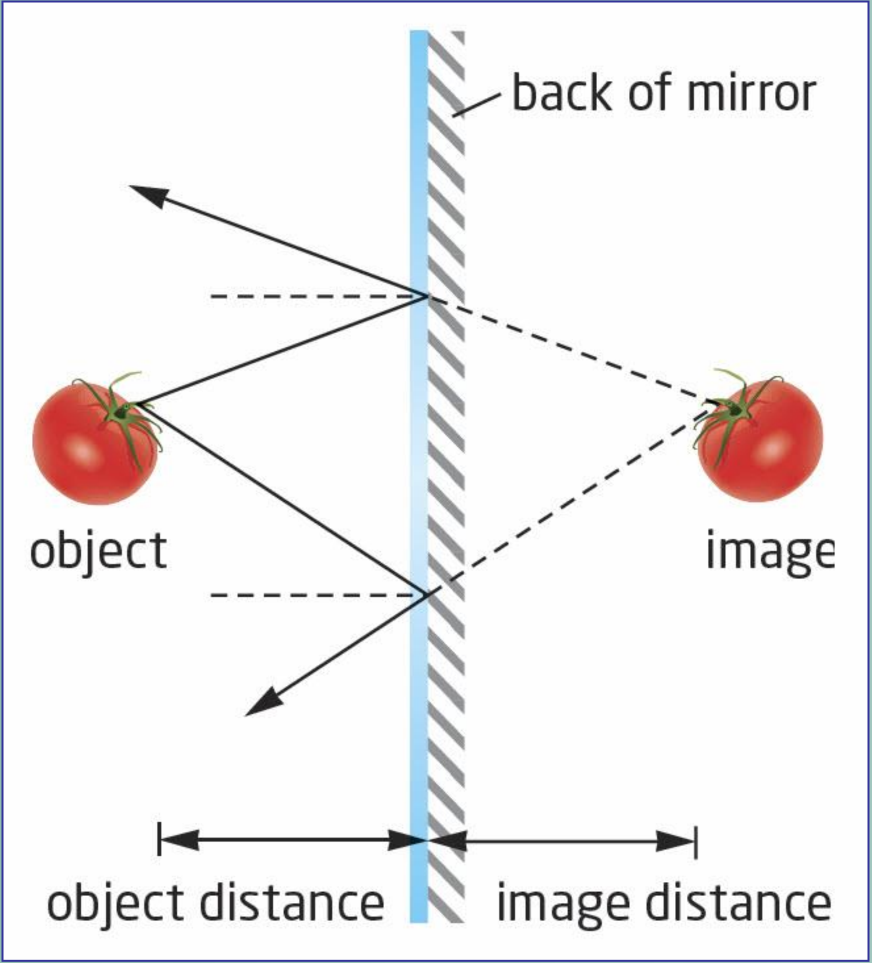


The rays that reach your eye appear as if they are coming from a point behind the mirror.

Your brain interprets the pattern of light that reaches your eye as an image of the object behind the mirror.

Ray Diagrams for Plane Mirrors

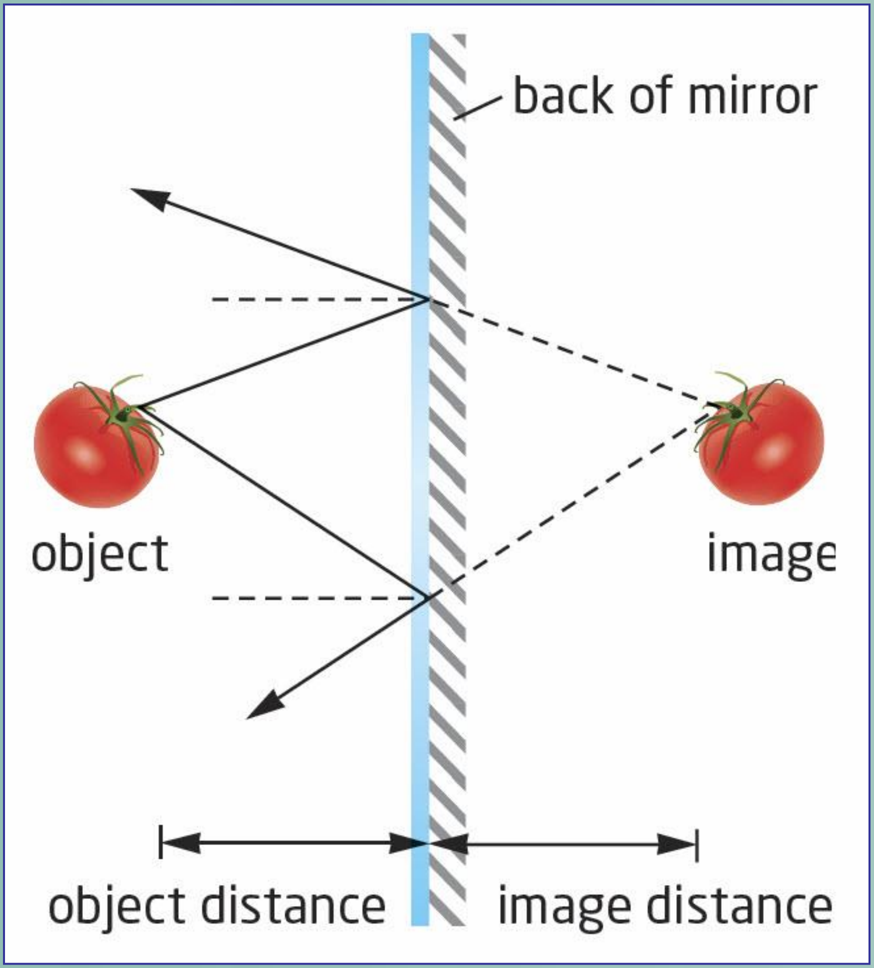
You need just two rays reflecting from a mirror to find the point where the reflection of an object is located.



The terms **object**, **image**, **object distance**, and **image distance** are used when drawing ray diagrams for plane mirrors.

The **virtual image** is an image located where no light rays ever meet. Rays must be extended behind the mirror to find where they meet.

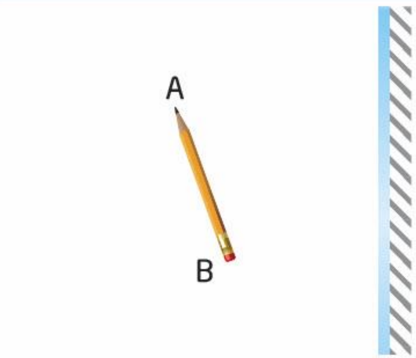
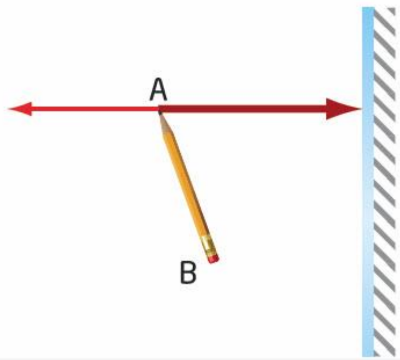
Ray Diagrams for Plane Mirrors



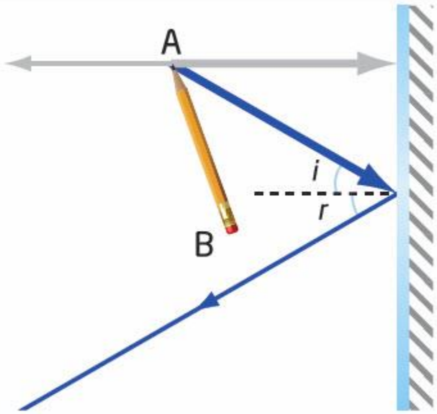
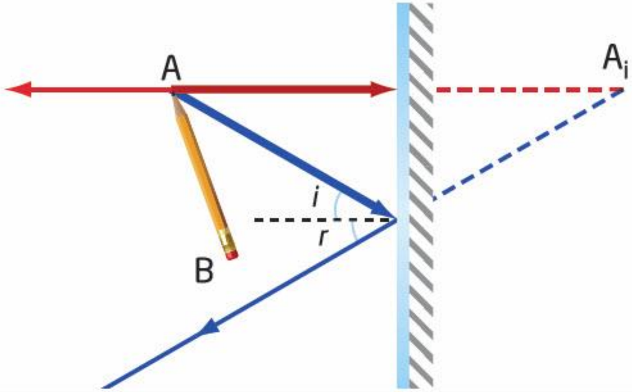
- **Object**: the item in front of the mirror
- **Image**: the reflection of the object in the mirror
- **Object distance**: the distance from the mirror to the object
- **Image distance**: the distance from the mirror to the image.

Drawing Ray Diagrams for Plane Mirrors

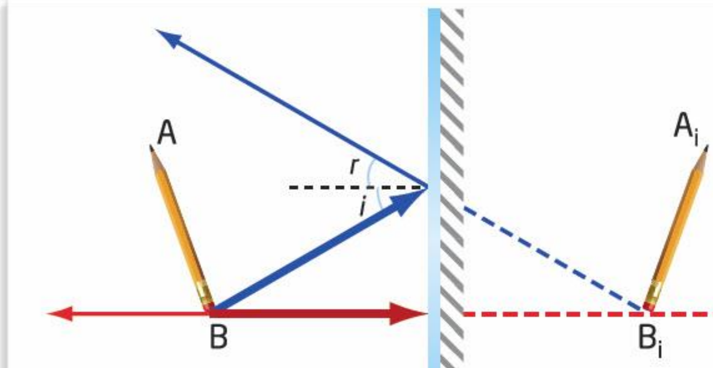
To find the image of an object in a plane mirror, you need to find the image location of at least two points on the object. The next three slides outline the steps involved in drawing a ray diagram for plane mirrors.

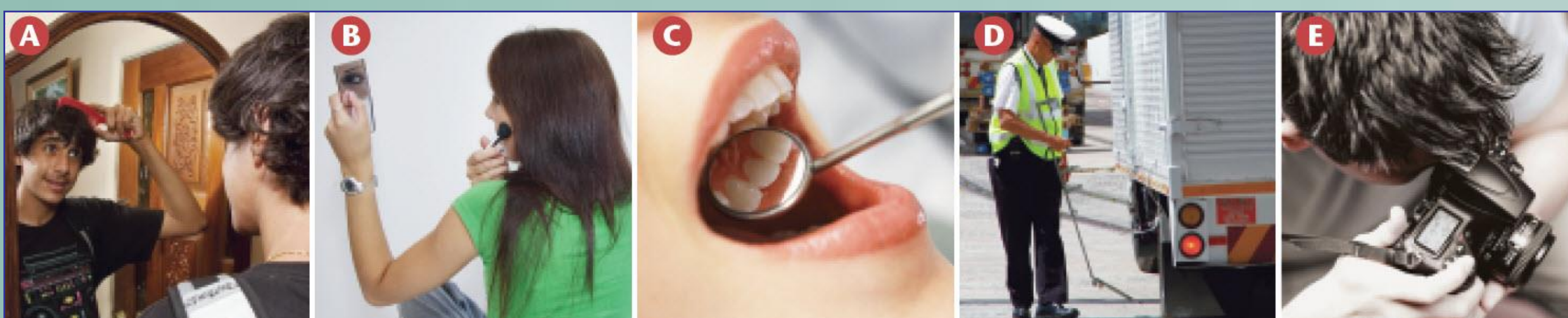
Directions	Example
Step 1 • Draw a line to represent a plane mirror. • Draw a simple object. • Label a point at one end of the object "A", and label a point at the other end "B."	
Step 2 • Draw an incident ray from point A directly to the mirror at a 90° angle. • Draw the reflected ray backward along the same line as the incident ray.	

Drawing Ray Diagrams for Plane Mirrors

Directions	Example
Step 3 • Draw another incident ray from point A at an angle to the mirror. • At the point where the incident ray hits the mirror, draw a normal. (That's the dashed line shown here.) • Measure the angle of incidence with a protractor. • Using the law of reflection (angle of incidence = law of reflection), draw the reflected ray.	
Step 4 • Using dashed lines, extend both reflected rays behind the mirror until they meet. • Label the point where they meet "A_i" to indicate that it is the image of point A.	

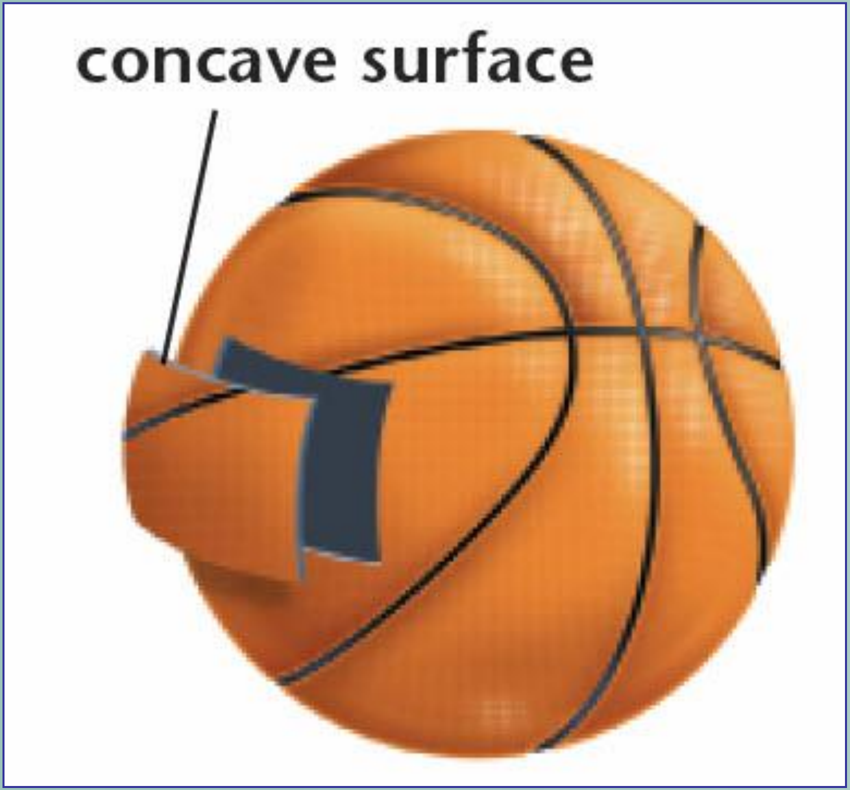
Drawing Ray Diagrams for Plane Mirrors

Directions	Example
Step 5 • Repeat steps 2 to 4 for point B. • Draw the image between points A_i and B_i.	



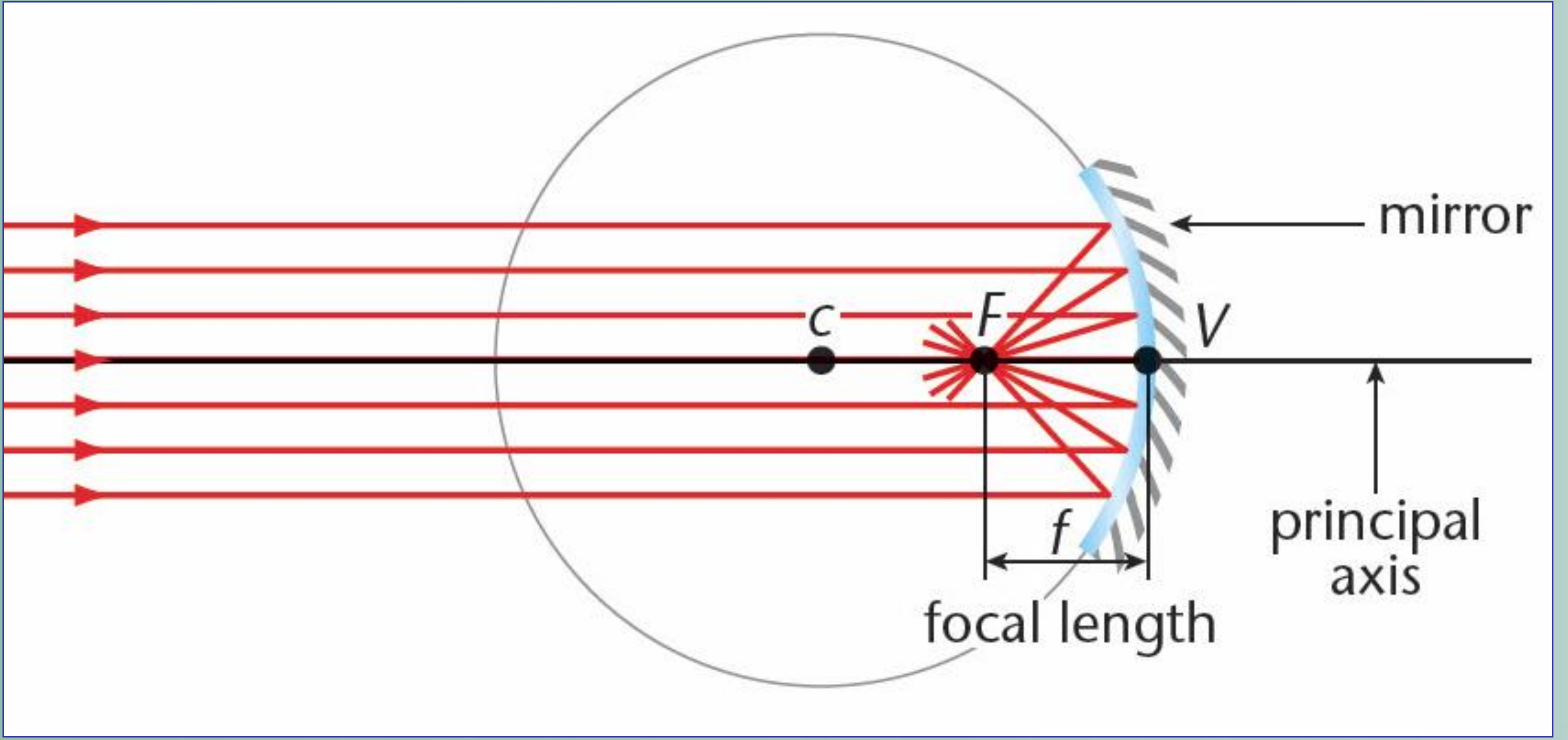
Concave mirrors can form real, inverted images.

