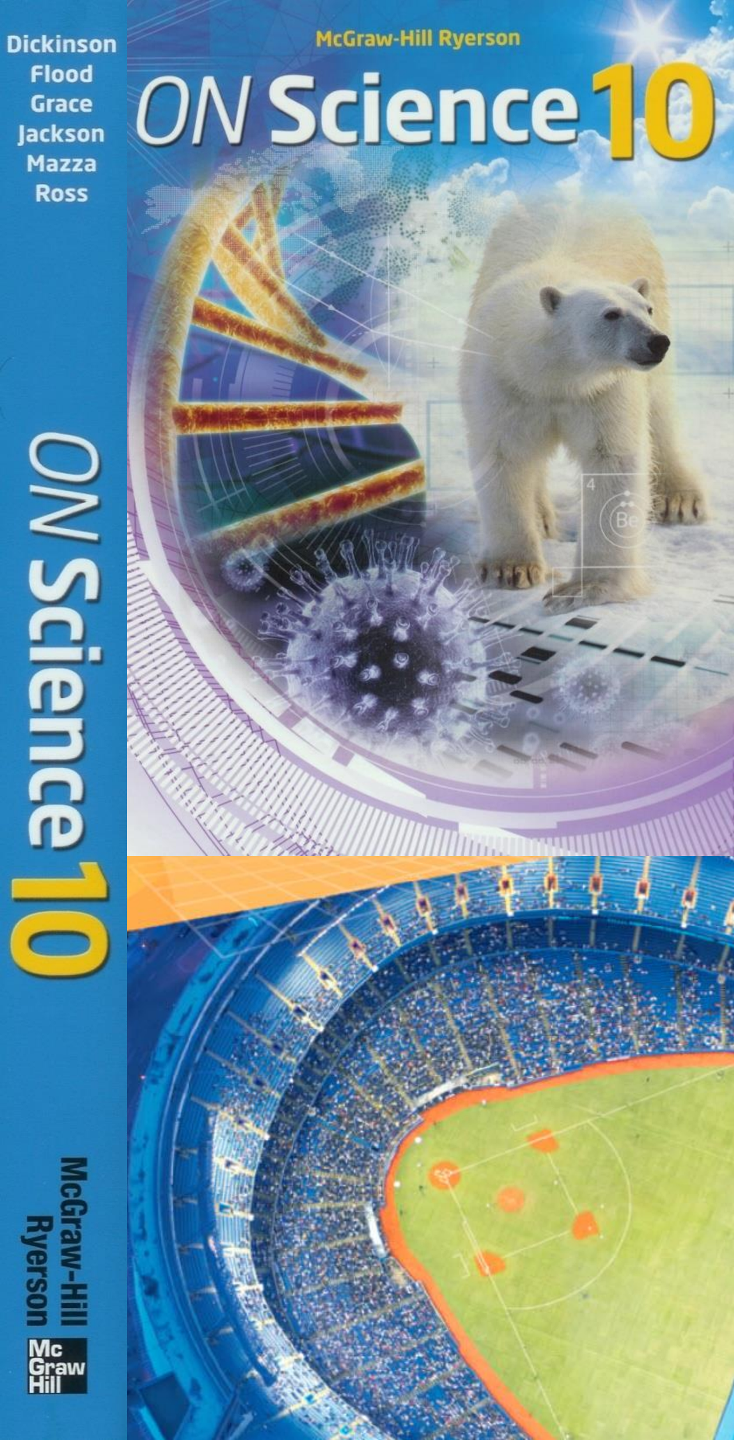


UNIT 4

Light and Geometric Optics

Chapter 10: *Light and Reflection*

Chapter 11: *Refraction*

Chapter 12:*Lenses and Lens Technology*

CHAPTER 10 *Light and Reflection*

In this chapter, you will:

- ***describe*** *examples of technologies that use light*
- ***describe*** *and* ***explain*** *a variety of sources of light*
- ***explain*** *how technologies that use light benefit society*
- ***investigate*** *the laws of reflection using plane and curved mirrors*
- ***predict*** *both quantitatively and qualitatively, the characteristics of images in plane and curved mirrors*
- ***analyze*** *a technological device that uses properties of light*

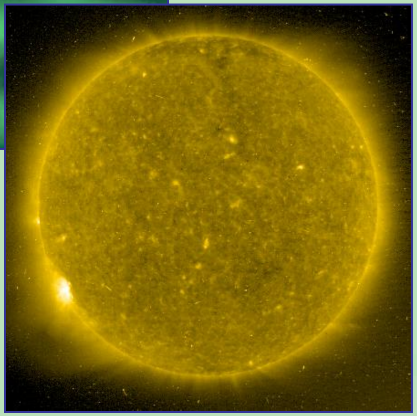
Growing Slime

Attempt to explain how glow-in-the-dark substances like the slime you make in this activity absorb and then give off light.

How might your understanding of electrons help explain what you observed?

10.1 Sources and Nature of Light (Page 403)

There are many sources of light, both natural and artificial. All sources of light must absorb some form of energy that raises the atoms in the substance to an excited state. These excited atoms then release energy, often in the form of **light**.

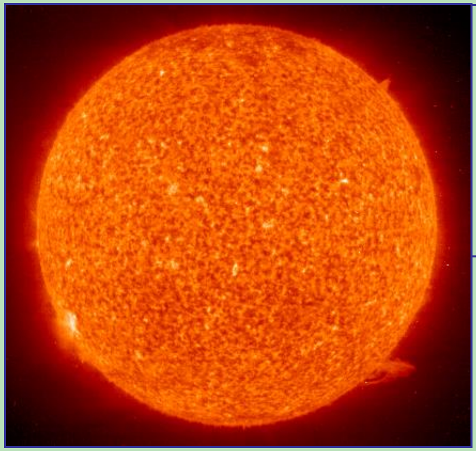


http://umbra.nascom.nasa.gov/images/latest_eit_284.gif

Natural Sources:
Fluorescent Zebrafish
Sun

Artificial Source:
Incandescent Light Bulb

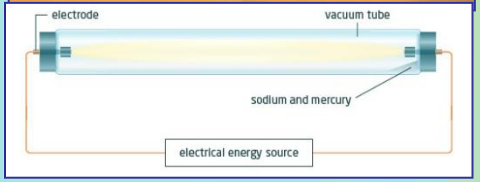
Sources of Light



http://umbra.nascom.nasa.gov/images/latest_eit_304.gif

Hydrogen atoms in the **Sun's** core collide and fuse to form helium. This **fusion reaction** releases vast amounts of energy.

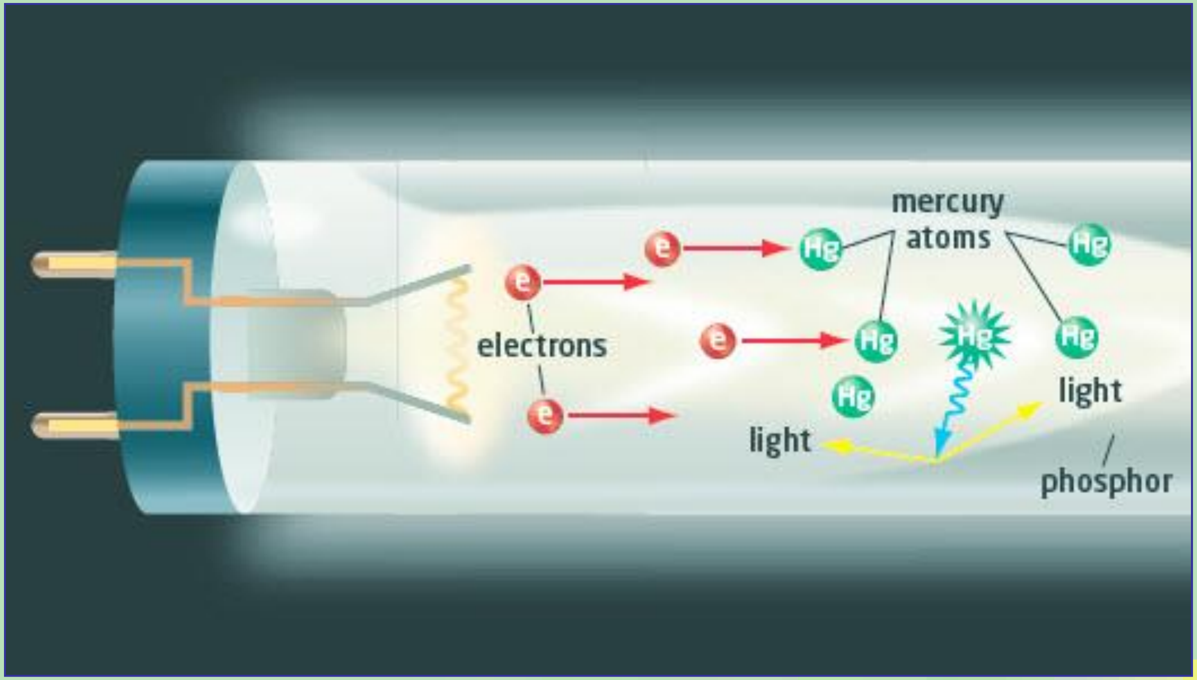
Incandescent Light is light emitted from a material because it is at a high temperature. An **incandescent light bulb** has a tiny tungsten wire that gets very hot when an electric current runs through it.



Bulbs in streetlights emit light from a gas or vapour instead of a heated wire. This process is called **electric discharge**.

Fluorescence

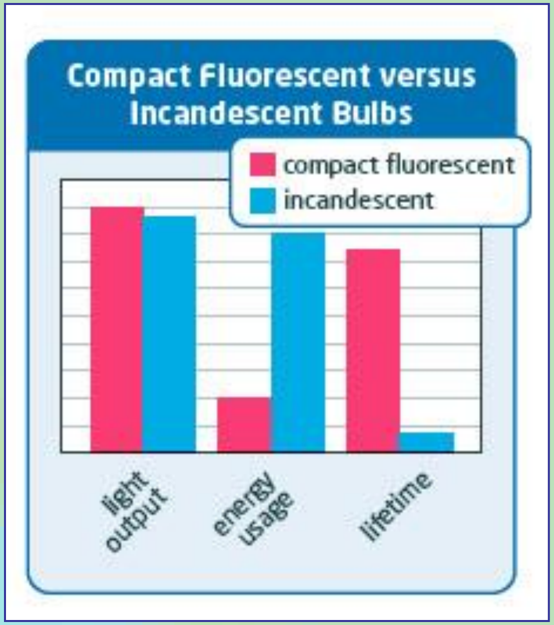
Fluorescence describes light that is emitted during exposure of the source to ultraviolet light. In a **fluorescent** light bulb, a powdery substance called phosphor emits visible light when it is bombarded by ultraviolet light produced by excited mercury atoms.