A **concave mirror** is a mirror whose reflective surface is on the "caved-in" part of it. This type of mirror would be shaped like the inside surface of a section cut out of a ball.



Concave mirrors can form real, inverted images.

The important parts of a concave mirror are illustrated and below and described on the next slide.



Concave mirrors can form real, inverted images.

- **Principal axis**: a straight line that passes through the centre of curvature
- **Vertex (V)**: the point where the principal axis meets the mirror
- **Focal point (F)**: the point where all light rays that are parallel and close to the principal axis reflect from the mirror and meet
- **Centre of curvature (C)**: the centre of the sphere that the mirror fits on
- **Radius of curvature**: the distance from the centre of the sphere the mirror fits on to the mirror
- **Focal length (*f*)**: the distance from the focal point to the mirror

Characteristics of Images in Curved Mirrors

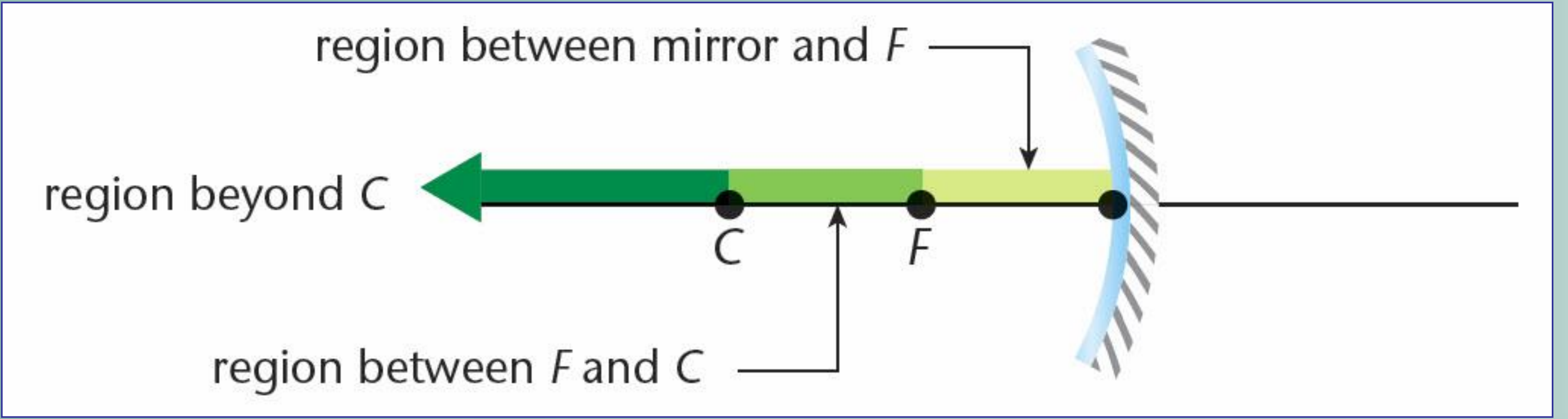
Images in curved mirrors have four key characteristics:

- **Location**: Is the image distance shorter or longer than the object distance? Is the image behind or in front of the mirror?
- **Orientation**: Is the image oriented in the same direction as the object? In other words, is it **upright** (right side up) or **inverted** (upside down)?
- **Size**: How big is the image compared to the object? (sometimes referred to as **magnification**) Is it larger or smaller?
- **Type**: Is the image **real** (the rays meet) or **virtual** (the rays must be extended backward to meet)?

Ray Diagrams for Concave Mirrors

The characteristics of concave mirrors make it easy to draw two rays from any point on an object.

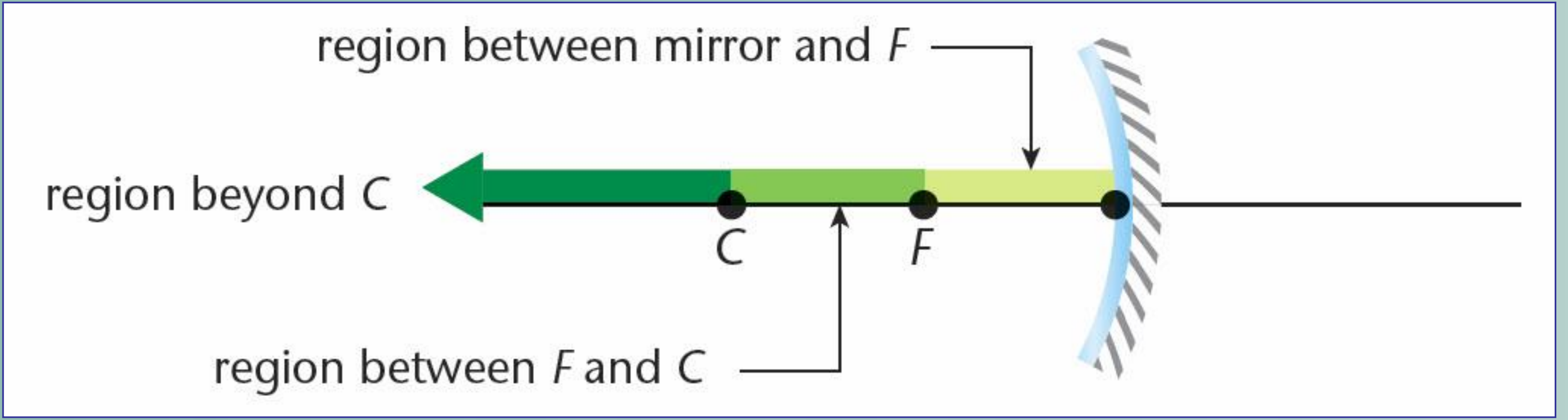
- The first ray is drawn parallel to the principal axis, and it will reflect back through the focal point.
- The second ray is drawn from a point on the object through the focal point toward the mirror, and it will reflect back, parallel to the principal axis.



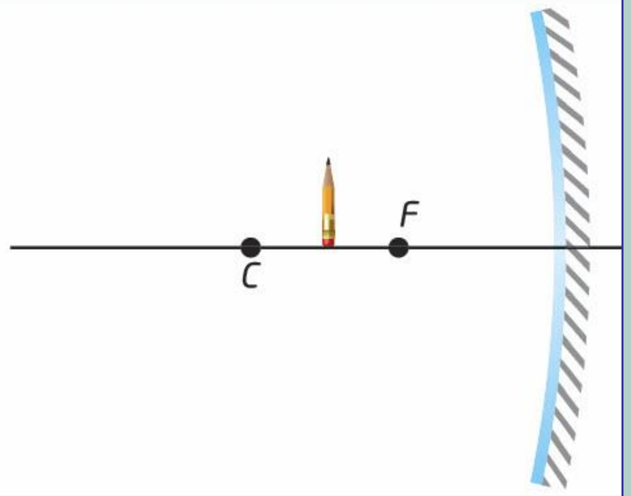
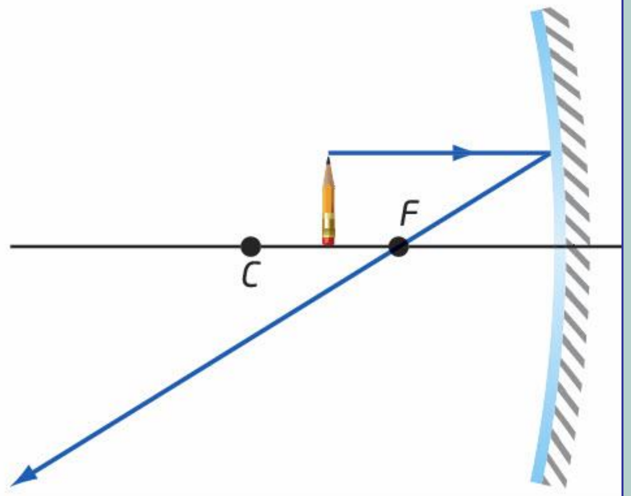
Ray Diagrams for Concave Mirrors

There are three regions where an object can be located:

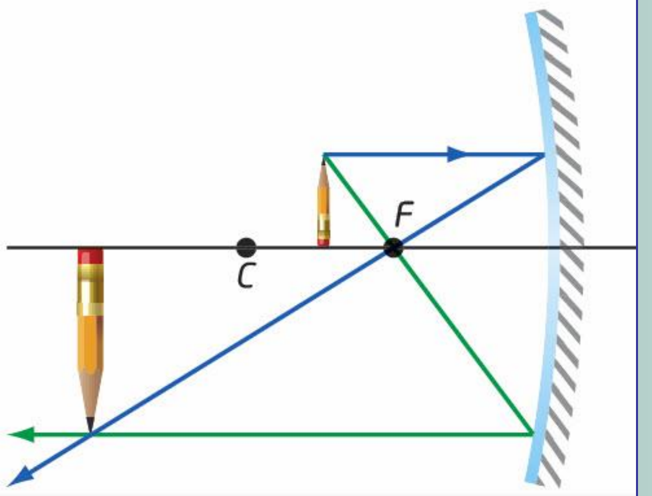
- **beyond C**
- **between C and F**
- **between the mirror and F**



Ray Diagrams for Objects beyond F for Concave Mirrors

Directions	Example
Step 1 • Draw the principal axis and a very slight curve to represent the concave mirror. • Mark *F* and *C* so that *C* is twice as far from the mirror as *F*. • Draw the object between *F* and *C* with the bottom on the principal axis.	
Step 2 • Draw a ray (shown in blue) from the top of the object toward the mirror and parallel to the principal axis. • Draw the reflected ray back through *F*.	

Ray Diagrams for Objects beyond F for Concave Mirrors

Directions	Example
Step 3 • Draw a ray (shown in green) from the top of the object through *F* and continuing to the mirror. • The reflected ray will travel backward, parallel to the principal axis. • Draw the image so the top is at the point where the rays meet and the bottom is on the principal axis. (Since the reflected rays meet, you don't have to extend them backwards. So the image is real.)	

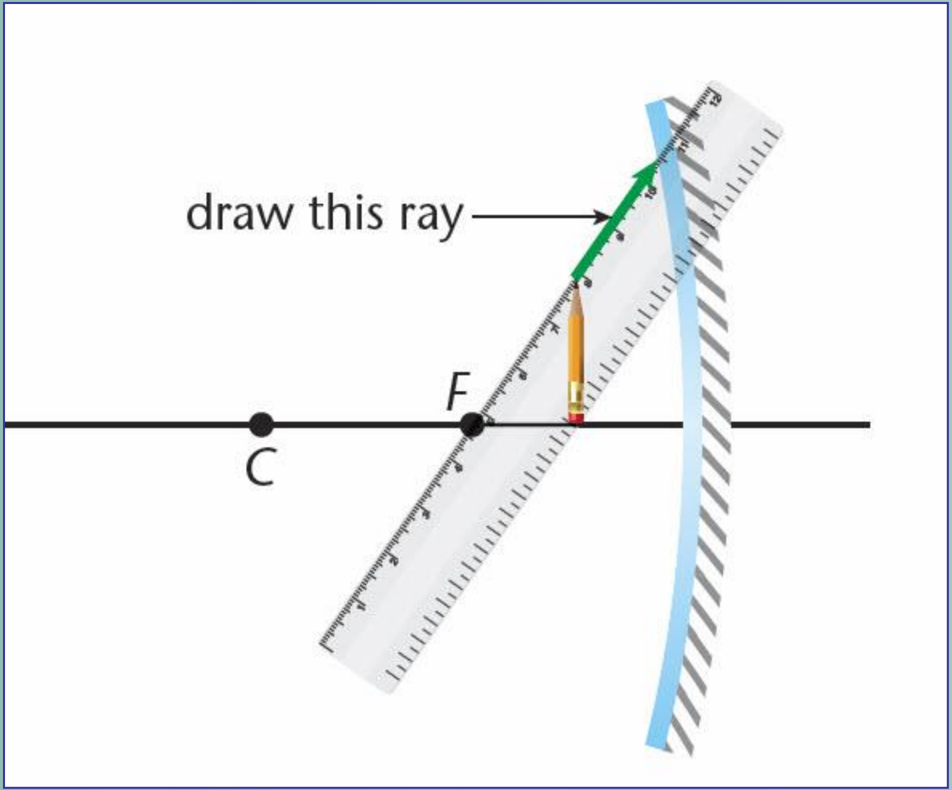
Ray Diagrams for Objects beyond F for Concave Mirrors

The characteristics of the image of an object placed between **F** and **C** of a concave mirror are:

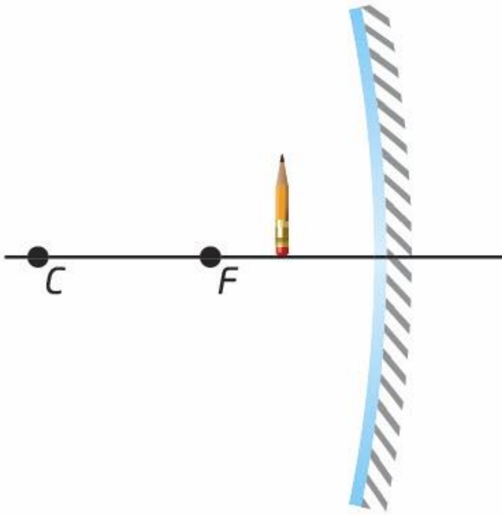
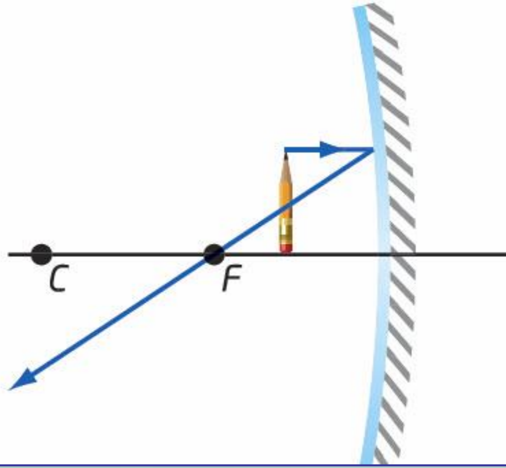
- the image is **farther** from the mirror than the object is
- the image is **inverted**
- the image is **larger** than the object
- the image is **real**

Concave mirrors can form upright, virtual images.

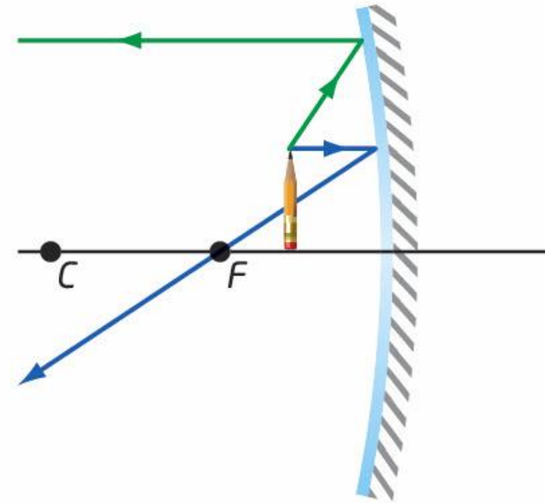
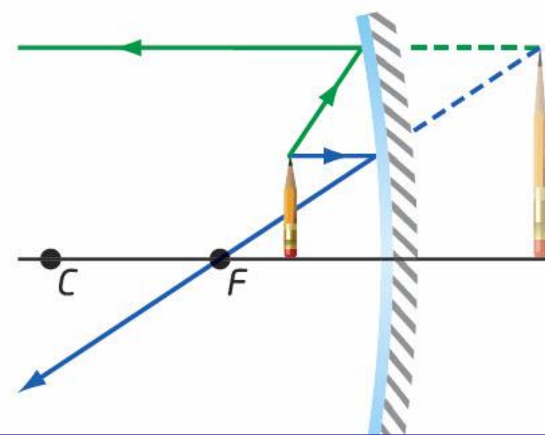
The image below shows how concave mirrors can form magnified, upright images, much like a makeup mirror does. For this to occur the object must be between the mirror and the focal point (**F**). If not, the image is inverted.



Ray Diagrams for an Object between a Concave Mirror and the Focal Point

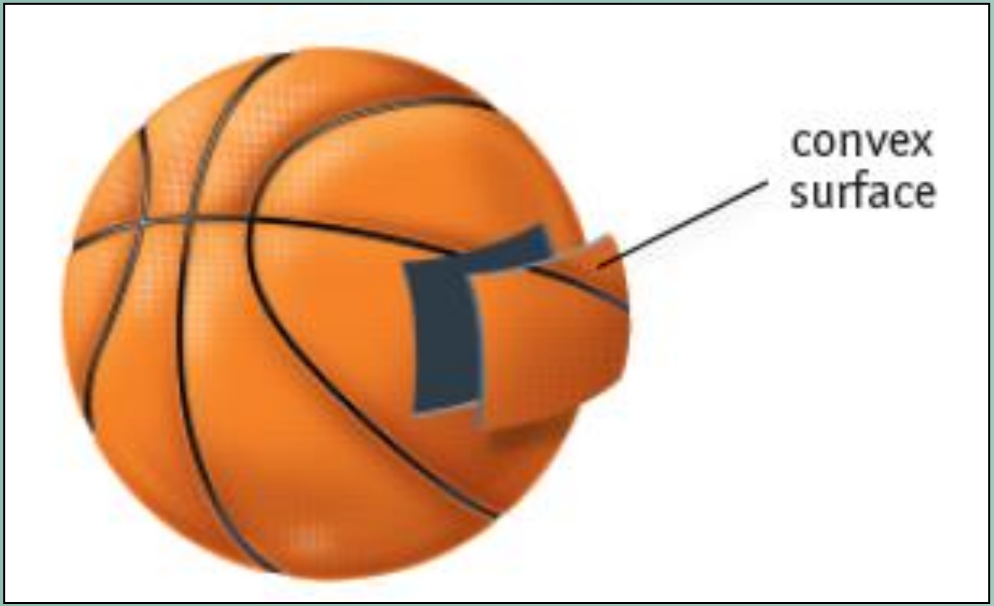
Directions	Example
Step 1 • Draw the principal axis and a line with a very slight curve to represent the concave mirror. • Mark *F*. • Draw an object between the *F* and the mirror.	
Step 2 • Draw a ray (shown in blue) from the top of the object toward the mirror and parallel to the principal axis. • Draw the reflected ray back through the focal point.	

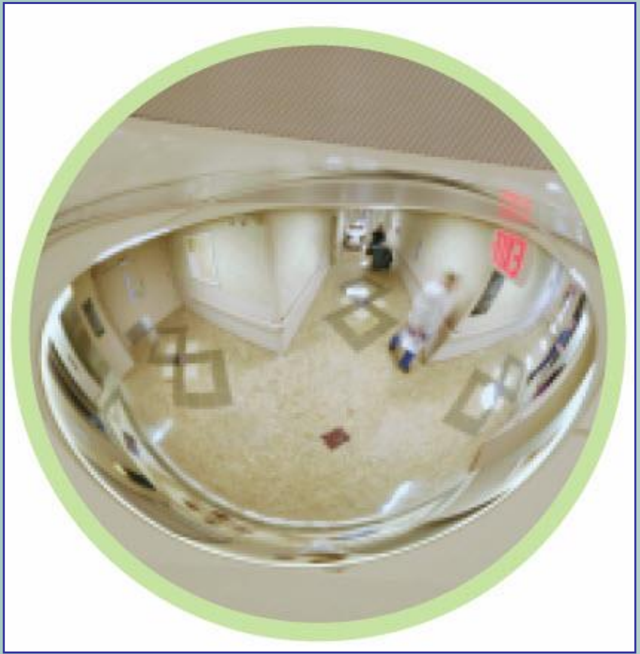
Ray Diagrams for an Object between a Concave Mirror and the Focal Point

Directions	Example
Step 3 • Position your ruler as shown in **Figure 4.29** and draw the ray (shown in green) from the top of the object to the mirror. • Draw the reflected ray backward and parallel to the principal axis.	
Step 4 • Extend the reflected rays behind the mirror with dashed lines. • Draw the image between the point where the dashed lines meet and the principal axis.	

Convex mirrors always form images that are smaller than the object.

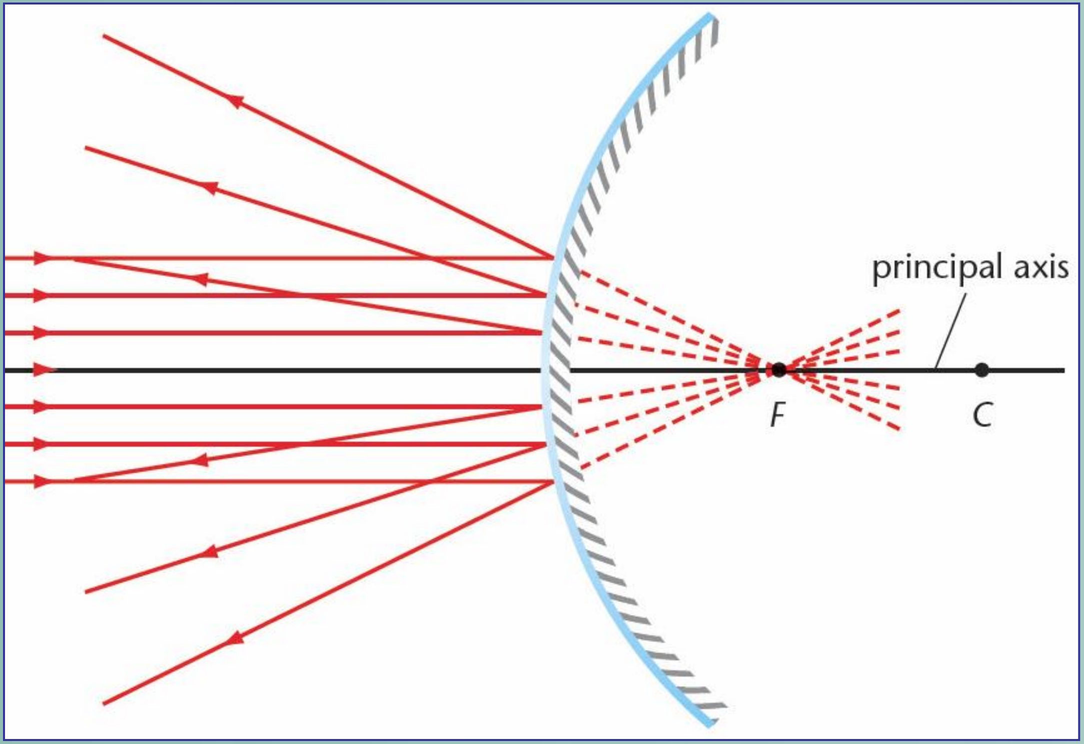
A **convex mirror** is a mirror that bulges out in the centre. The surface of a convex mirror is shaped like the surface of the outside of a ball. A convex mirror lets you see in more directions. This is illustrated in the image from the security mirror shown below.





Convex mirrors always form images that are smaller than the object.

A **convex mirror** has a focal point and a centre of curvature just like a concave mirror does, but they are found in a different way. When rays travel toward a convex mirror parallel to the principal axis, the reflected rays spread out.

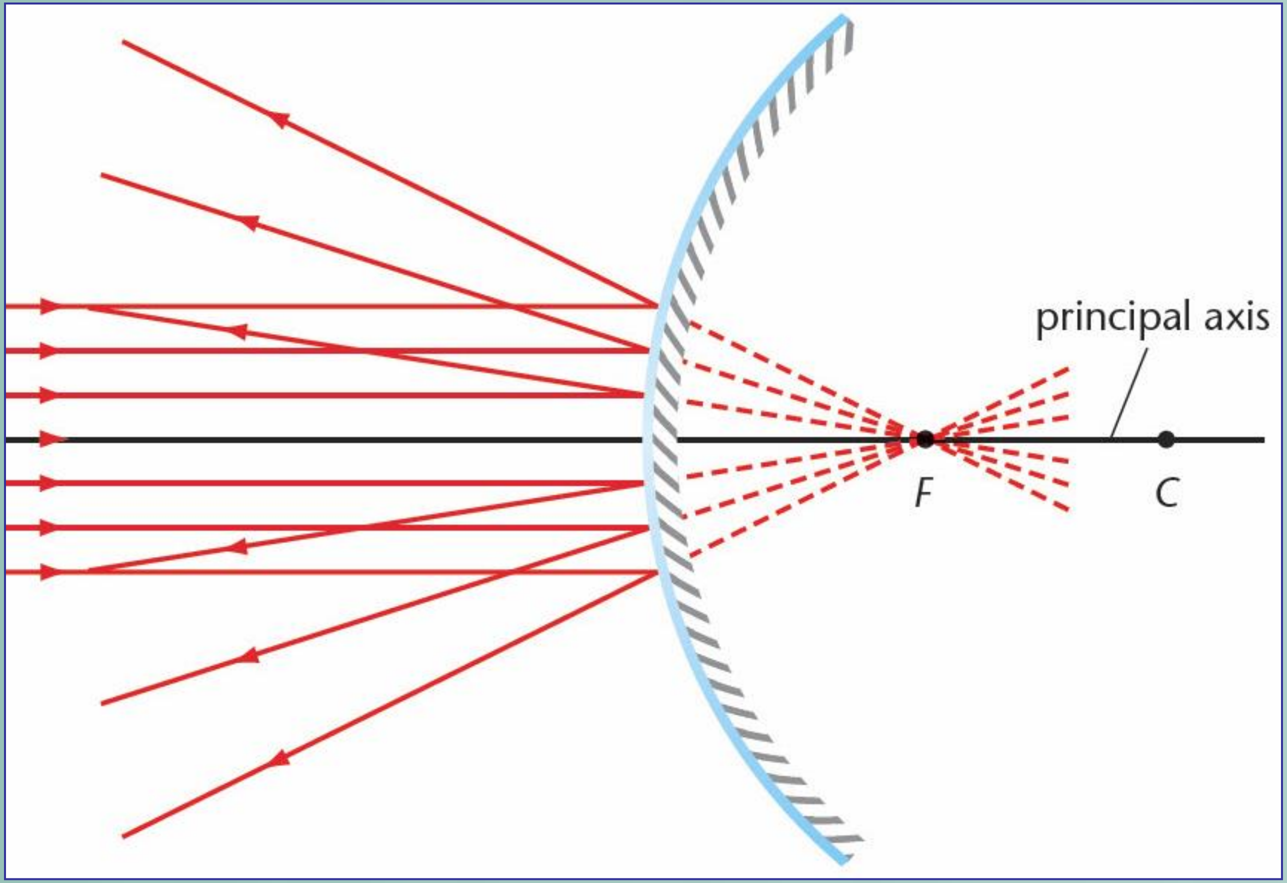


Reflected rays must be extended backward, behind the mirror to find the focal point.

The centre of curvature (**C**) is twice the distance from the mirror as the focal point (**F**).

Ray Diagrams for Convex Mirrors

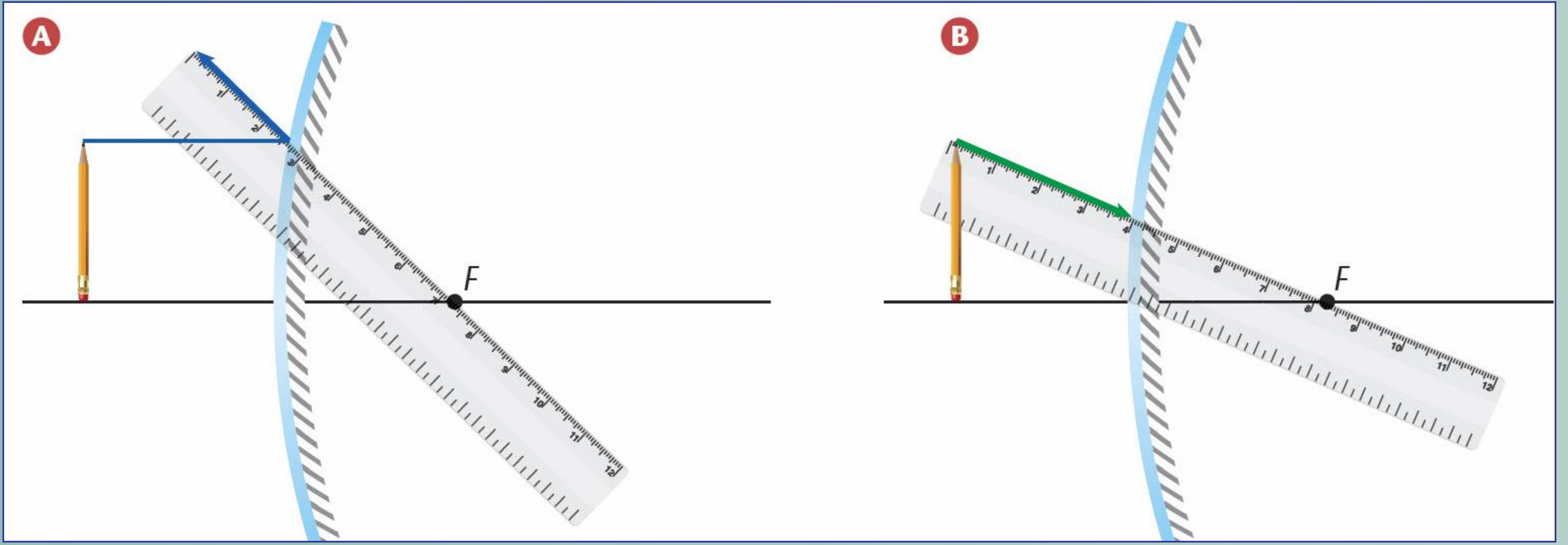
The rays used to draw a ray diagram for a convex mirror are similar to those for a concave mirror. However, because the focal point is behind the mirror, rays never go through it.



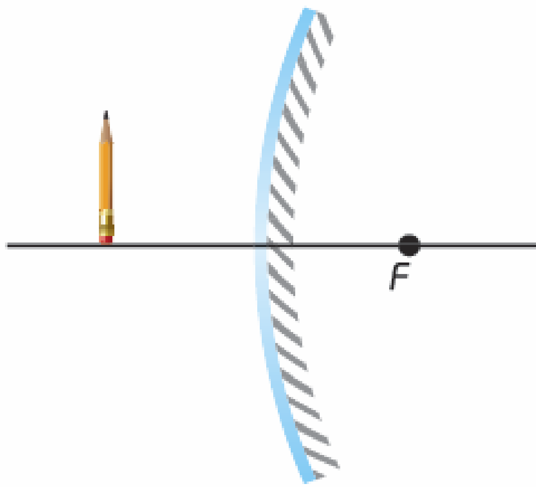
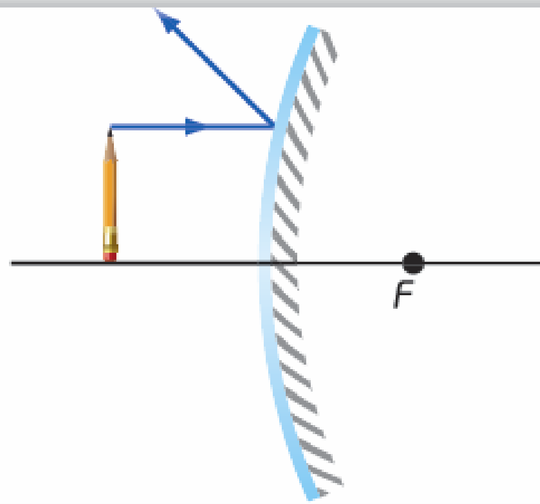
Ray Diagrams for Convex Mirrors

With convex mirrors the two rays can be described as follows:

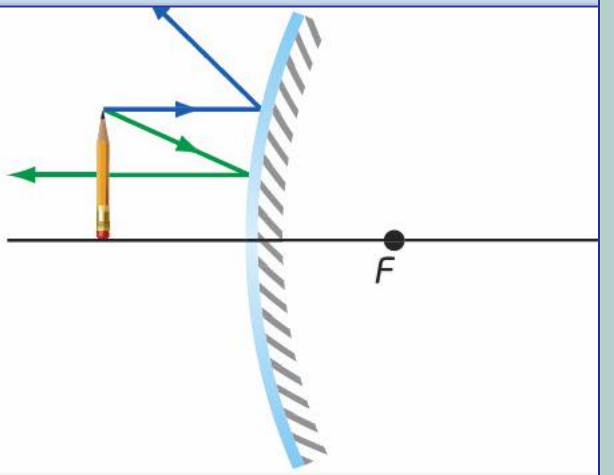
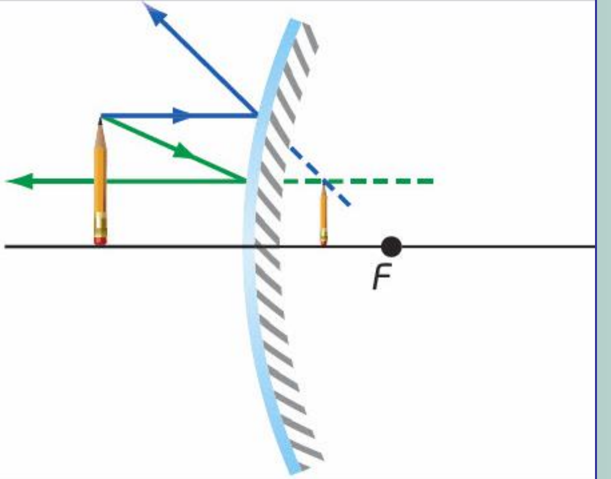
- *A ray travelling parallel to the principal axis will reflect as though it was coming from the focal point.* (**A**)
- *A ray that is travelling as though it is going through the focal point will reflect back parallel to the principal axis.* (**B**)



Ray Diagrams for Convex Mirrors

Directions	Example
Step 1 • Draw the principal axis and a slightly curved line to represent the convex mirror. • Mark *F*. • Draw the object so that the bottom is on the principal axis.	
Step 2 • Draw a ray (shown in blue) from the top of the object toward the mirror and parallel to the principal axis. • Position your ruler as shown in **Figure 4.33A** and draw the reflected ray as though it was coming from *F*.	