Efficiency of Fluorescent Lighting

(Page 406)

Fluorescent light bulbs use less electricity and last longer, making them more energy efficient than incandescent bulbs.



A variety of uses for fluorescent light are illustrated on the right.

Many body fluids contain fluorescent molecules. Forensic scientists use ultraviolet lights at crime scenes to find blood, urine, and semen (all fluorescent).

The tongue's natural fluorescence changes when abnormal tissue is present. A dentist or hygienist can shine a blue light in the mouth and look through a special filter to detect unhealthy oral tissue, which appears as very dark spots.

Fluorescent materials are used in many types of documents. Banks, businesses, and other organizations have detectors that use ultraviolet lights to check legal documents, admission tickets, currency, and clothing for counterfeit documents and money.

Some theatre performers use paint with fluorescent dyes. When the theatre is dark and only ultraviolet light is shining on the performers, all the audience can see is the fluorescent light coming from the paint.

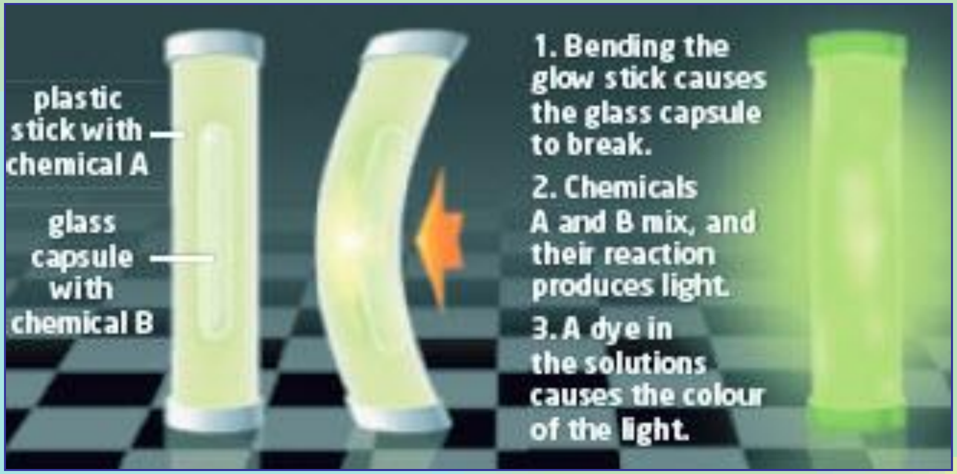
Types of Luminescence

(Page 407)

Luminescence is light generated without heating the object. The energy used to excite the atoms comes from a variety of sources.

Phosphorescence is a type of luminescence. Many glow-in-the-dark objects contain phosphorescent materials. The excited atoms may retain energy for several minutes or up to a few hours.

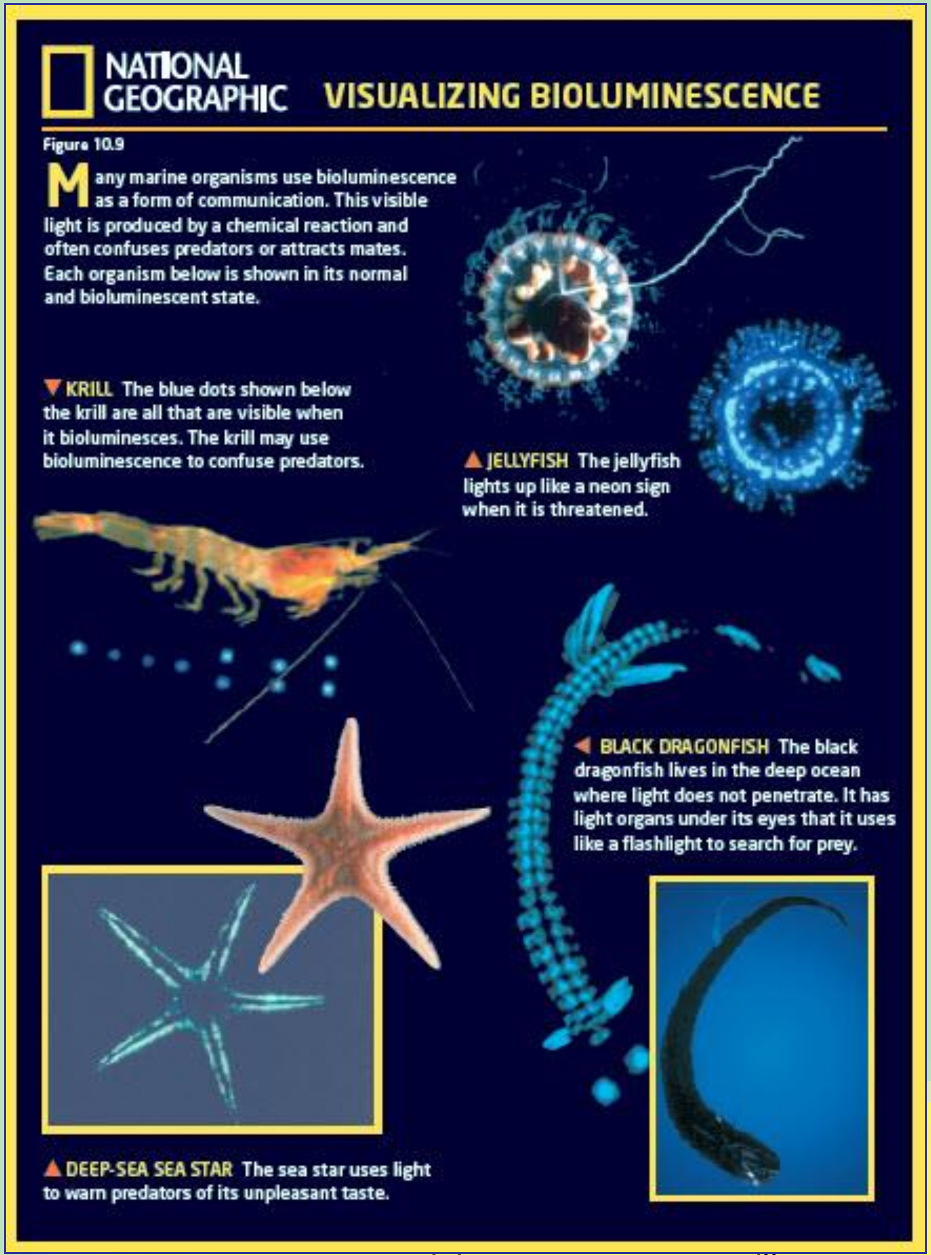
Chemiluminescence is light that is generated by the energy released in a chemical reaction without a rise in temperature.



Bioluminescence

Bioluminescence is light that is produced by a biochemical reaction in a living organism.

Several examples of bioluminescent organisms are illustrated on the right.

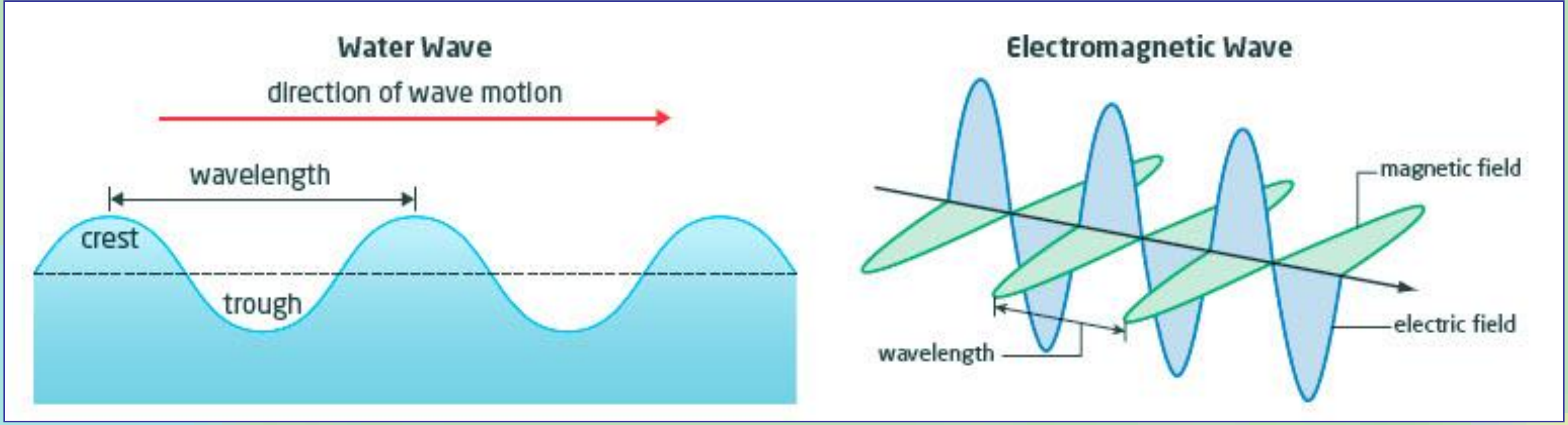


The Nature of Light

(Page 409)

Light is the only form of energy that can travel like a wave through empty space and through some materials.

Light waves are called **electromagnetic waves**. Similar to water waves, light waves involve the movement of energy from one point to another. These waves are invisible and can travel through a vacuum. (This means they do not require particles of matter in order to move.) The waves travel at 3×10^8 m/s (the speed of light).