Ray Diagrams for Convex Mirrors

Directions	Example
Step 3 • Position your ruler as shown in **Figure 4.33B** and draw the incident ray (shown in green) as though it was going to *F*. Stop when the ray hits the mirror. • Draw the reflected ray backward, parallel to the principal axis.	
Step 4 • Draw dashed lines to extend the rays backward, behind the mirror, until they meet. This is the top of the image. • Draw the image, with the bottom of the image on the principal axis.	

Ray Diagrams for Convex Mirrors

The image of an object in a convex mirror will have the following characteristics:

- the image is **closer** to the mirror than the object is
- the image is **upright**
- the image is **smaller** than the object
- the image is **virtual**

The images in convex mirrors are much more similar to each other than those in concave mirrors.

STRANGE TALES OF SCIENCE

Not Seeing is Believing

Move over Invisible Woman and Harry Potter. Science will soon be bringing you something you probably never thought you'd see (or not see!)—a way to turn invisible, for real! Brought to you by metamaterials, the invisibility cloak of the future might be just around the corner.

Human-made materials called metamaterials are designed to cause light to bend (refract) in ways that it normally wouldn't, including backwards and around objects.

Metamaterials can render an object invisible by bending light waves around it so they reconnect behind the object. Think of water flowing around a tree stump and you get the idea.

One day, perhaps soon, metamaterial fabrics will be made into clothing such as this prototype jacket. While wearing the jacket, light will bend around you so the space behind you is visible, but you are not!

So... What do you think?

1. What are some beneficial uses for this technology? What are some negative uses? Do the positives outweigh the negatives? Explain your opinions.
2. Imagine you are wearing an invisibility cloak. Create a graphic novel or script that tells the tale of a day in your life.
3. Do you think you would cast a shadow while wearing the cloak? Why or why not?

Topic 4.4 Review

Key concepts to be reviewed:

- The angle of reflection is equal to the angle of incidence.
- Plane mirrors form images that are nearly identical to the object.
- Concave mirrors can form real, inverted images.
- Concave mirrors can form upright, virtual images.
- Convex mirrors always form images that are smaller than the object.

Topic 4.5 What is refraction and how can it be used?

(Pages 332-43)

Key Concepts

- Refraction is the bending of light when it crosses a boundary between two substances.
- Refraction is used in communications and other technologies.

What is refraction and how can it be used?

When light enters some transparent materials on an angle, it reflects many times from the carefully shaped surfaces inside the material before it leaves at a different angle.

What applications are there for this property of light?

Refraction is the bending of light when it crosses a boundary between two substances.

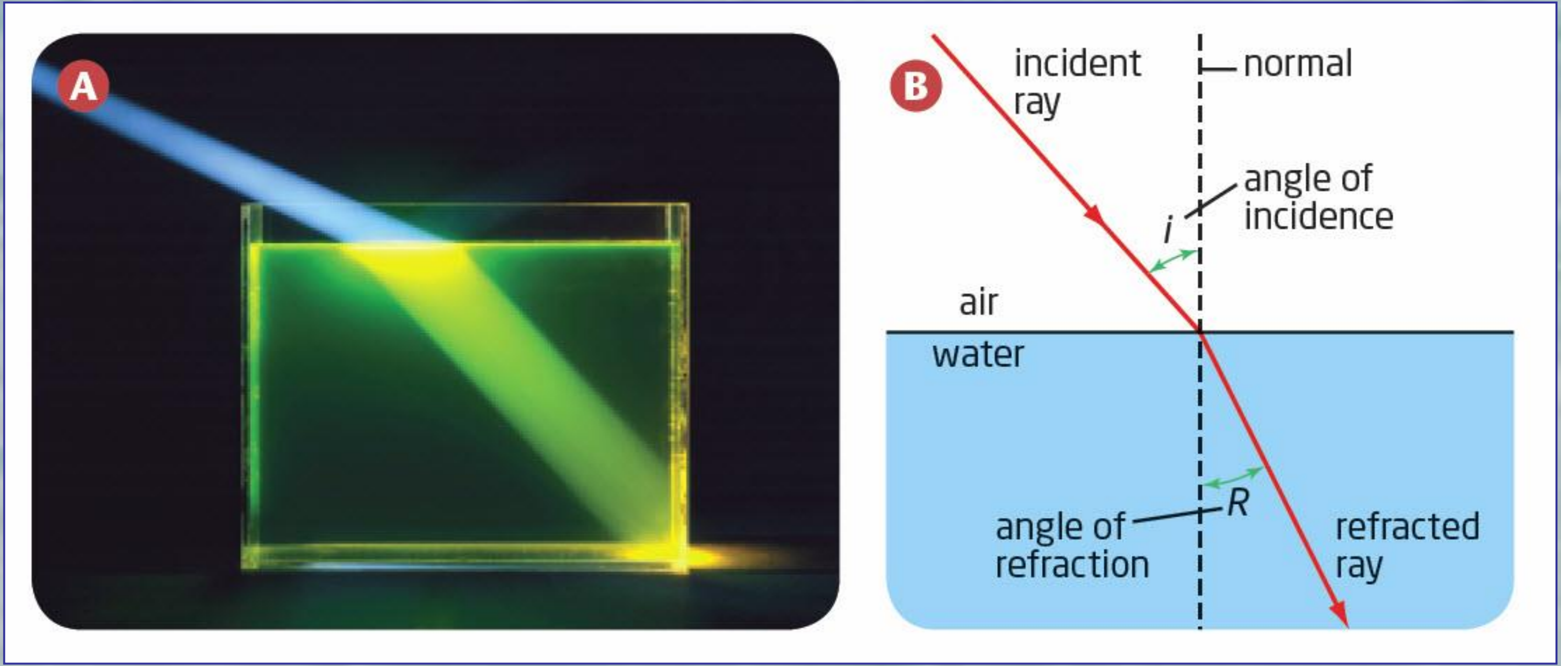
Refraction is the change in the direction of light when it crosses a boundary between two substances.

A **medium** is the substance or material through which light is travelling. The plural of medium is media.

Through what medium or media is light travelling in the image on the left?

Refraction is the bending of light when it crosses a boundary between two substances.

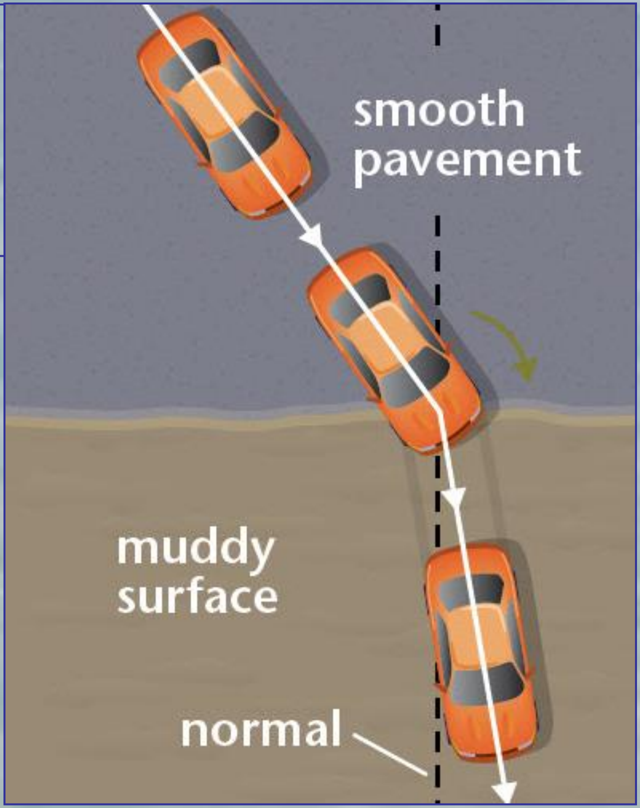
The images below show how light is refracted when it moves from air into water. New terms related to refraction include **refracted ray** (the ray after crossing a boundary between media) and **angle of refraction** (the angle between the refracted ray and the normal).

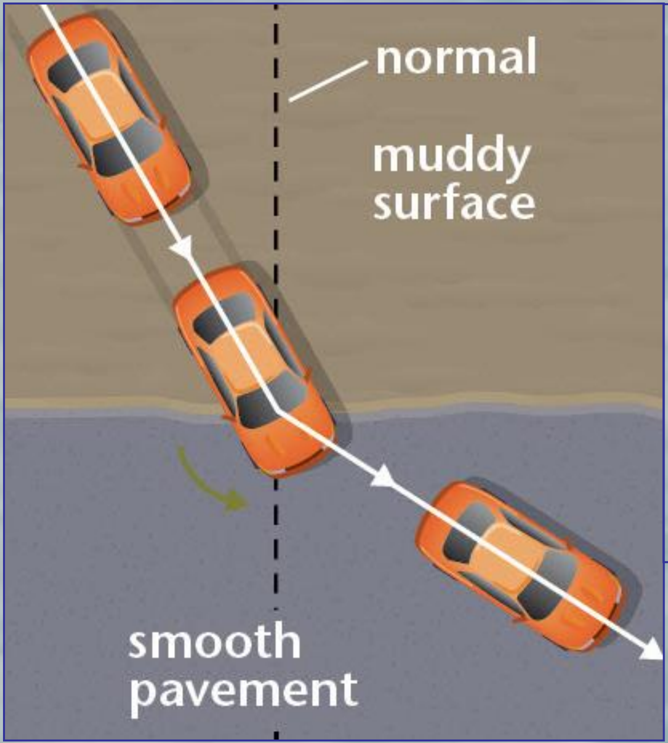


What Causes Refraction

Light refracts because it travels at different speeds in different media.

When light enters a medium that causes it to slow down, it bends toward the normal.





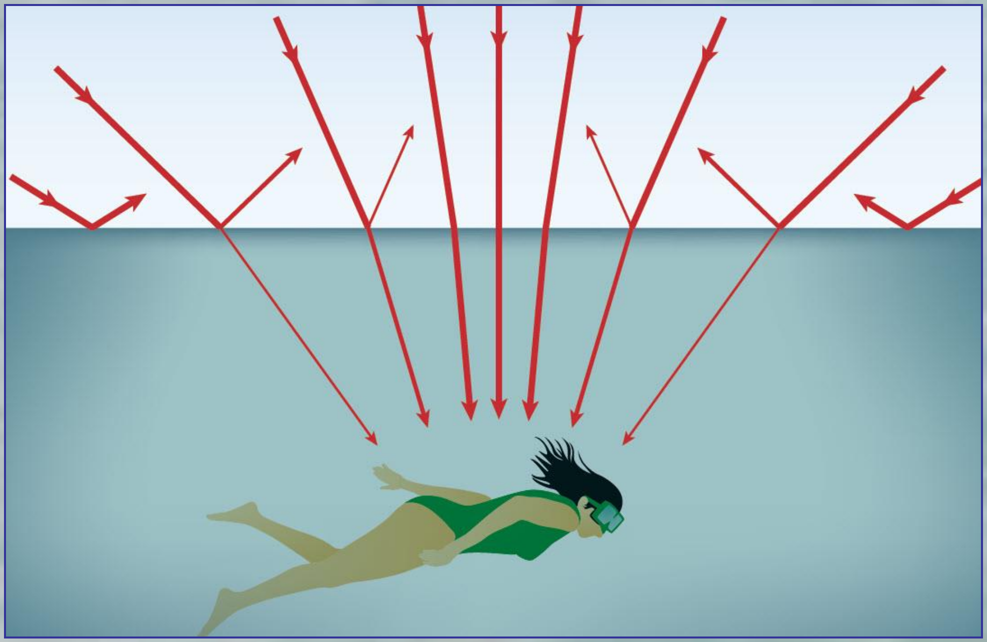
When light enters a medium that causes it to speed up, it bends away from the normal.

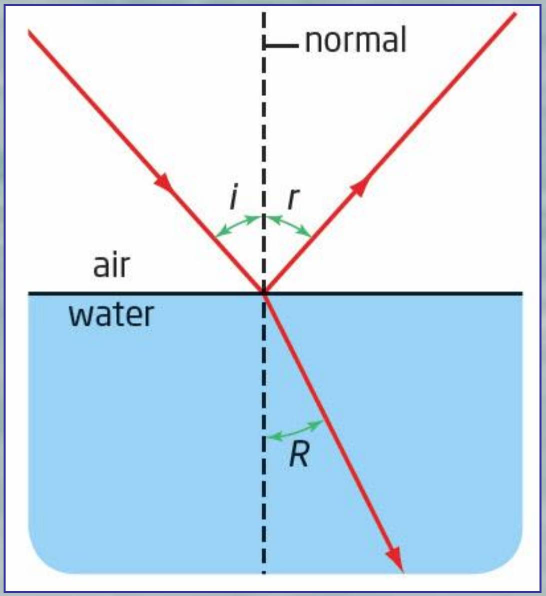
Refraction is used in communications and other technologies.

• When the angle of incidence of the light entering the water is very small, nearly all of the light enters the water and refracts.

• As the angle of incidence gets larger, more of the light reflects and less refracts.

most reflecting most refracting most reflecting



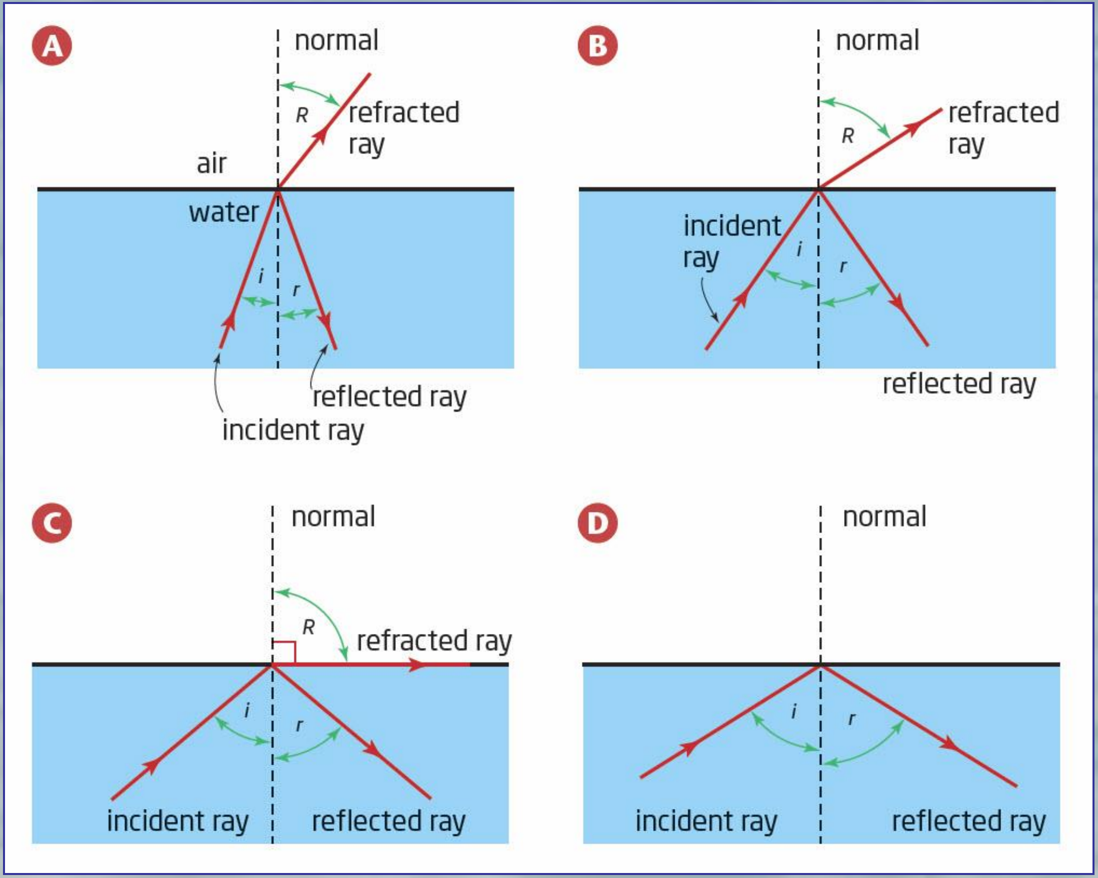


Refraction is used in communications and other technologies.