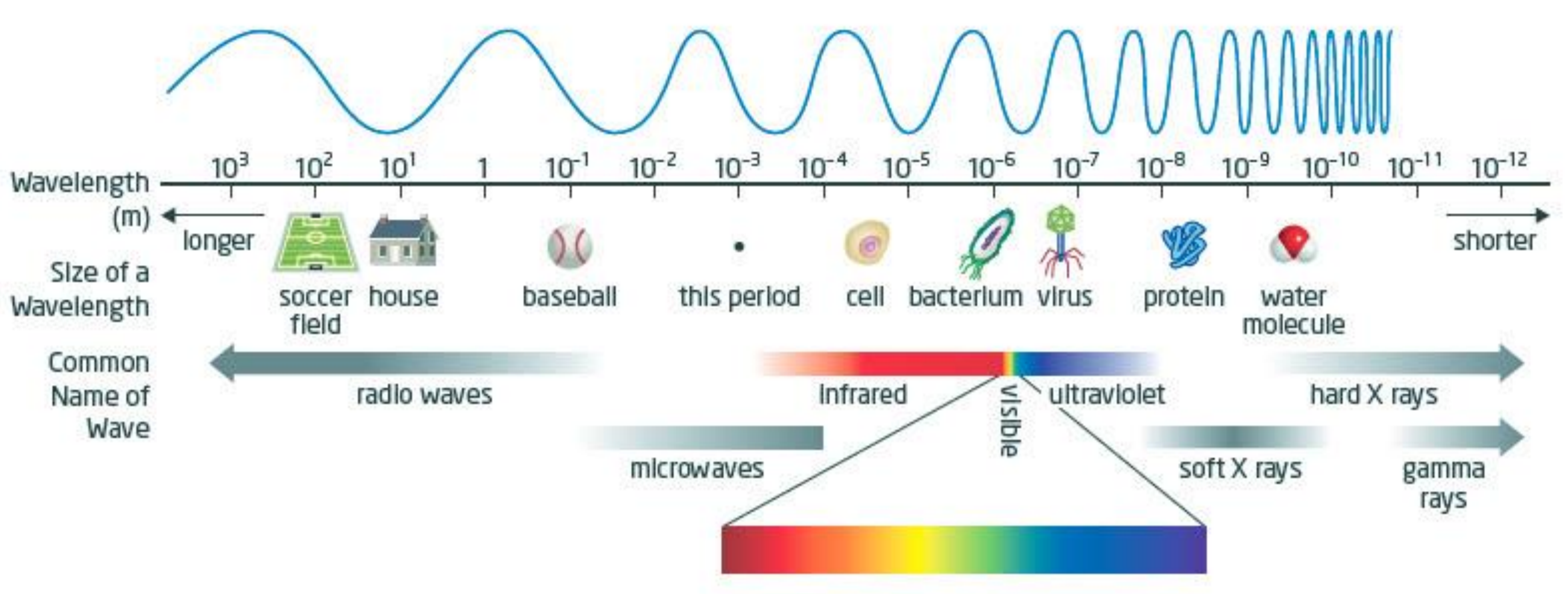


A **wavelength** is the distance from one crest (or trough) to the next.

The Electromagnetic Spectrum

(Page 409)

The **electromagnetic spectrum** is a diagram that illustrates the range, or spectrum, of electromagnetic waves, in order of wavelength or frequency.



The **frequency** of a wave represents the number of crests (or troughs) that pass a given point in one second.

Section 10.1 Review

(Page 410)

Concepts to be reviewed:

- *incandescence and how incandescent light is produced*
- *luminescence and examples of luminescent light*
- *light and how is it transmitted*
- *the electromagnetic spectrum*

10.2 Properties of Light and Reflection (Page 411)

All **light,** regardless of its source, behaves in the same way. In a natural setting such as the one below, the light that allows us to see the scene originated at the Sun. The **light rays** travelled through several different **media** and then **reflected** off all of the visible objects in the picture on the way to our eyes.

Reflection is the change in direction of a light ray when it bounces off a surface.

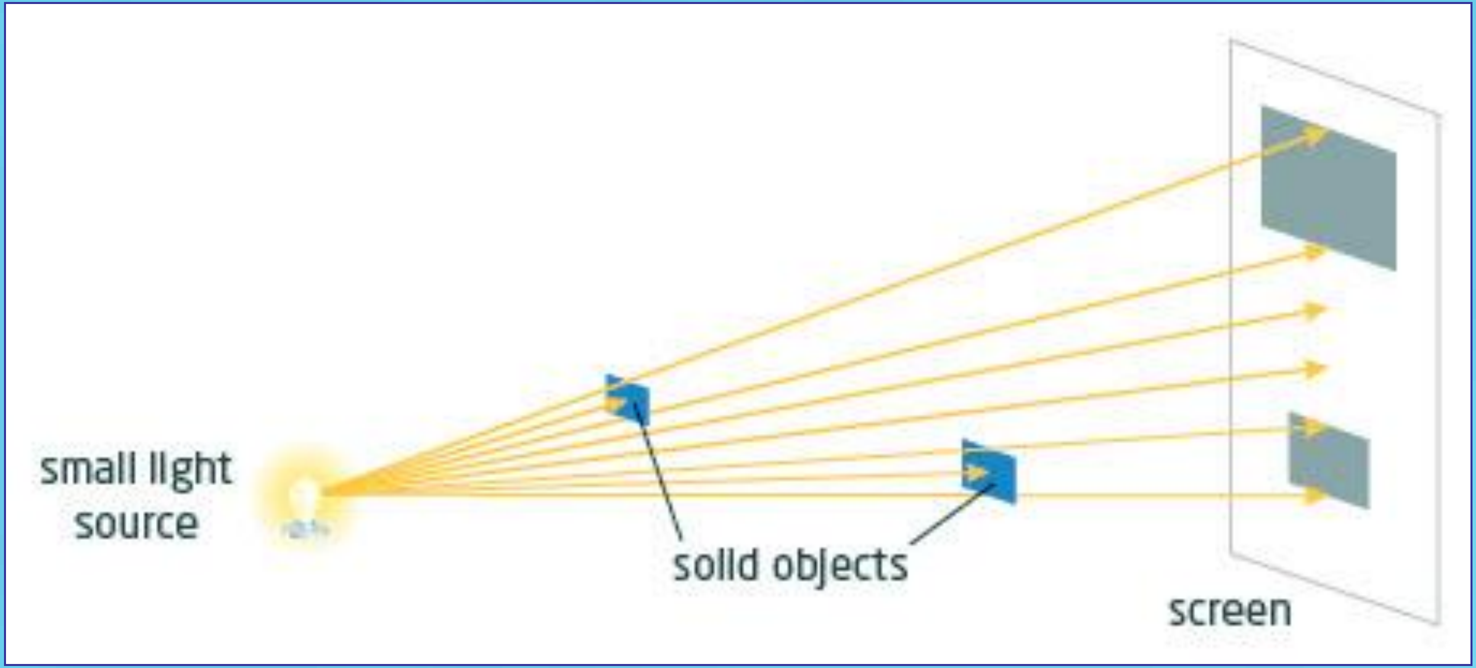
In diagrams, **rays** are straight lines with arrowheads that show the direction in which light rays are travelling.

A **medium** is the substance through which light travels.

Ray Tracing / Shadows

(Page 412)

Rays can be used to predict the location, size, and shape of the shadows of objects. **Shadows** represent areas on the screen that are receiving fewer or no rays of light.



The size of the object that is blocking the rays of light and its distance from the light source affect the size of the shadow that is cast.

Laws of Reflection

(Page 412)

Fermat's Principle states that light follows the path that takes the least amount of time ("light travels in a straight line"). The **Laws of Reflection** can be derived from this principle. To understand the **Laws of Reflection,** the following terms must be understood.

- An **incident ray** is a ray of light that travels from a light source towards a surface.
- The **normal** is a line that is perpendicular to a surface where a ray of light meets the surface.
- The **angle of incidence** is the angle between the incident ray and the **normal** in a ray diagram.
- A **reflected ray** is the ray that begins at the point where the incident ray and the **normal** meet (where the incident ray hits the surface).
- The **angle of reflection** is the angle between the reflected ray and the normal in a ray diagram.

Laws of Reflection

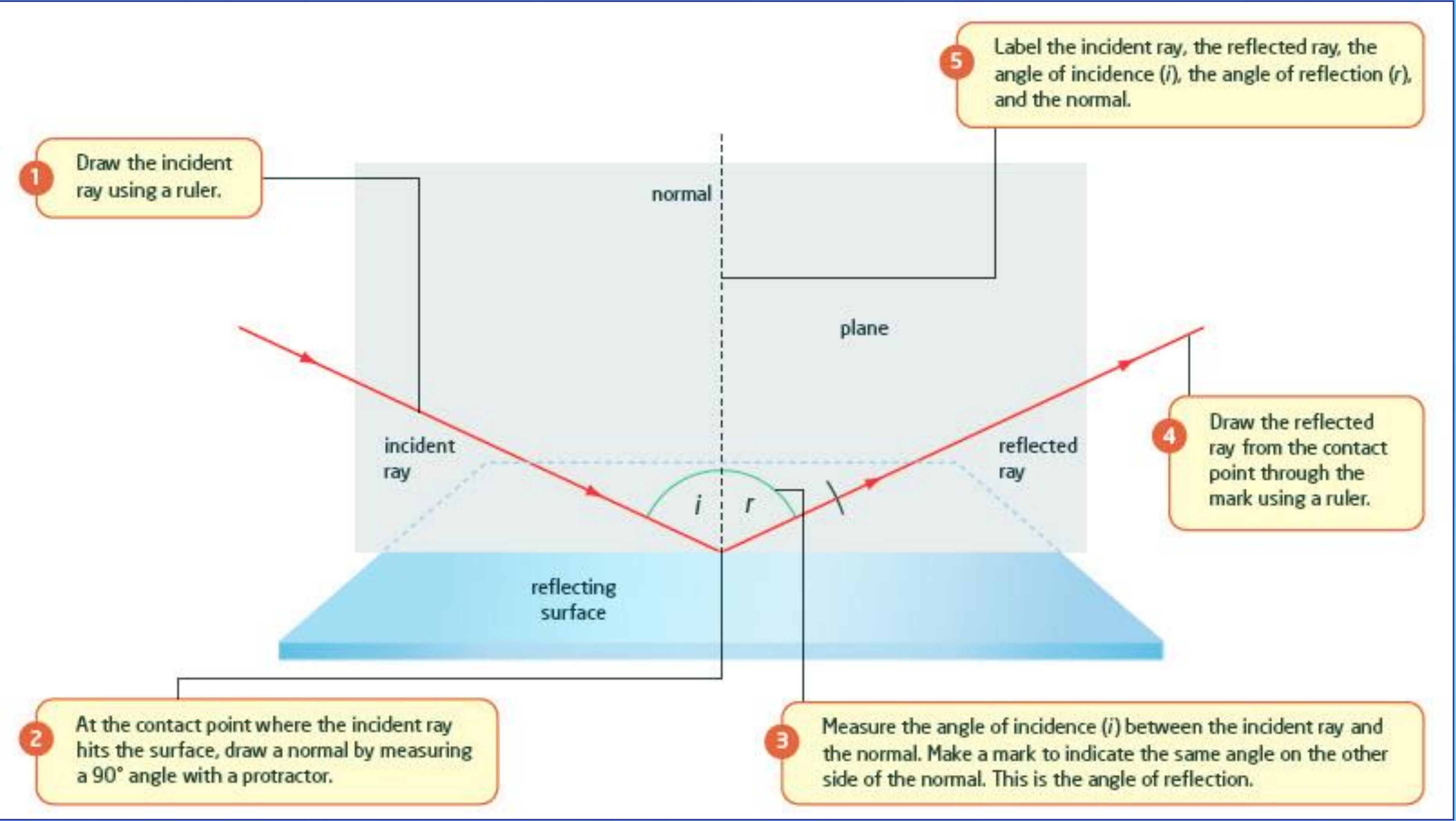
Laws of Reflection

1. The incident ray, the reflected ray, and the normal always lie on the same plane.
2. The angle of reflection, $\angle r$, is equal to the angle of incidence, $\angle i$.

$$\angle r = \angle i$$

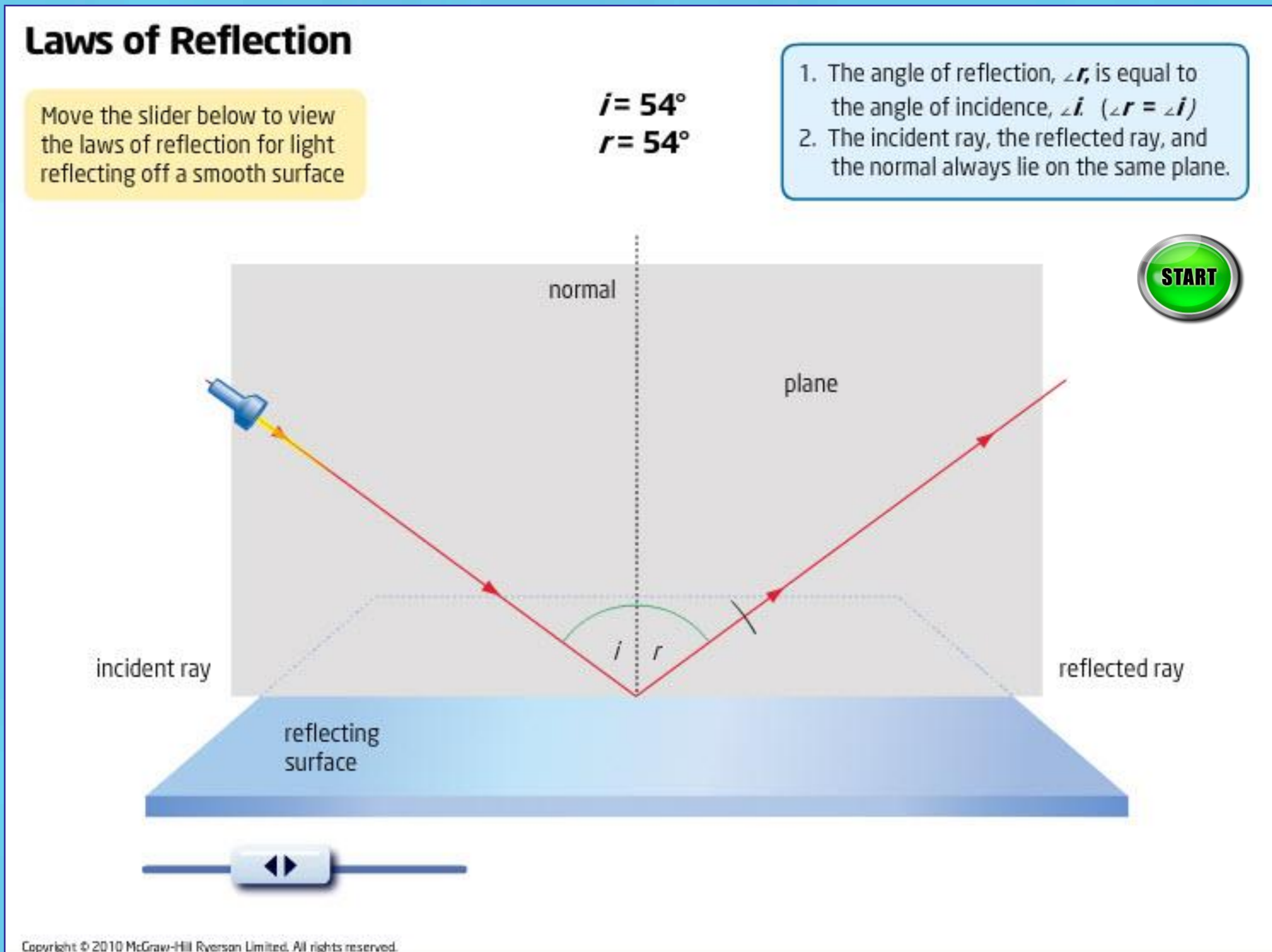
Drawing Ray Diagrams

The following steps should be followed when drawing a **ray diagram**.



The Laws of Reflection and Parts of a Ray Diagram

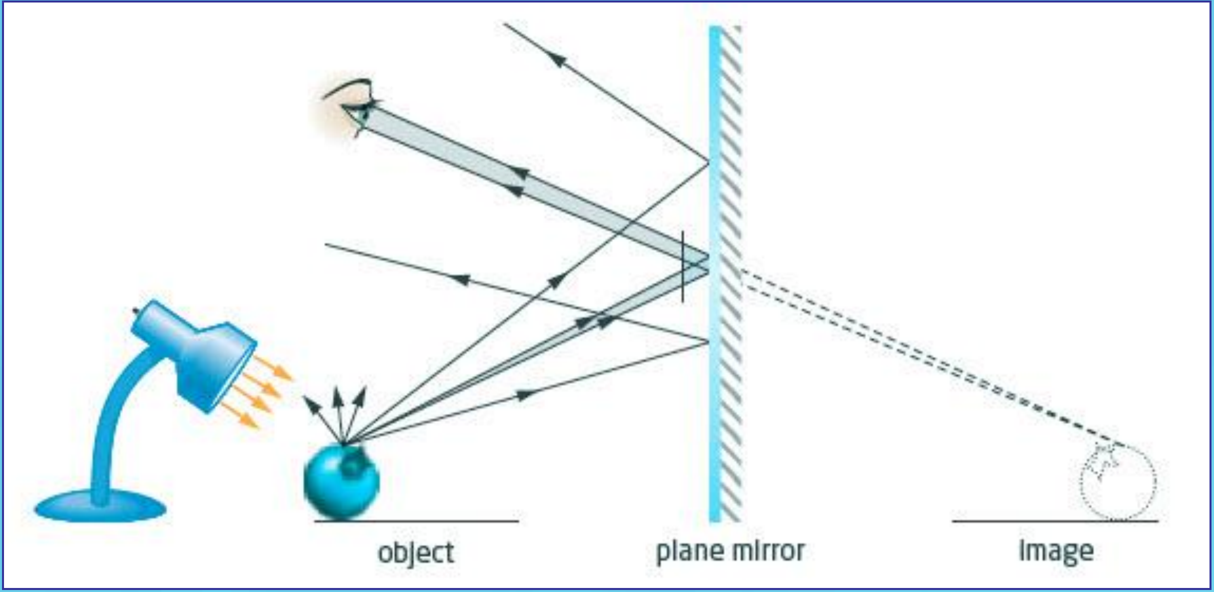
Click the "Start" button to review the Laws of Reflection.



Images in Plane Mirrors

(Page 414)

When examining the image produced by an object's reflection in a mirror, the object is called the ***object*** and the reflection is called the ***image***. Using the **Laws of Reflection**, you can predict where the image will be and what the image will look like.



A **plane mirror** is a mirror with a flat, reflective surface.

A **virtual image** is an image formed by rays that appear to be coming from a certain position but are not actually coming from this position. The image does not form a projection on a screen.

Ray Diagrams and Plane Mirrors

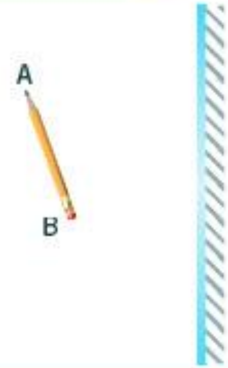
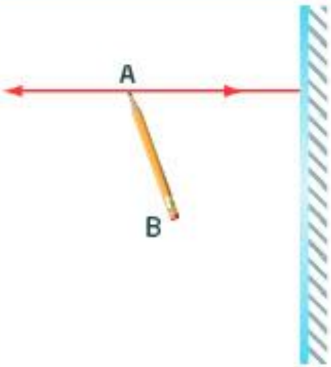
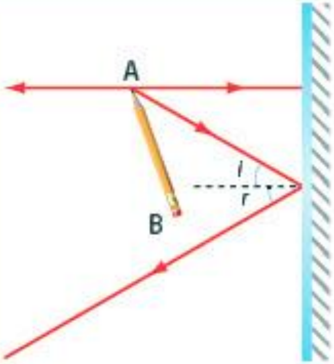
In general, an image observed in a mirror has four characteristics:

1. its **location** (closer than, farther than, or the same distance as the object to the mirror)
2. **orientation** (upright or inverted)
3. **size** (same size, larger than, or smaller than the object)
4. **type** (real image or virtual image)

You can predict these characteristics by drawing a **ray diagram**.

Locating an Image in a Plane Mirror Using a Ray Diagram

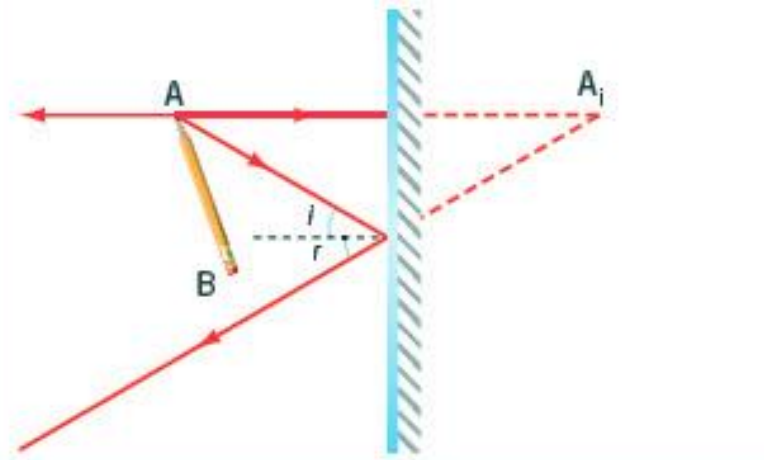
(Page 416)

Description	Example
1. Draw a line to represent a mirror. Add hatch marks to show the non-reflecting surface of the mirror. Draw a simple object. The distance between the mirror and the object is called the *object distance*. Label a point at one end of the object "A," and label a point at the other end "B."	
2. Draw an incident ray from point A directly to the mirror at a 90° angle. Because this line is normal to the mirror, the angle of incidence is zero. Therefore, the angle of reflection is also zero. The reflected ray goes directly backward along the same line as the incident ray.	
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. Measure the angle of incidence with a protractor. Using the knowledge that the angle of reflection is equal to the angle of incidence, draw the reflected ray.	