Some of the light hitting the surface of a body of water reflects, and some refracts.

Total Internal Reflection

Total internal reflection describes a condition in which no light can escape from a medium because the angle of incidence is larger than the critical angle (i where R = 90°).

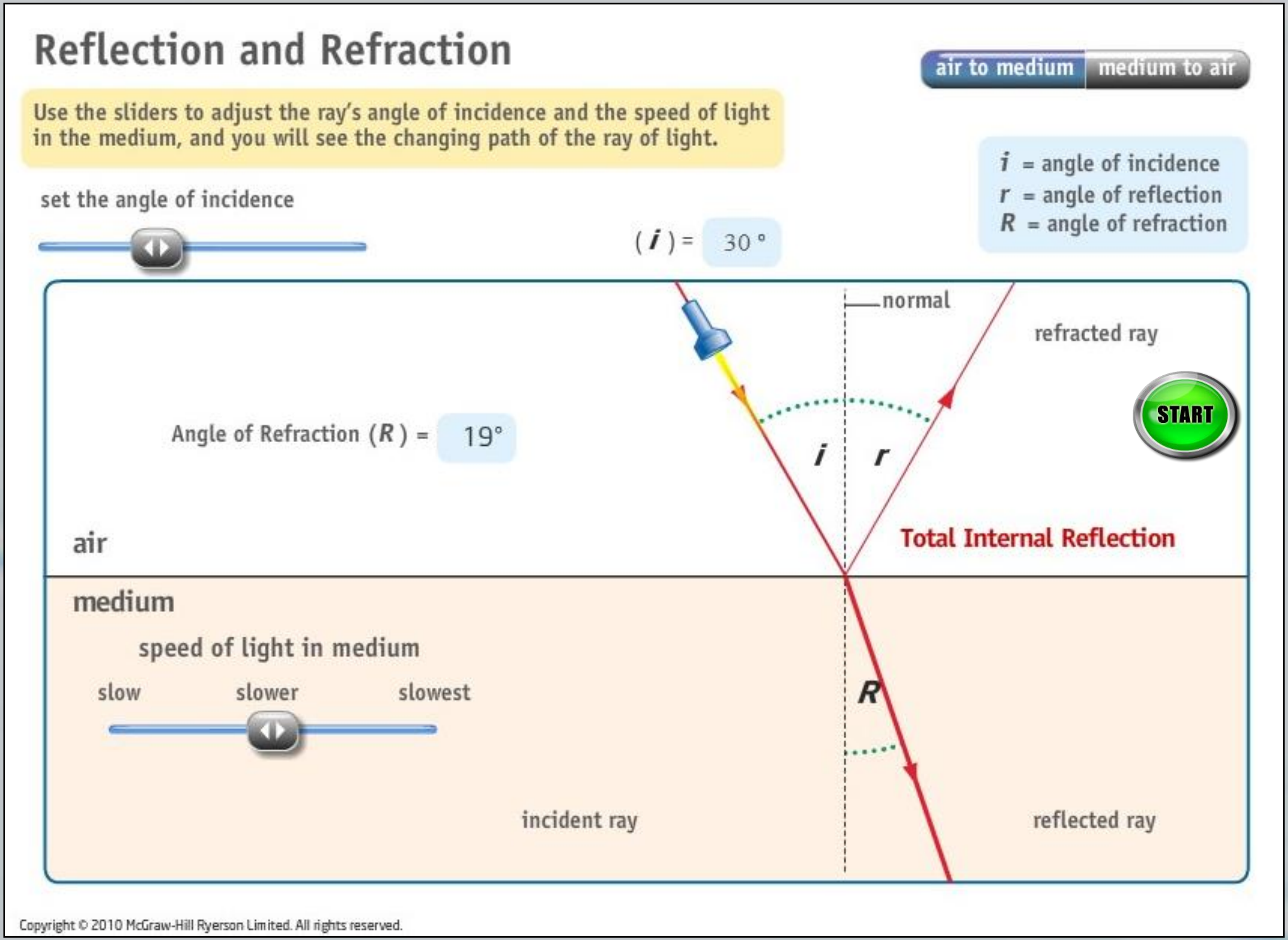


In images **A** and **B**, as the angle of incidence increases, less light is reflected.

In images **C** and **D**, the angle of incidence is so large that the ray of light never leaves the water. The critical angle is reached in **C**.

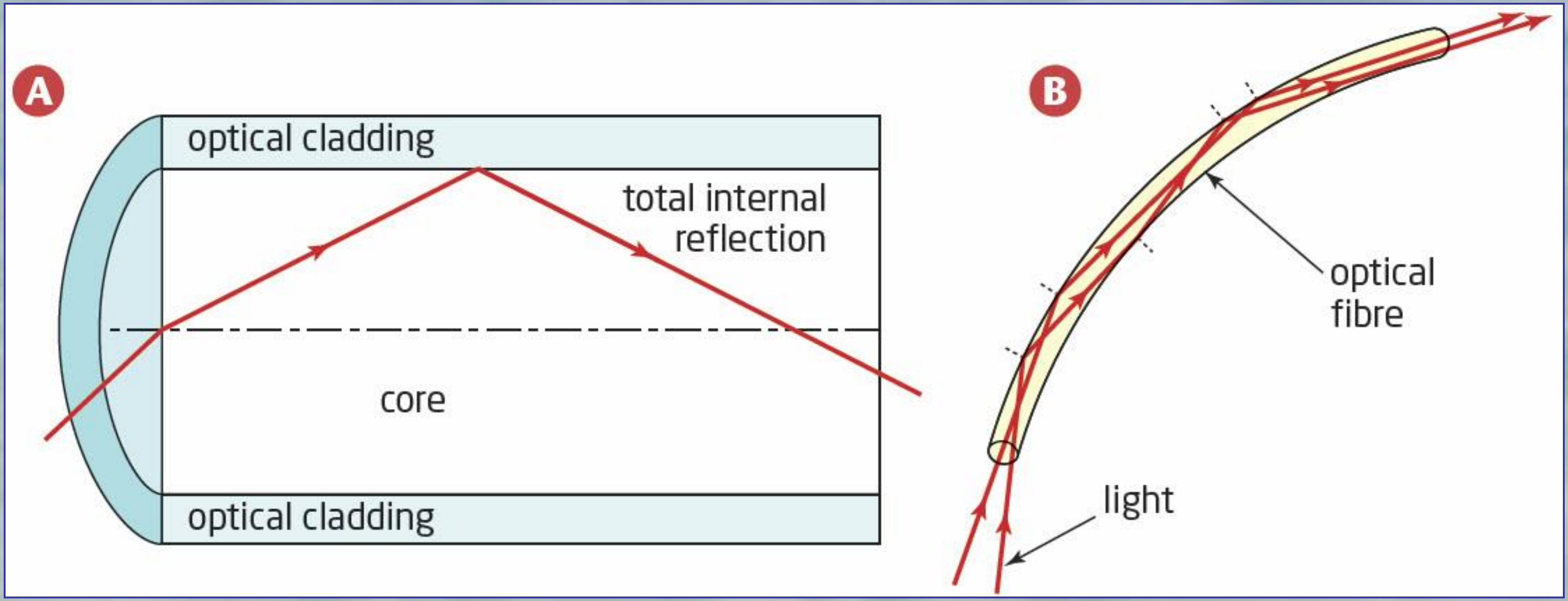
Reviewing Refraction and Reflection

Click the "Start" button to review refraction and reflection.



Fibre Optics

Fibre optic cables rely on total internal reflection. If the angle of incidence of light entering the cable is larger than the critical angle, the beam of light carrying the information stays within the cable.



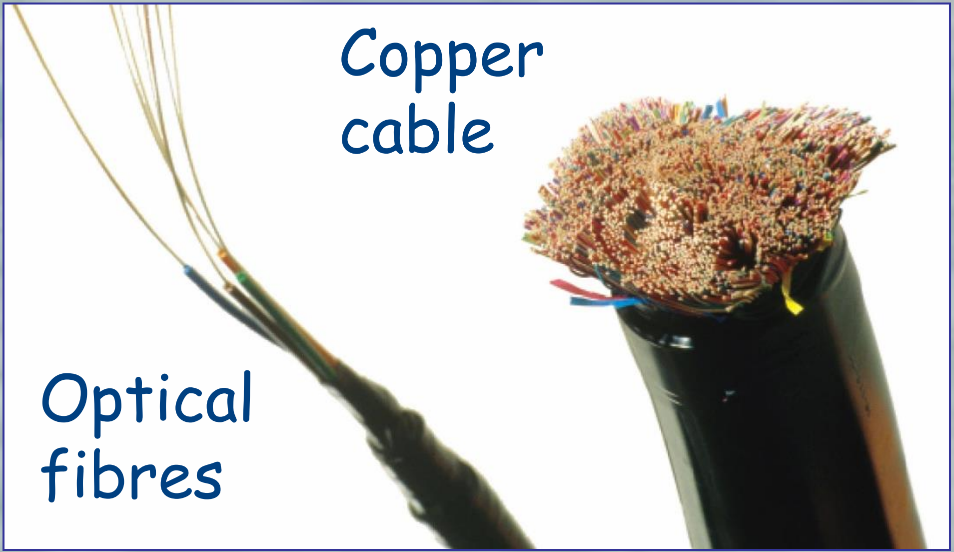
Achieving total internal reflection

How light travels through an optical fibre

Fibre Optics

By sending light in pulses, optical fibres can carry information long distances at nearly the speed of light. Optical fibres are more practical for sending signals than copper wire for the following reasons:

- The signals are not affected by electrical storms.
- More signals can be carried over longer distances.
- Fibre optic cable is smaller and lighter than copper cable.

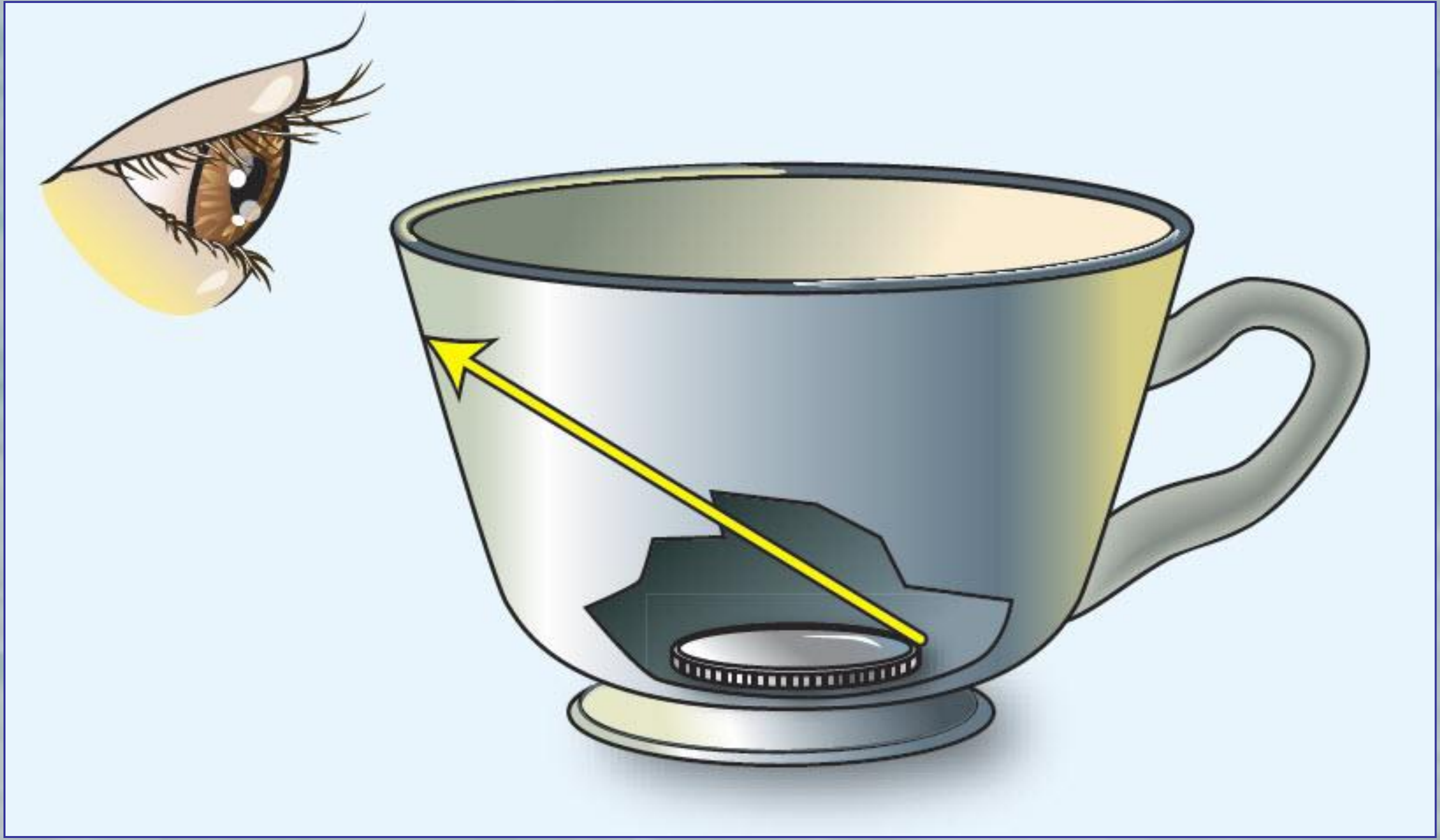


Modelling an Optical Fibre

Why does light appear to be travelling along the curved stream of water?

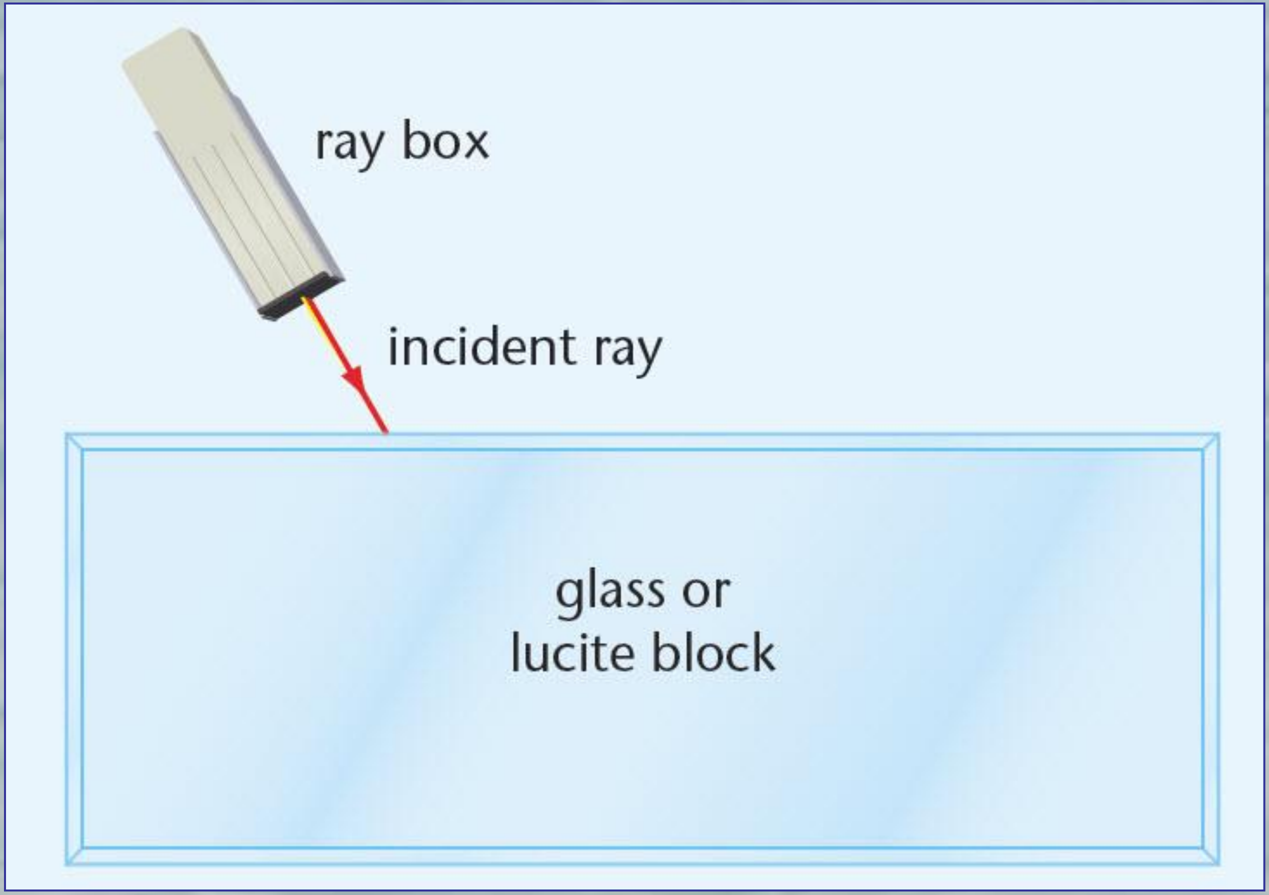
The Reappearing Coin

How can the coin pictured below, at the bottom of a cup of water, be seen, even though it is not in the person's "line of sight"?