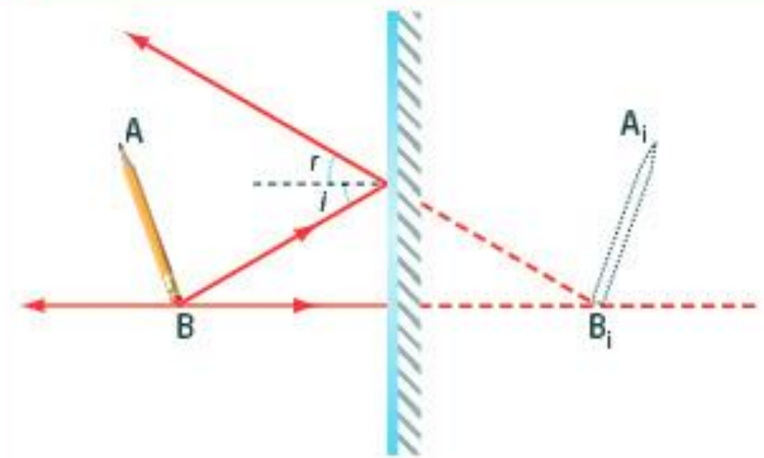
Locating an Image in a Plane Mirror Using a Ray Diagram

(Page 416)

4. Using a dashed line, extend both reflected rays behind the mirror until they meet. Label this point "A_i" to indicate that it is the image point of the tip of the pencil.

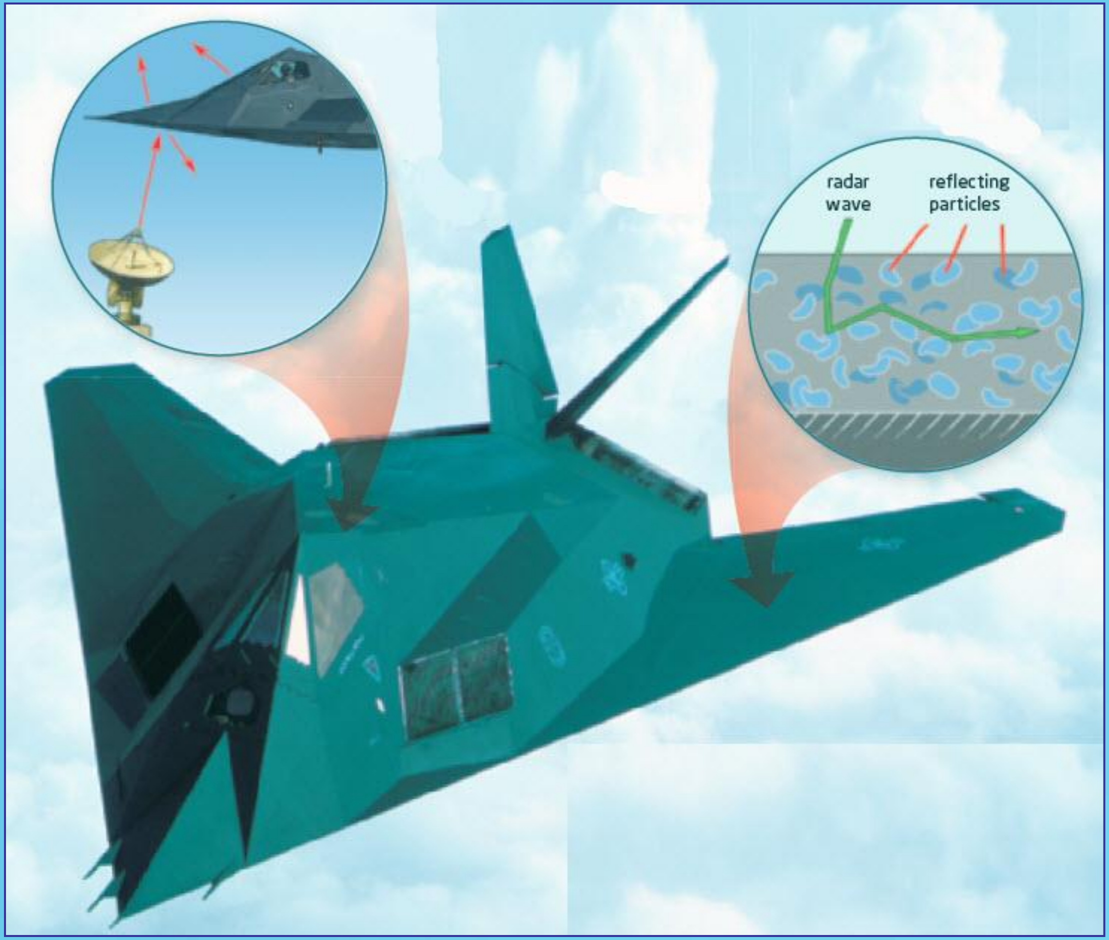


5. Repeat steps 2 to 4 for point B. Join A_i and B_i using a ruler. The distance between the mirror and the image is called the *image distance*.



Reflection and Stealth Technology (Page 417)

The shape of and surface coatings on stealth aircraft absorb and reflect radar waves so that only a few of the waves reach the ground radar station. This renders the aircraft virtually invisible.



Section 10.2 Review

(Page 418)

Concepts to be reviewed:

- *defining a ray and how it can be used to describe light*
- *an understanding of the Laws of Reflection and how they can be represented using ray diagrams*
- *how ray diagrams can be used to locate images in a plane mirror*
- *the four characteristics of an image reflected in a plane mirror*

10.3 Images in Concave Mirrors

(Page 419)

How does a **concave mirror** change the size, shape, and orientation of objects reflected in it?

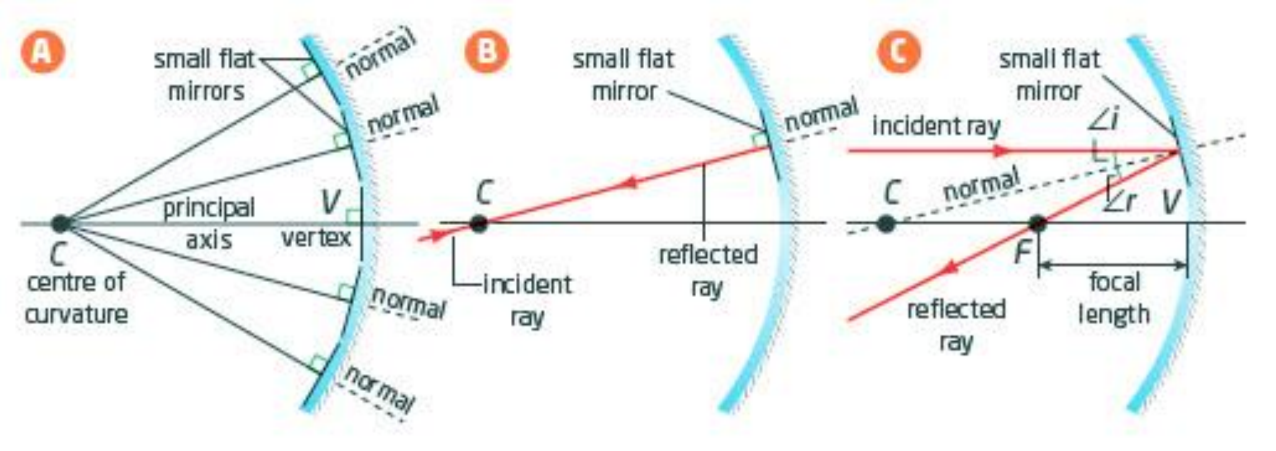
Properties of Concave Mirrors

(Page 420)

A **concave mirror** has reflecting surfaces that curve inward.

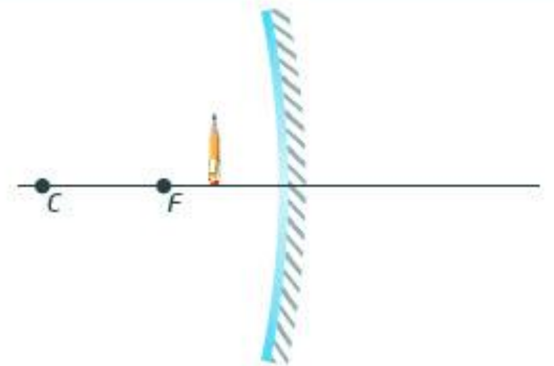
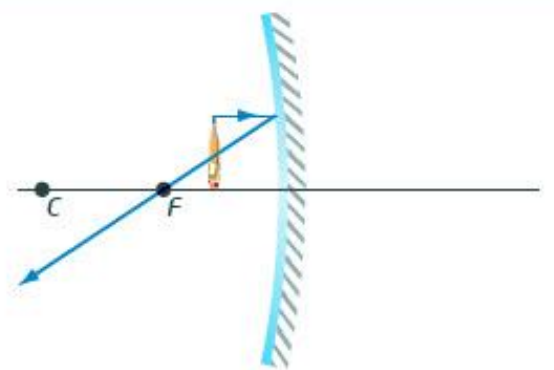
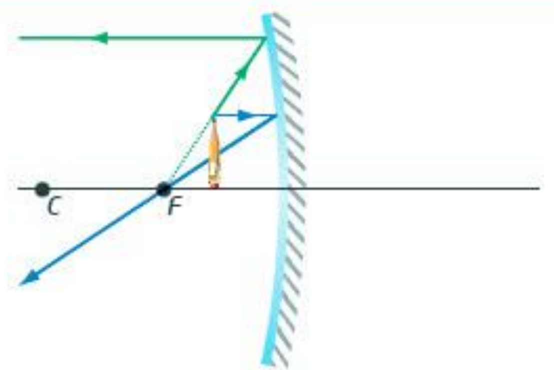
To understand and describe how light behaves when it hits a **concave mirror** you must be familiar with the following terms.

- The **principal axis** is the line that passes through the centre of curvature (***C***) of the mirror and is normal to the centre of the mirror.
- The **focal point** (***F***) is the point on the central axis through which reflected rays pass when the incident rays are parallel to and near the principal axis.
- The **focal length** is the distance between the vertex (***V***) of a mirror and the focal point.



Ray Diagrams for Concave Mirrors (object between F and the mirror)

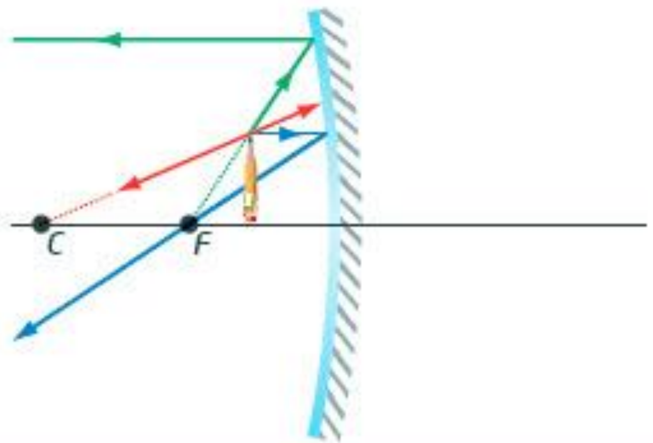
(Page 422)

Directions	Diagram
1. Draw the principal axis and a curve to represent the concave mirror. • Mark a focal point. • Draw the object so that the bottom is on the principal axis between the focal point and the mirror.	
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.	
3. If you draw a ray from the top of the object to the focal point, the ray will be going away from the mirror. Instead, start at the focal point and draw a dotted line (shown in green) going toward the top of the object. The dotted line represents the ray coming from the focal point. The actual ray starts at the top of the object and goes toward the mirror. Draw the reflected ray travelling backward, parallel to the principal axis.	

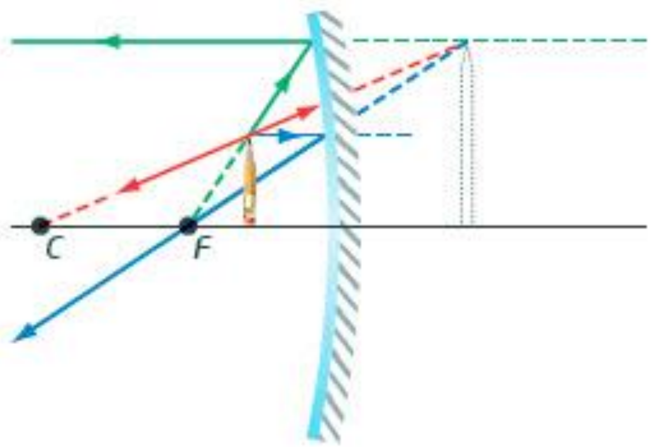
Ray Diagrams for Concave Mirrors (object between F and the mirror)

(Page 422)

4. Starting at *C*, draw a dotted line (shown in red) to the top of the object. This dotted line represents the ray coming from *C*. The actual ray starts at the top of the object and goes toward the mirror. Draw the reflected ray travelling backward, along the incident ray.



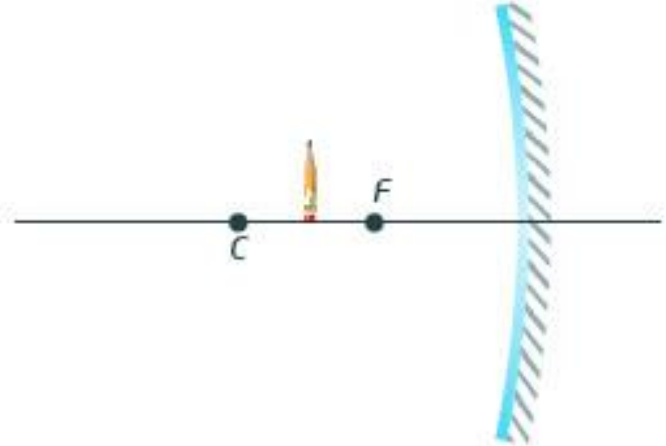
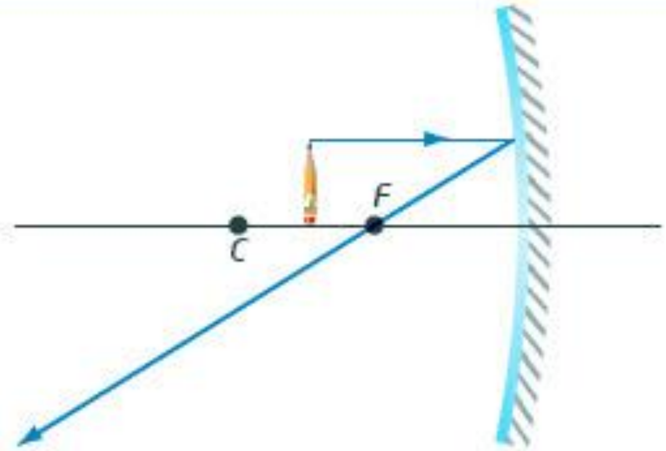
5. As you can see, the reflected rays are travelling away from each other and will never intersect. Therefore, extend the reflected rays behind the mirror with dashed lines. The point where the reflected rays meet is the top of the image. The bottom of the image is on the principal axis. Draw the image. Notice that the image is larger than the object.



Ray Diagrams for Concave Mirrors (object between F and C)

(Page 423)

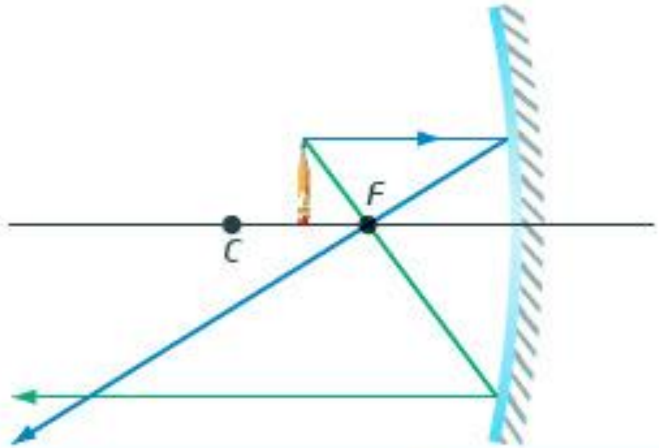
A **real image** is an image that is formed when reflected rays meet.

Directions	Diagram
1. Draw the principal axis and a curve to represent the concave mirror. • Mark a focal point. • Then mark the point *C* so that it is twice as far from the mirror as the focal point is. • Draw the object so that the bottom is on the principal axis between the focal point and *C*.	
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.	

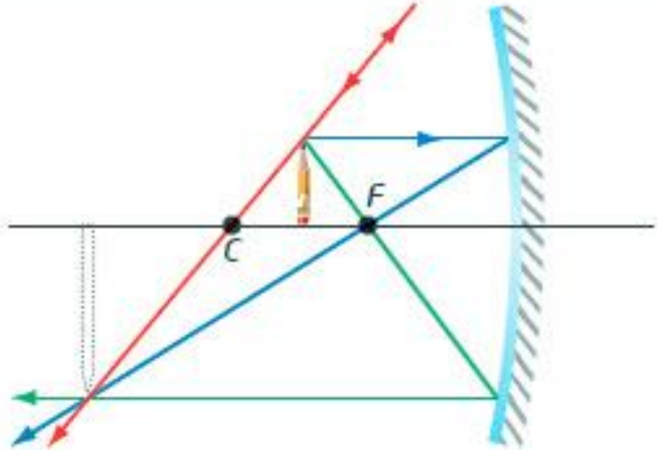
Ray Diagrams for Concave Mirrors (object between F and C)

(Page 423)

3. Draw a ray (shown in green) from the top of the object through the focal point, continuing to the mirror. The reflected ray will travel backward, parallel to the principal axis.

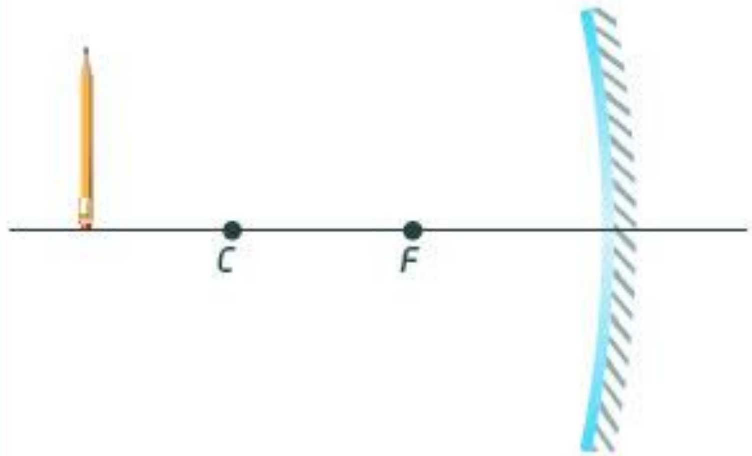
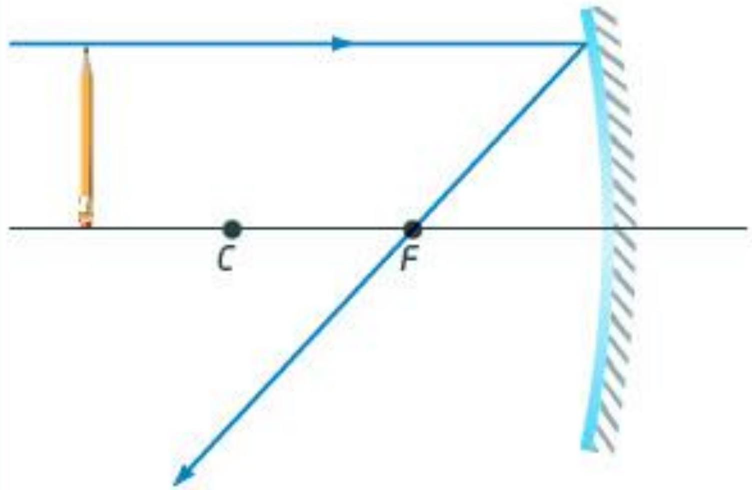


4. Draw a line (shown in red) from the top of the object toward the mirror, as though it is coming from *C*. The ray will not reach the mirror in the drawing. You know that the reflected ray will travel back along the incident ray. The point where the reflected rays meet is the top of the image. The bottom of the image is on the principal axis. Draw the image.