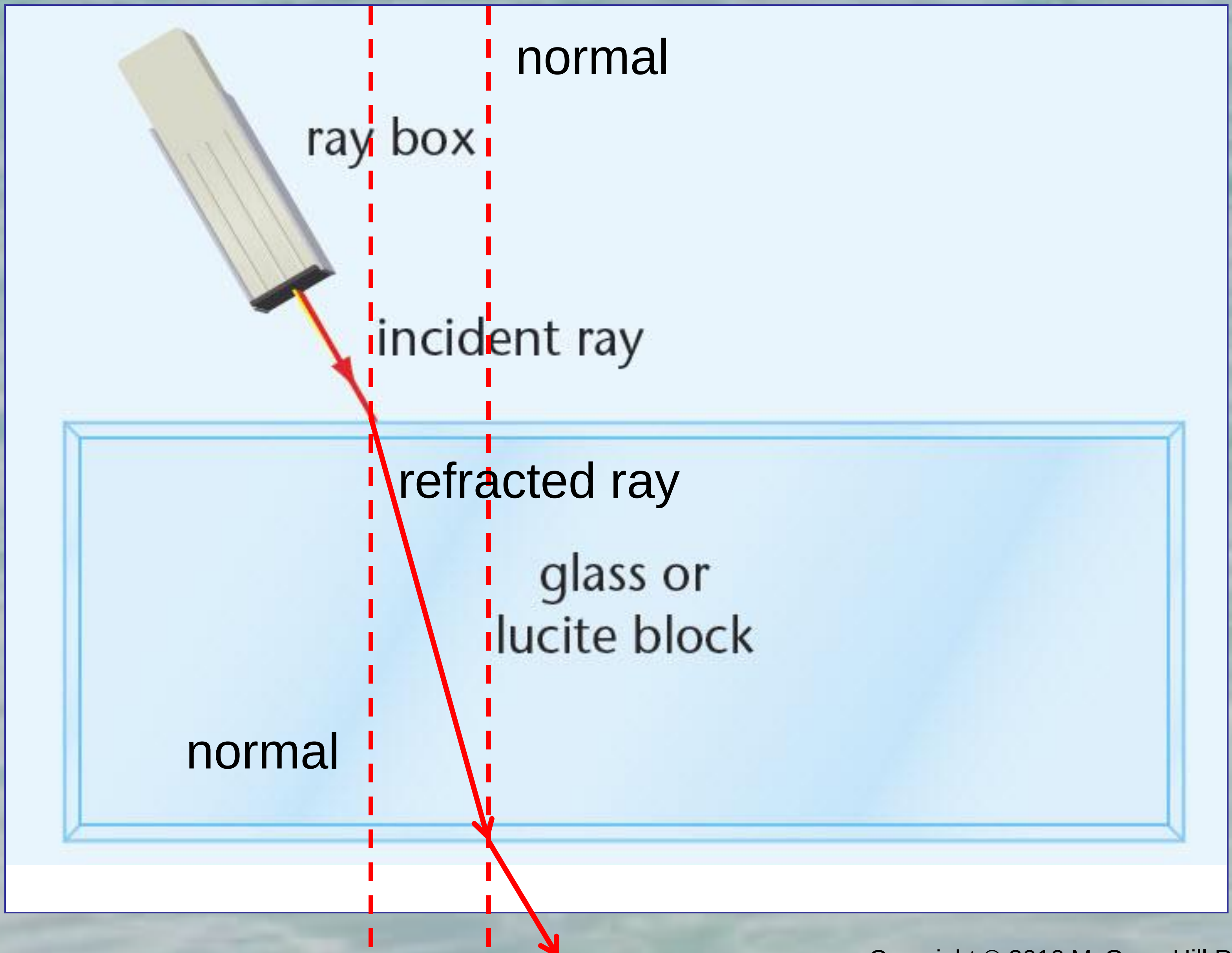


Refraction Through Lucite

How would the beam of light from the ray box travel through the glass or Lucite block pictured below? Explain your reasoning.



Refraction Through Lucite



Topic 4.5 Review

Key Concepts to be reviewed:

- Refraction is the bending of light when it crosses a boundary between two substances.
- Refraction is used in communications and other technologies.

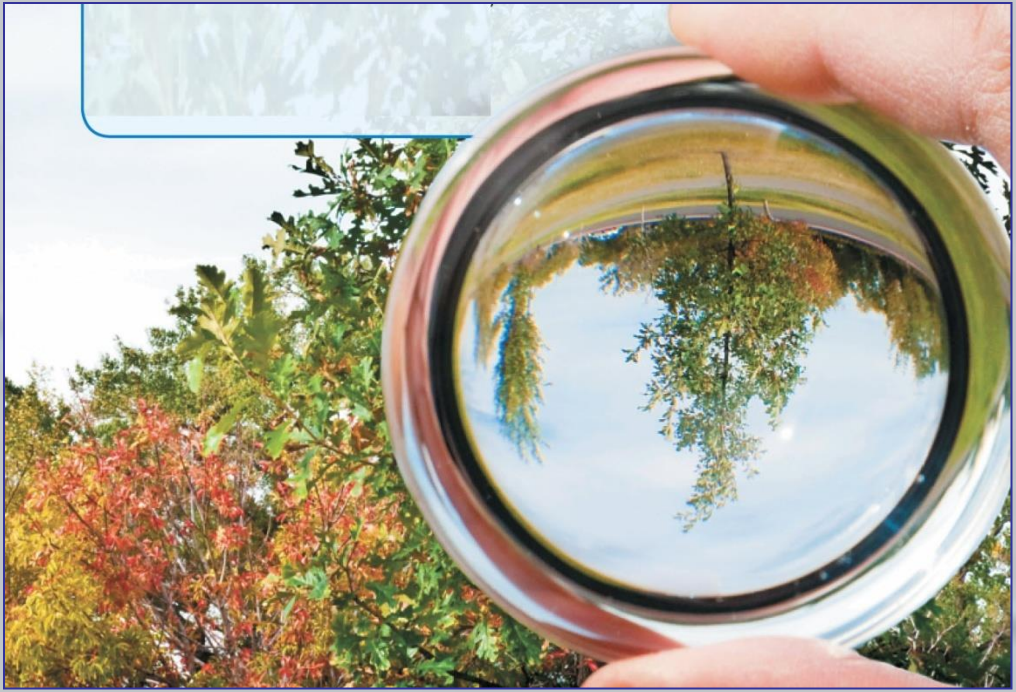
Topic 4.6 What are lenses and what are some of their applications? (Pages 344-55)

Key Concepts

- Lenses have at least one curved surface and refract light in predictable ways.
- Converging lenses can be used to produce different types of images.

What are lenses and what are some of their applications?

Lenses can change the appearance of objects, making images appear larger or smaller than the object or making them upside down or even misshapen.

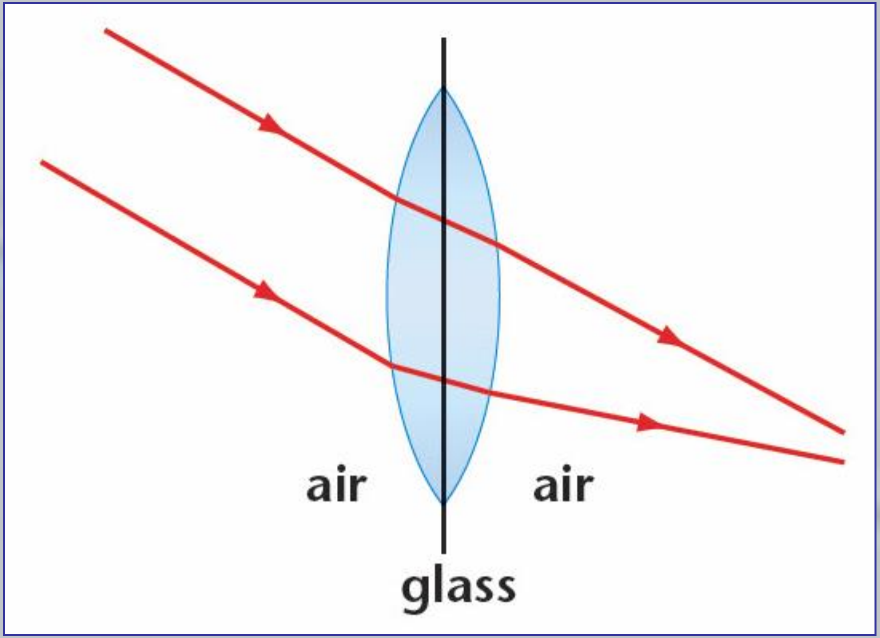


Lenses can focus light because of refraction. Light refracts when entering and leaving a lens.

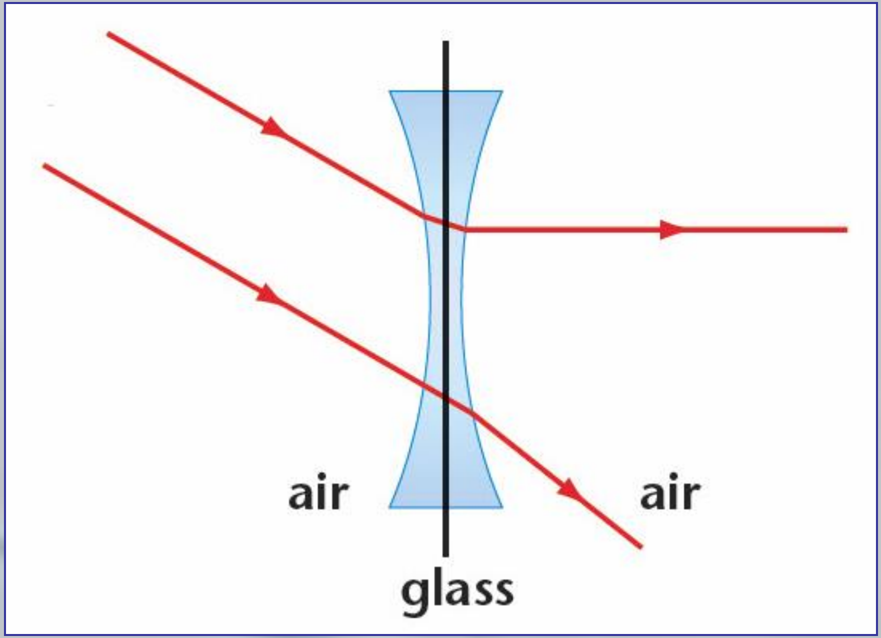
What lenses do you use in your life?

Lenses have at least one curved surface and refract light in a particular way.

A **lens** is a thin, transparent piece of glass or plastic that has at least one curved side. The curved side or sides may be concave or convex. Lenses come in many sizes and shapes and are made for many purposes.



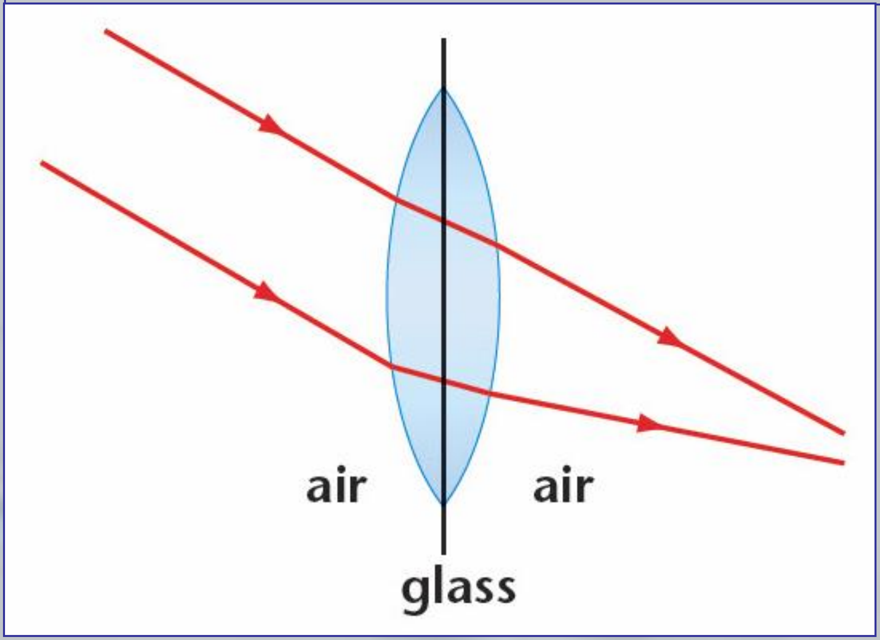
A Converging Lens

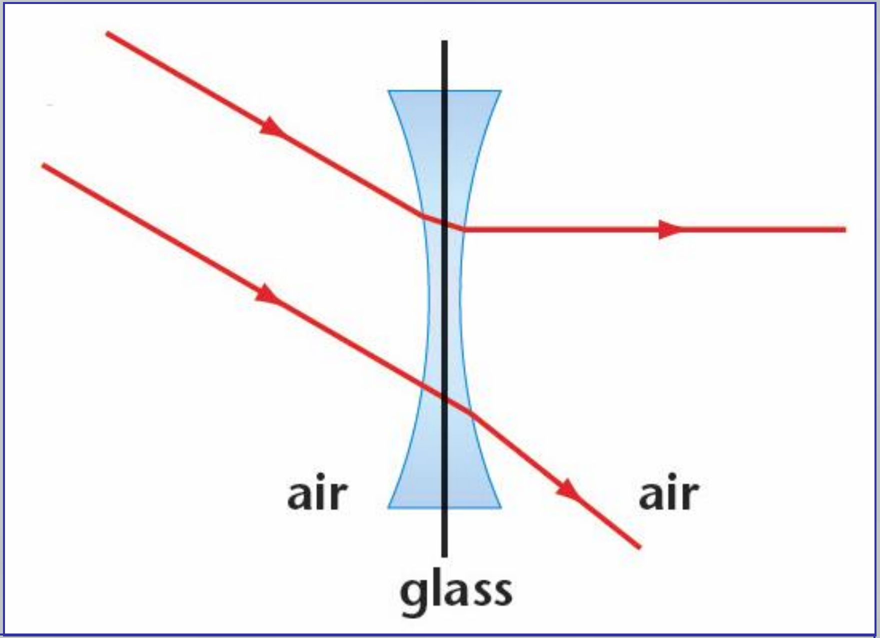


A Diverging Lens

Lenses have at least one curved surface and refract light in a particular way.

A **converging lens** makes parallel light rays come together.



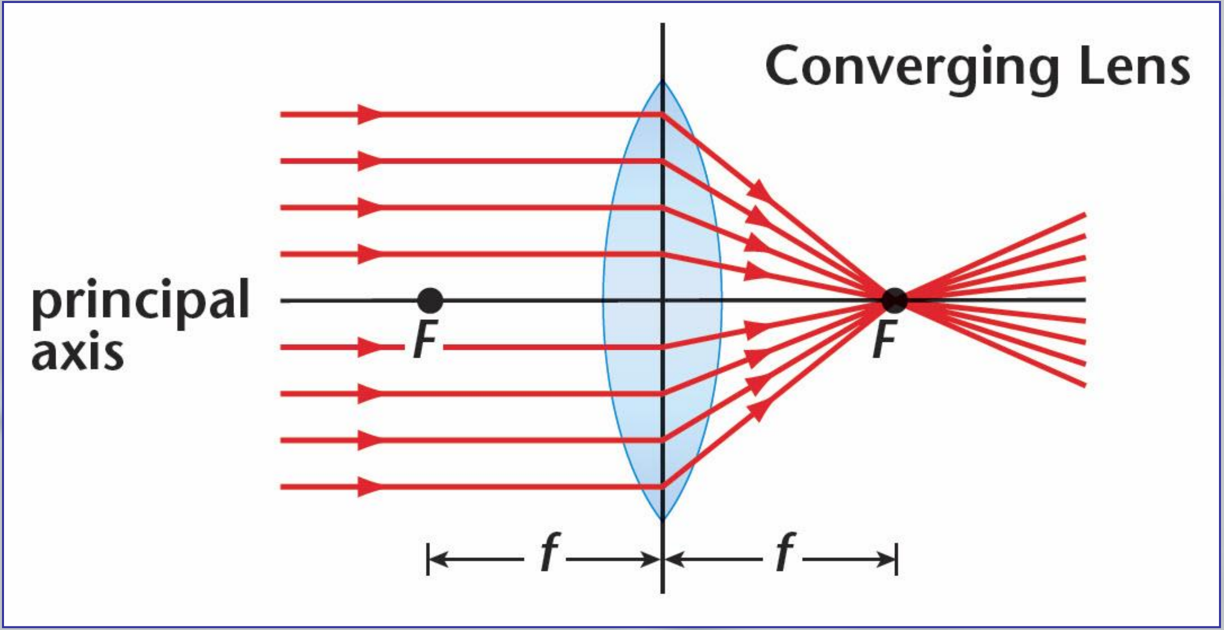


A **diverging lens** makes parallel light rays move apart.