Ray Diagrams for Concave Mirrors (object beyond C)

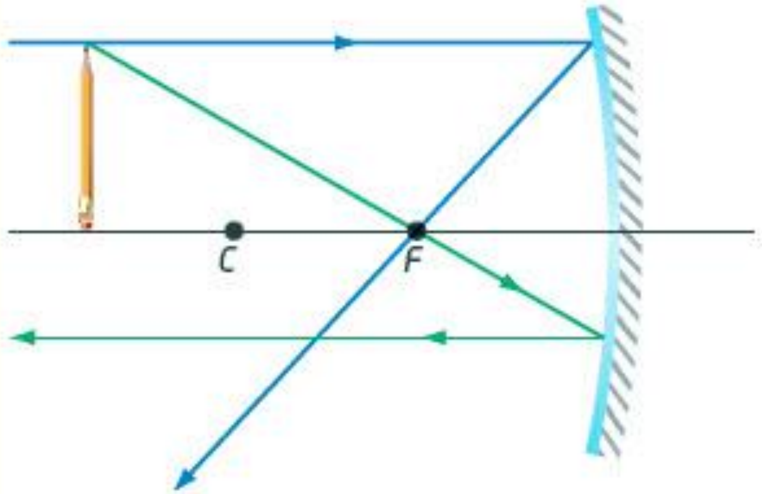
(Page 424)

Directions	Diagram
1. Draw the principal axis and a curve to represent the concave mirror. • Mark a focal point. • Then mark *C* so that it is twice as far from the mirror as the focal point. • Draw the object so that the bottom is on the principal axis beyond *C*.	
2. Draw a ray (shown in blue) from the top of the object toward the mirror, parallel to the principal axis. Draw the reflected ray back, through the focal point.	

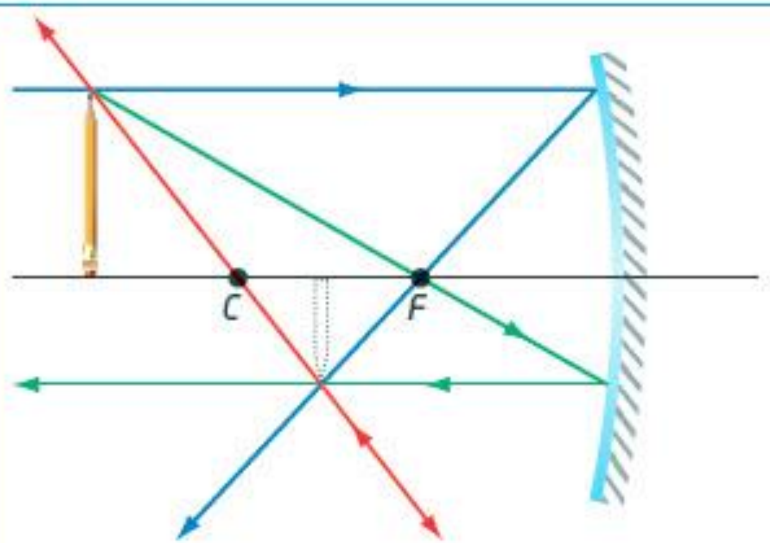
Ray Diagrams for Concave Mirrors (object beyond C)

(Page 424)

3. Draw a ray (shown in green) from the top of the object through the focal point, continuing to the mirror. The reflected ray will travel backward, parallel to the principal axis.



4. Draw a ray (shown in red) from the top of the object through C, continuing toward the mirror. Although the line does not reach the mirror in the diagram, draw the reflected ray back along the incident ray. The point where the reflected rays meet is the top of the image. The bottom of the image is on the principal axis. Draw the image.



Mirror and Magnification Equations (Page 425)

The characteristics of an image can be predicted using the **mirror equation** that allows you to calculate the location of an image and the **magnification equation** that allows you to determine the size (or height) of the image relative to the object, using object and image distances.

Mirror Equation

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

The image distance, d_i, is negative if the image is behind the mirror (a virtual image).

Magnification Equation

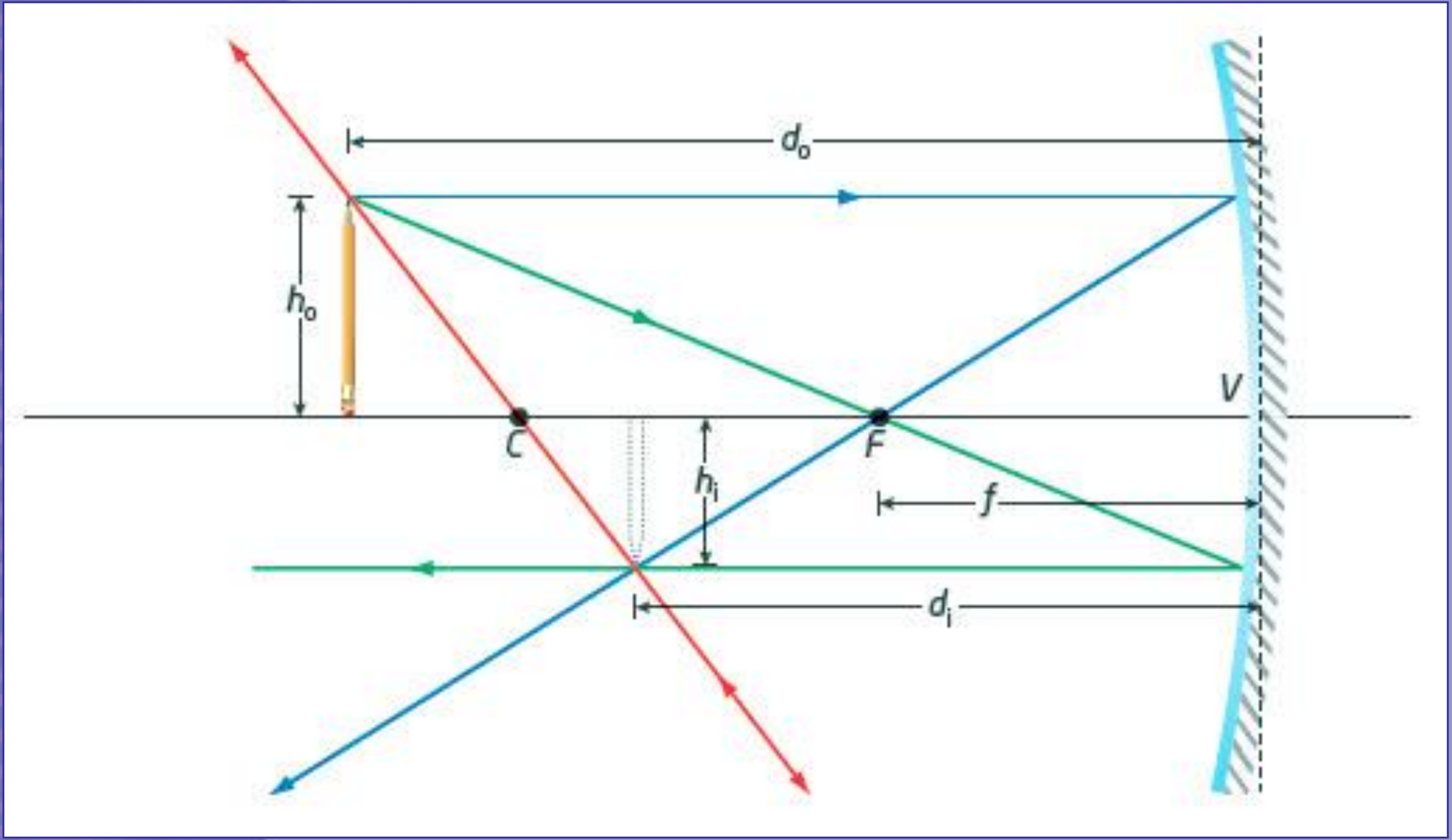
$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

The image height, h_i, is negative if the image is inverted relative to the object.

Mirror and Magnification Equation Variables

(Page 425)

F = *Focal Point*	*C* = *Centre of Curvature*	*V* = *Vertex*
d_o = *Object Distance*	d_i = *Image Distance*	
f = *Focal Length*	h_o = *Object Height*	h_i = *Image Height*



Using Mirror and Magnification Equations

Click the “Start” button to review mirror and magnification equations.

Using Mirror and Magnification Equations

START

Given the values for d_o, h_o, and f in the diagram below, solve for d_i and h_i, using the magnification and mirror equations

m = magnification
h_i = image height
d_i = image distance
h_o = object height
d_o = object distance

*All numbers in cm

Magnification Equation

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

Mirror Equation

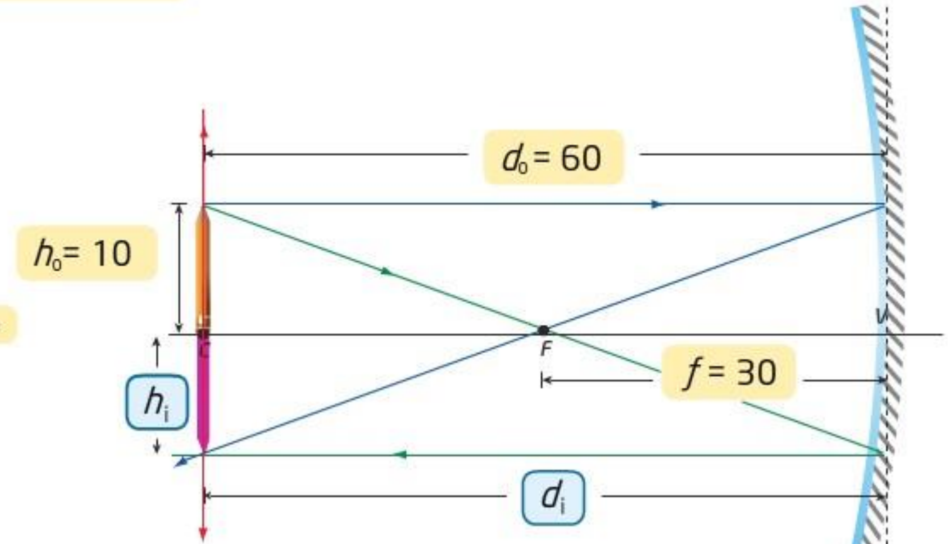
$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

show answer

d_i = ???
h_i = ???