The extent that the rays converge or diverge is determined by the material the lens is made of and its shape.

Converging Lenses

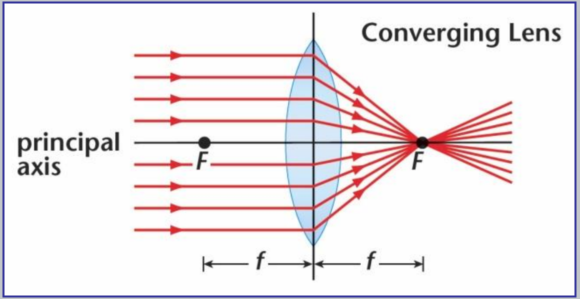
Since lenses have two sides, they have a focal point on each side. When parallel rays close to the principal axis pass through a converging lens, the rays all meet at one point on the other side of the lens. This point is the focal point.



The rays are drawn so they refract only once at the centre of the lens.

Rules for Drawing Ray Diagrams for Converging Lenses

Ray diagrams can be drawn to find an image formed by a lens. With lenses you draw three rays, and all three rays must meet at the same point. The rules for drawing rays for converging lenses are as follows:



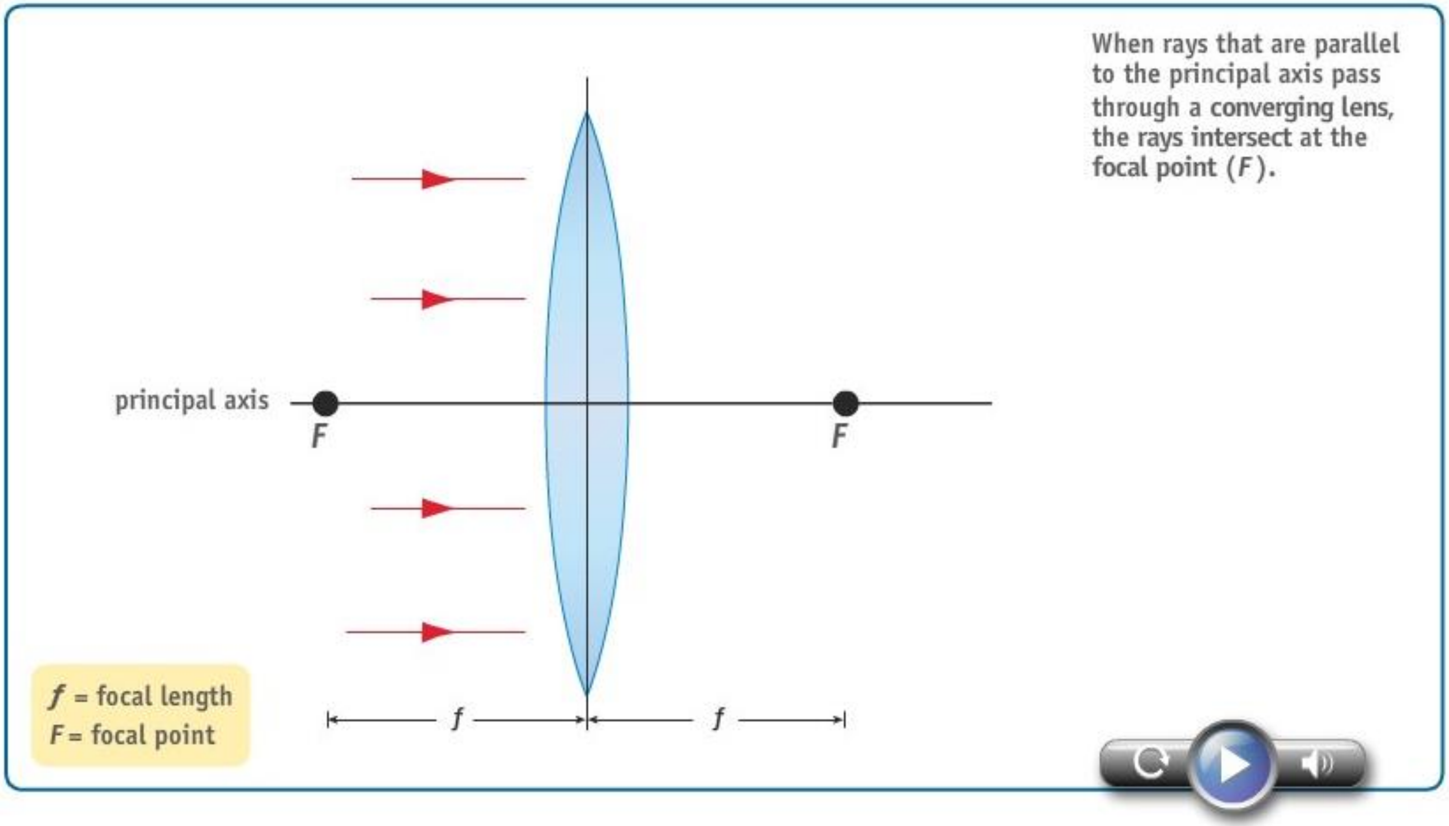
- Any ray that enters a lens parallel to the principal axis will pass through the focal point on the other side of the lens.
- Any ray that travels through the centre of the lens will keep travelling in the same direction.
- Any ray that enters the lens from the focal point will leave the lens parallel to the principal axis.

Reviewing the Focal Point of a Converging Lens

Click the "Start" button to review finding the focal point of a converging lens.

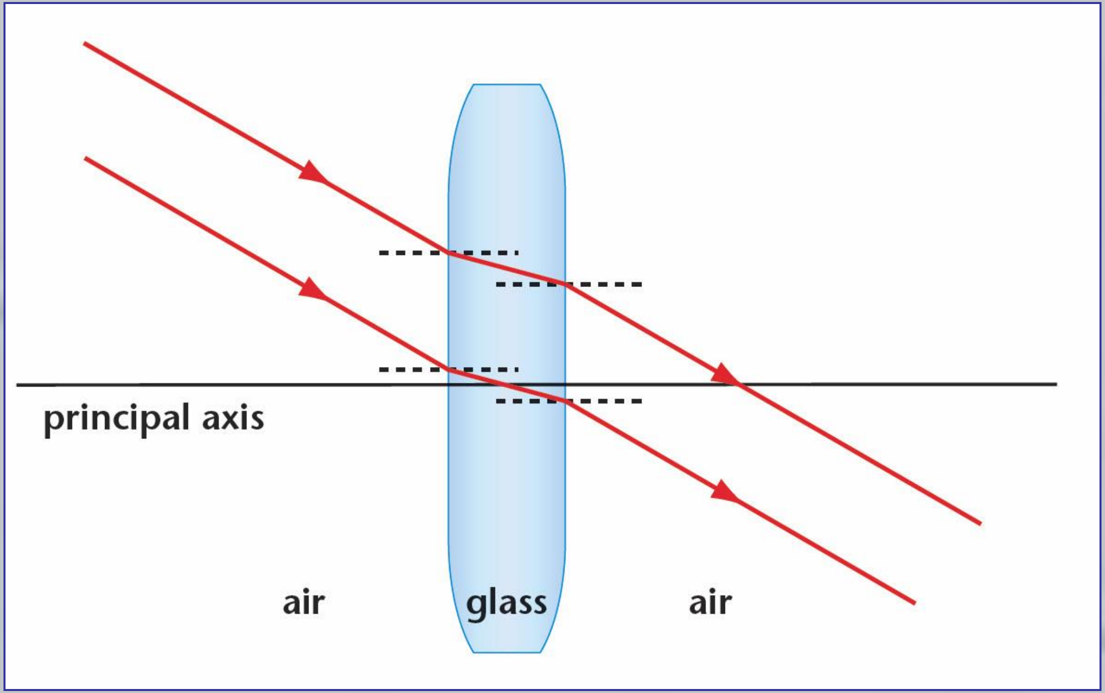
Finding the Focal Point of a Converging Lens

START

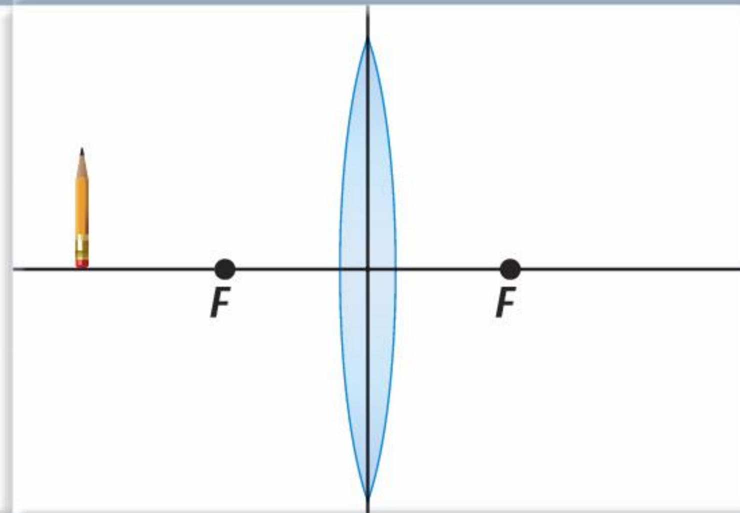
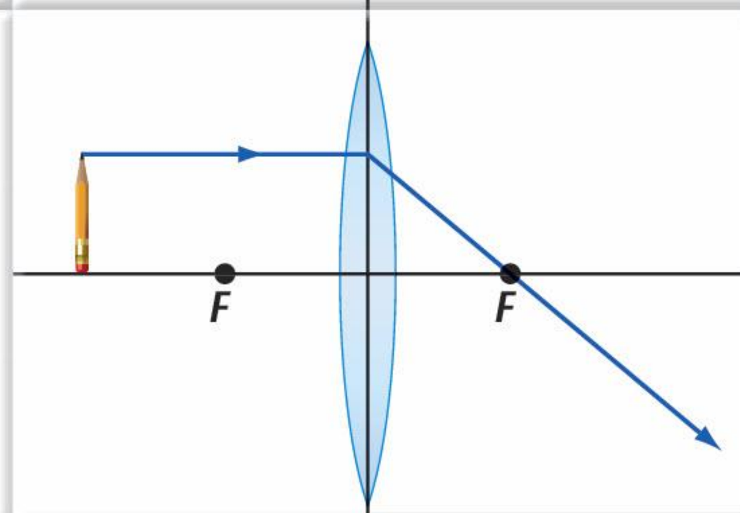


Rules for Drawing Ray Diagrams for Converging Lenses

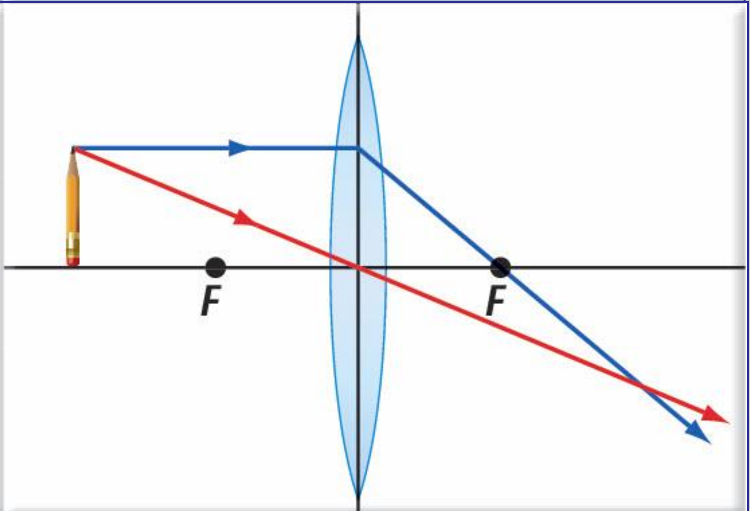
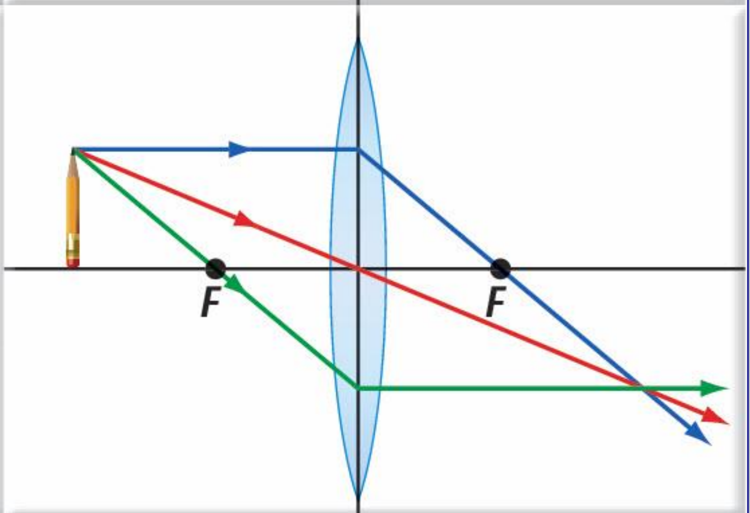
Rays passing through the centre of the lens at the principal axis do not change direction. This is because near the principal axis the lens is nearly flat on both sides. Therefore the ray of light is refracted by the same amount on both sides.



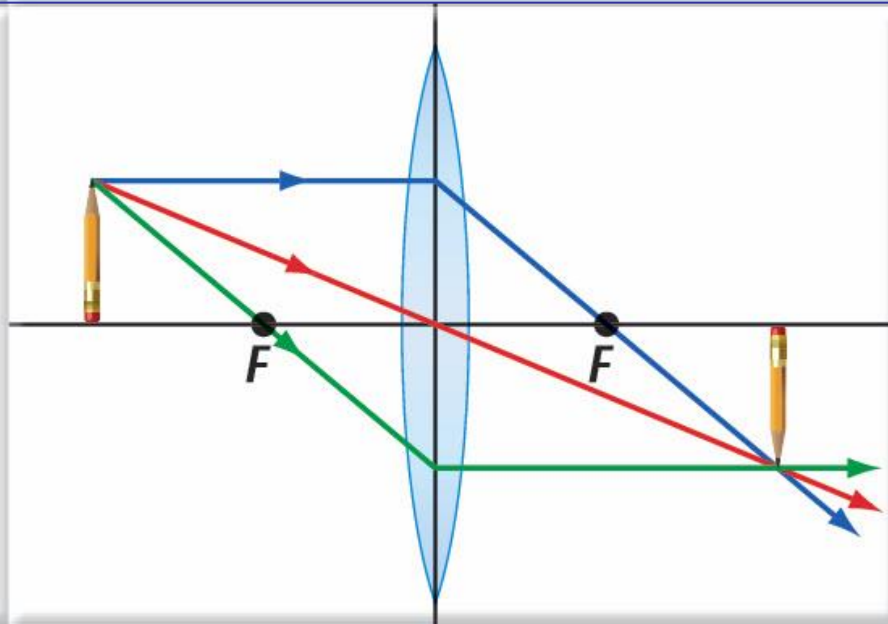
Drawing Ray Diagrams for Converging Lenses with Objects Beyond F

Directions	Example
Step 1 • Draw a principal axis and a vertical line through the axis to represent the centre of the converging lens. • Draw focal points on both sides of the lens at the same distance from the centre of the lens. • Add an object that is farther from the lens than the focal point.	
Step 2 • Draw the first ray (shown in blue). It starts at the top of the object and runs parallel to the principal axis until it reaches the centre of the lens. It leaves the lens and passes through the focal point on the far side of the lens.	

Drawing Ray Diagrams for Converging Lenses with Objects Beyond F

Directions	Example
Step 3 • Draw the second ray (shown in red). It starts from the top of the object and goes directly through the point where the centre of the lens meets the principal axis. It continues in the same direction.	
Step 4 • Draw the third ray (shown in green). It goes from the top of the object, through the focal point on the same side of the lens as the object. It leaves the lens running parallel to the principal axis.	

Drawing Ray Diagrams for Converging Lenses with Objects Beyond F

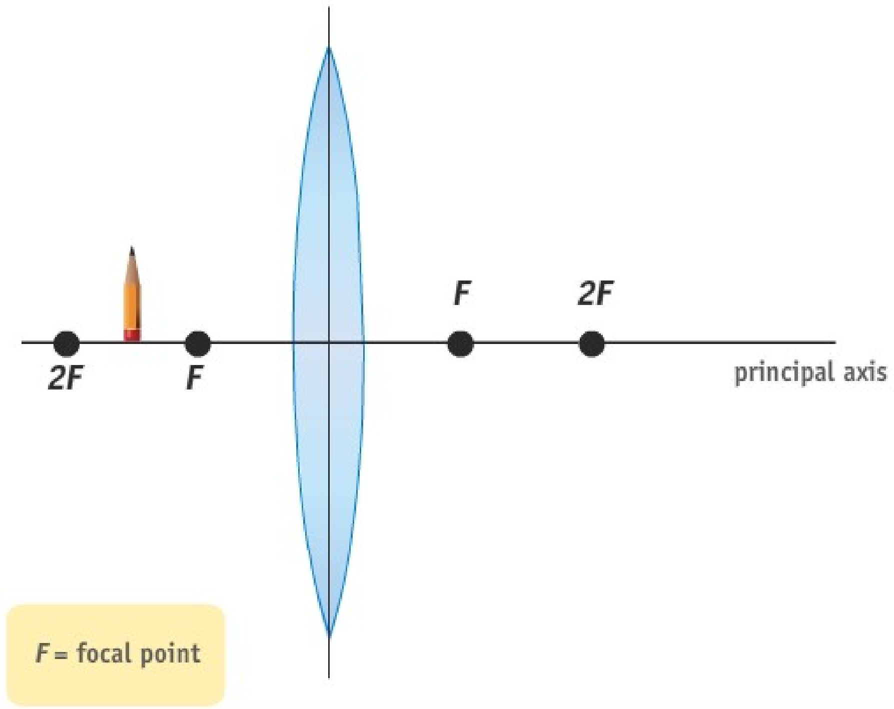
Directions	Example
Step 5 • Draw the image. The top of the image is at the point where the three rays meet. The bottom of the image is on the principal axis. The image is real and inverted.	

Analyzing Ray Diagrams for Converging Lenses

Click the “Start” button to analyze a ray diagram for a converging lens.

Ray Diagram for Converging Lens with Object Between *F* and *2F*

START



The object is between the focal point, F, and the point 2F, which is twice the distance from the lens as F.

Image Characteristics:

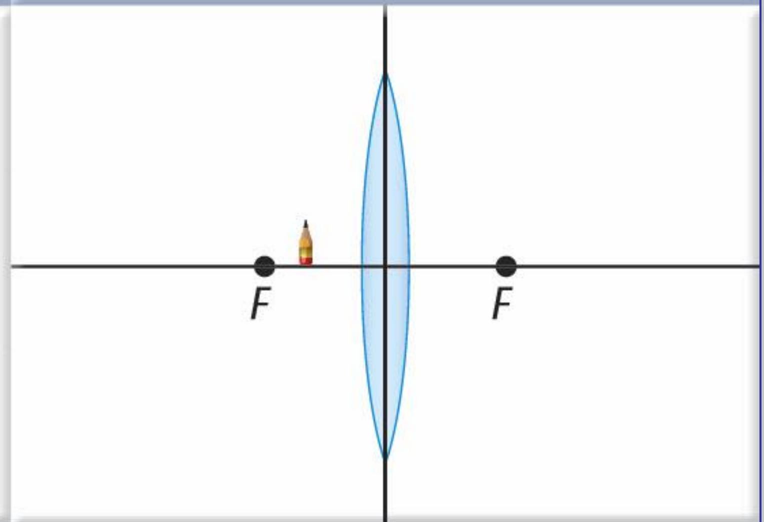
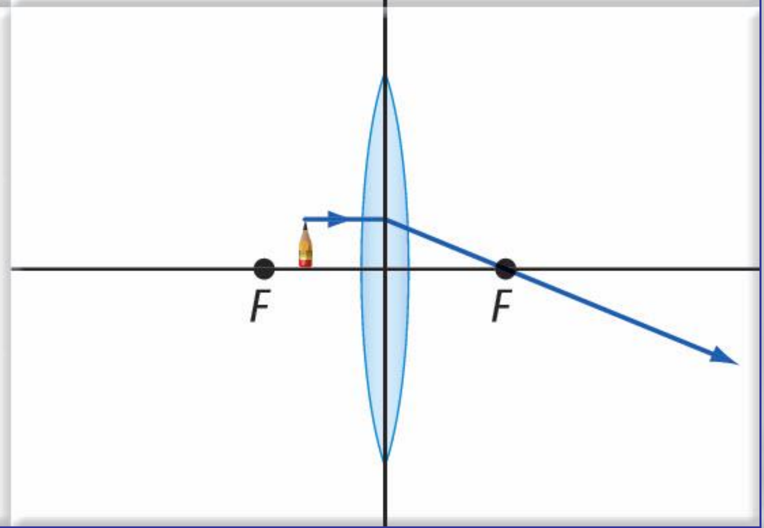
- farther from lens than object
- inverted
- larger than object
- real

Converging lenses can produce different types of images.

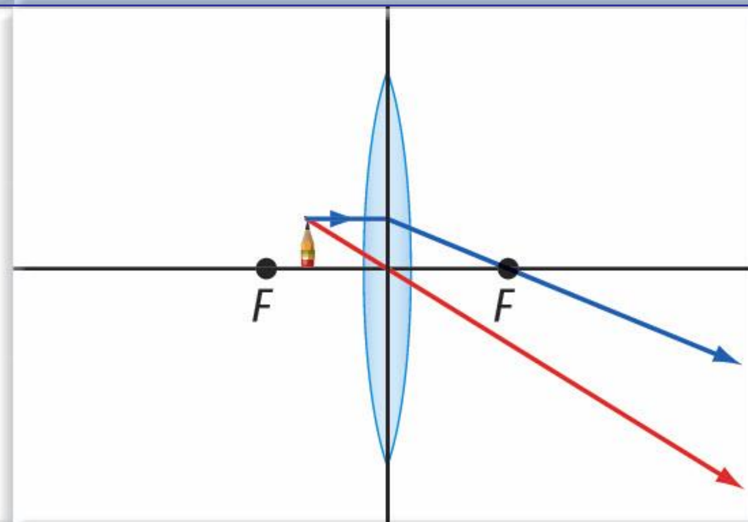
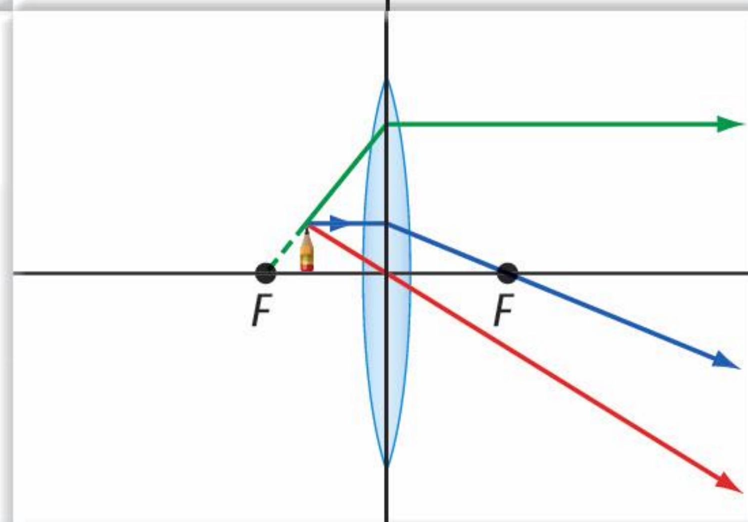
The first lens known to be used was a converging lens called a reading stone. Reading stones formed images that were upright and larger than the object.

How can a converging lens produce both upright and inverted images?

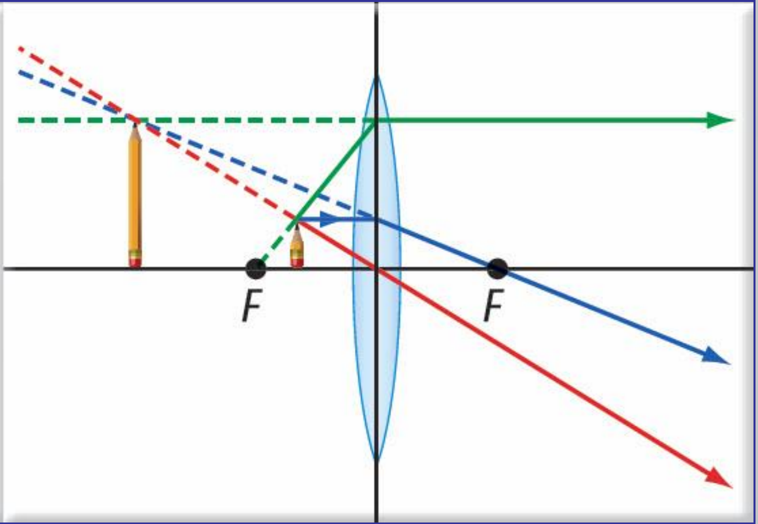
Drawing Ray Diagrams for Converging Lenses with the Object between the Lens and F

Directions	Example
Step 1 • Draw a principal axis and a vertical line through the axis to represent the centre of the converging lens. • Draw focal points on both sides of the lens at the same distance from the centre of the lens. • Add an object that is between the lens than the focal point.	
Step 2 • Draw the first ray (shown in blue). It starts at the top of the object and runs parallel to the principal axis until it reaches the lens. It then leaves the lens and passes through the focal point on the far side of the lens.	

Drawing Ray Diagrams for Converging Lenses with the Object between the Lens and F

Directions	Example
Step 3 • Draw the second ray (shown in red). It starts from the top of the object and goes directly through the centre of the lens at the principal axis. It continues in the same direction.	
Step 4 • Draw the third ray (shown in green). It appears to come from the focal point on the same side of the lens as the object as shown by the dotted green line. It continues from the top of the object to the lens. It leaves the lens and travels parallel to the principal axis.	

Drawing Ray Diagrams for Converging Lenses with the Object between the Lens and F

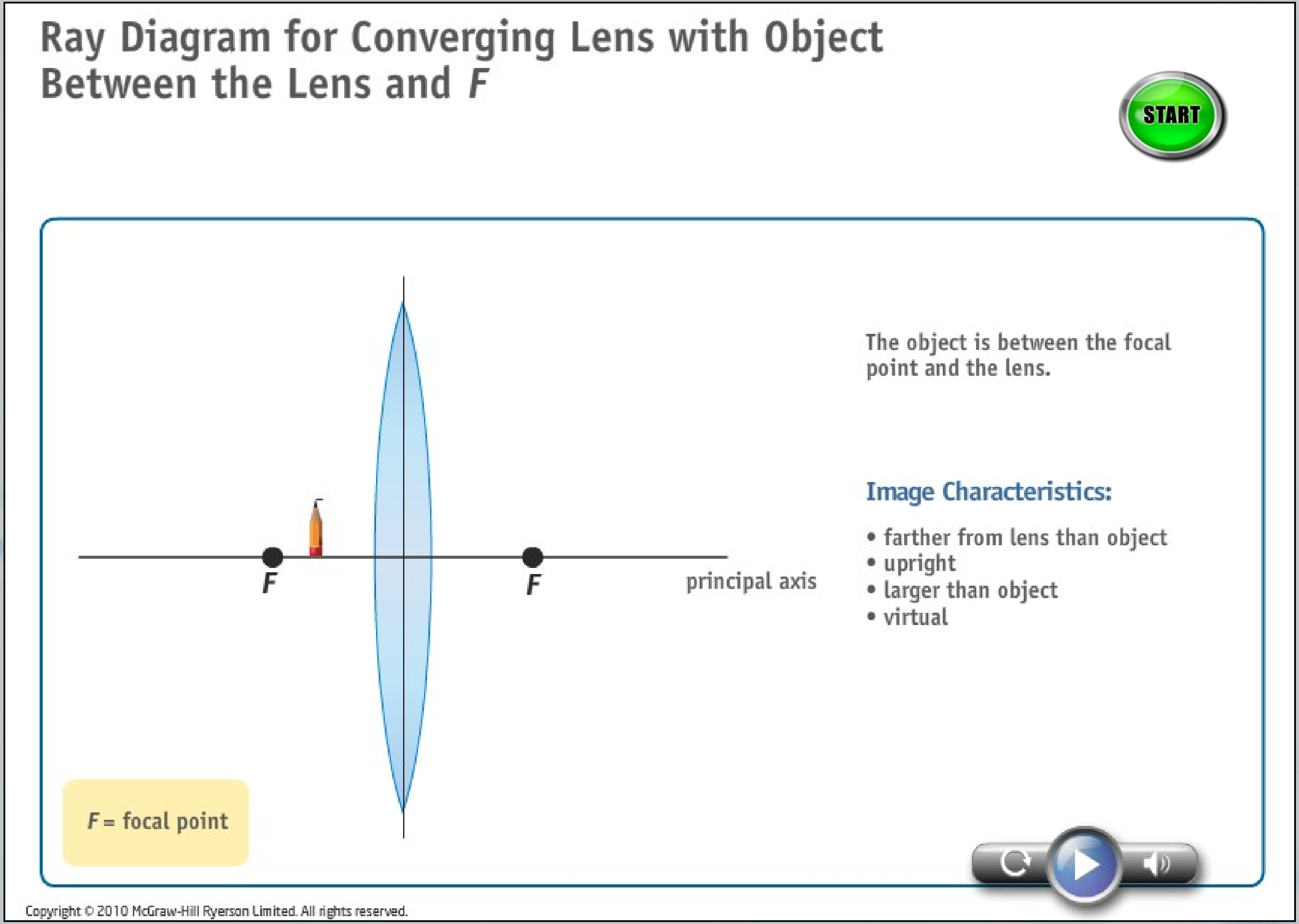
Directions	Example
Step 5 • The rays are spreading apart and will never meet. Therefore, extend the rays backwards until they meet, as shown with dashed lines. Draw the top of the image at the point where the extended rays meet. The bottom of the image is on the principal axis.	

If the object is between the focal point (F) and the converging lens, a larger (magnified) right-side-up image is formed.

Remember that when the object was outside the focal point (F), an inverted image was formed.

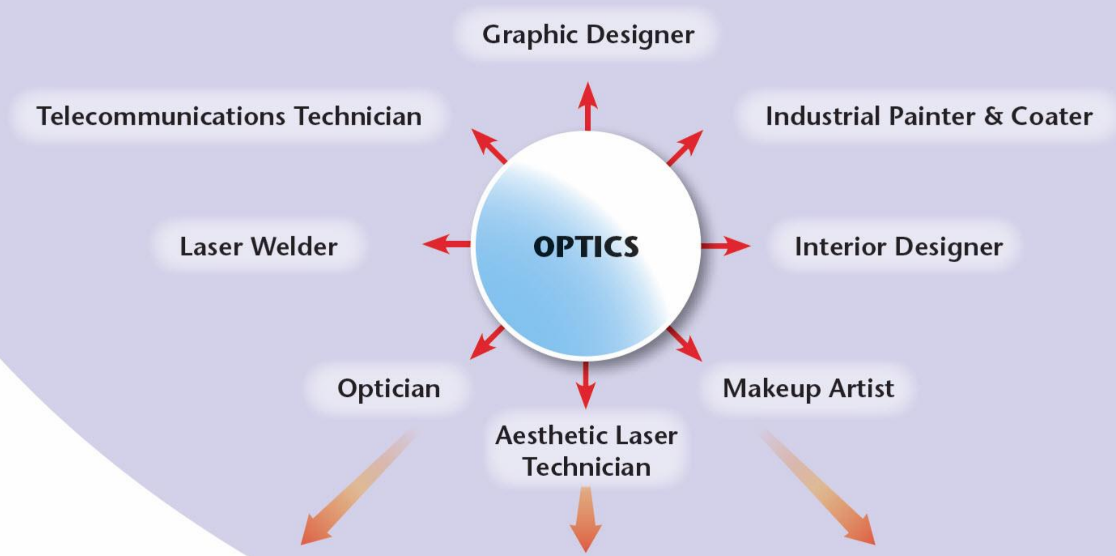
Reviewing a Ray Diagram for Converging Lens

Click the "Start" button to review a ray diagram for a converging lens.



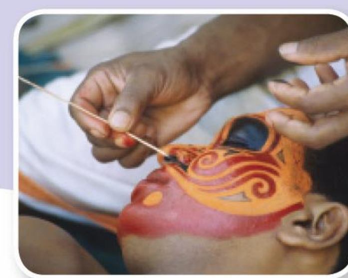
Put Science To Work

The study of optics contributes to these careers, as well as many more!



▲ Opticians work in retail stores, clinics, and doctor's offices with optical dispensing departments. They fit customers with prescription eyeglasses or contact lenses, help them choose frames for glasses, and process eyewear orders.

▲ Medical grade lasers enable aesthetic laser technicians to treat cosmetic and medical conditions including spider veins, cellulite, unwanted body hair, and wrinkles without the use of invasive surgery.



▲ Makeup artists for film, television, and live theatre must understand how skin colour can be enhanced under the intense multi-hued lights of the stage or studio in order to preserve a performer's natural appearance or to create a desired effect.

Topic 4.6 Review

Key concepts to be reviewed:

- *Lenses have at least one curved surface and refract light in a predictable way.*
- *Converging lenses can produce different types of images.*