Select another problem

problem 1
problem 2
problem 3

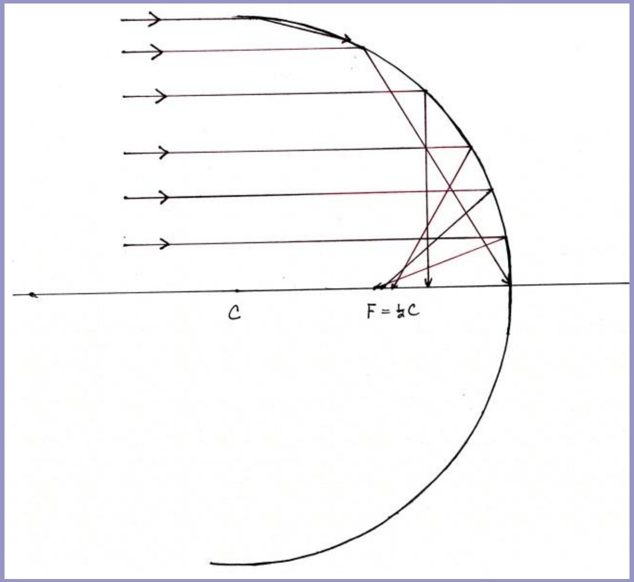


Distortion of Images in Curved Mirrors

(Page 428)

The images seen in curved mirrors sometimes seem distorted. This effect is called **spherical aberration.** It describes irregularities in an image in a curved mirror that result when reflected rays from the outer parts of the mirror do not go through the focal point.

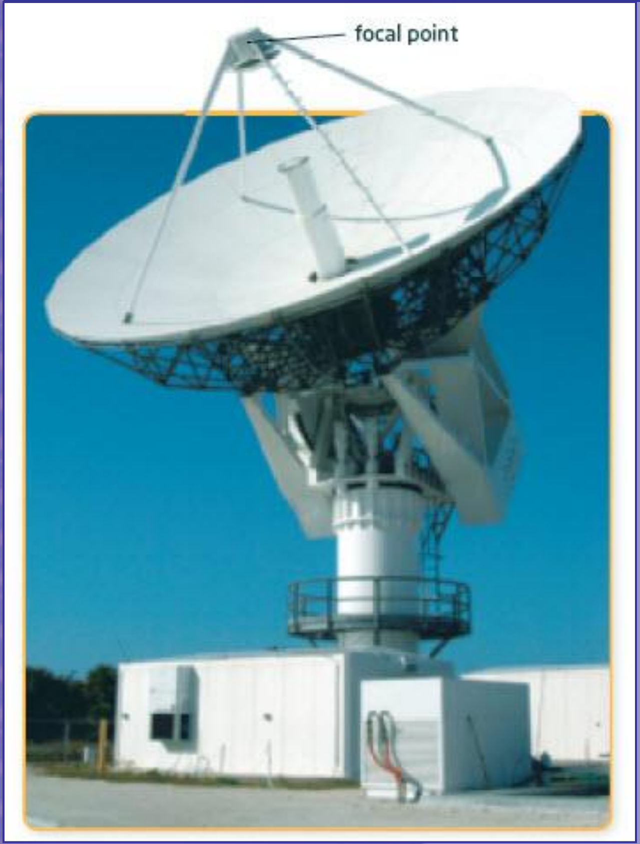
Scientists have found that a concave mirror in the shape of a **parabola** eliminates spherical aberration.

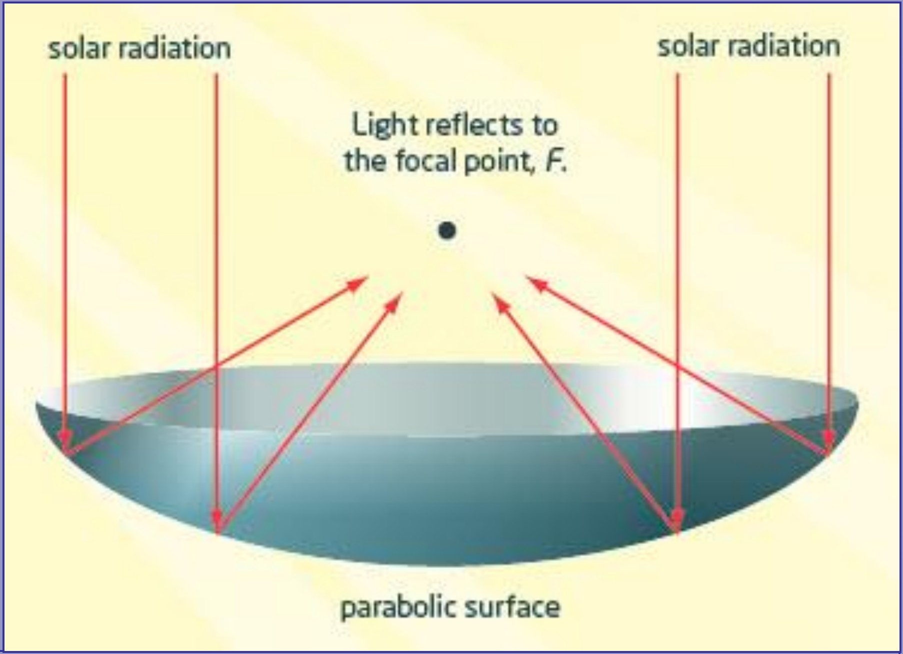


Technology and Concave Surfaces (Radar and Solar Ovens)

(Page 429)

Radar antennas are basically concave mirrors in the shape of a parabola that can send and receive radio waves.





Solar ovens are concave mirrors that collect and focus the Sun's energy, allowing people to cook food without the need for fuels such as wood or propane.

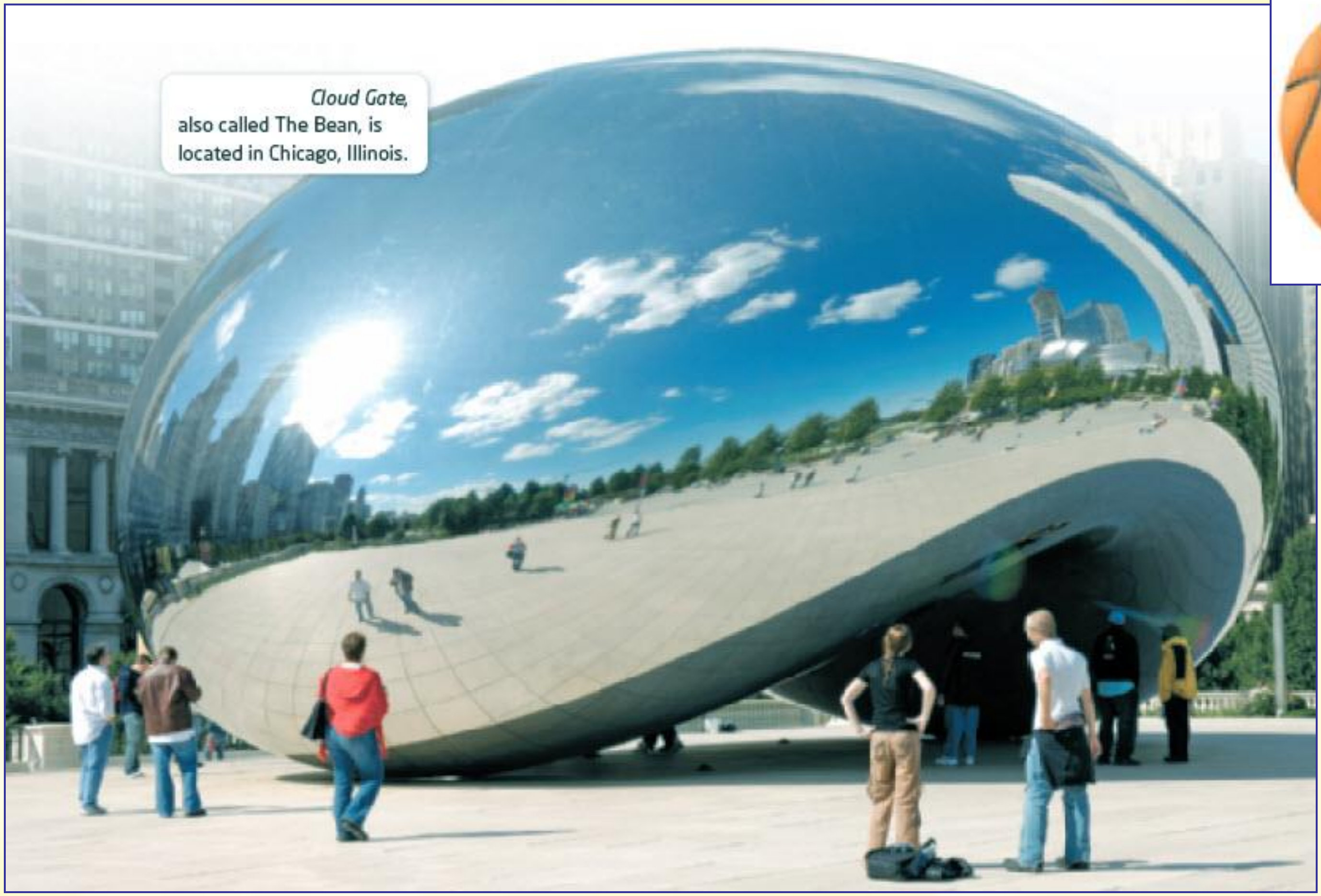
Section 10.3 Review

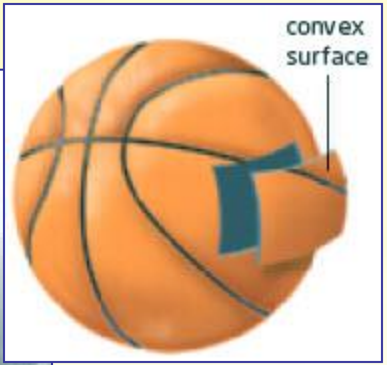
Concepts to be reviewed:

- *the shape and structure of concave mirrors*
- *the behaviour of rays travelling towards a concave mirror*
- *images produced when an object is between the focal point and a concave mirror*
- *images produced when the object is between the focal point (F) and the centre of curvature (C)*
- *characteristics of images when the object is beyond C*
- *the mirror and magnification equations*
- *the nature and cause of spherical aberration*

10.4 Images in Convex Mirrors (Page 431)

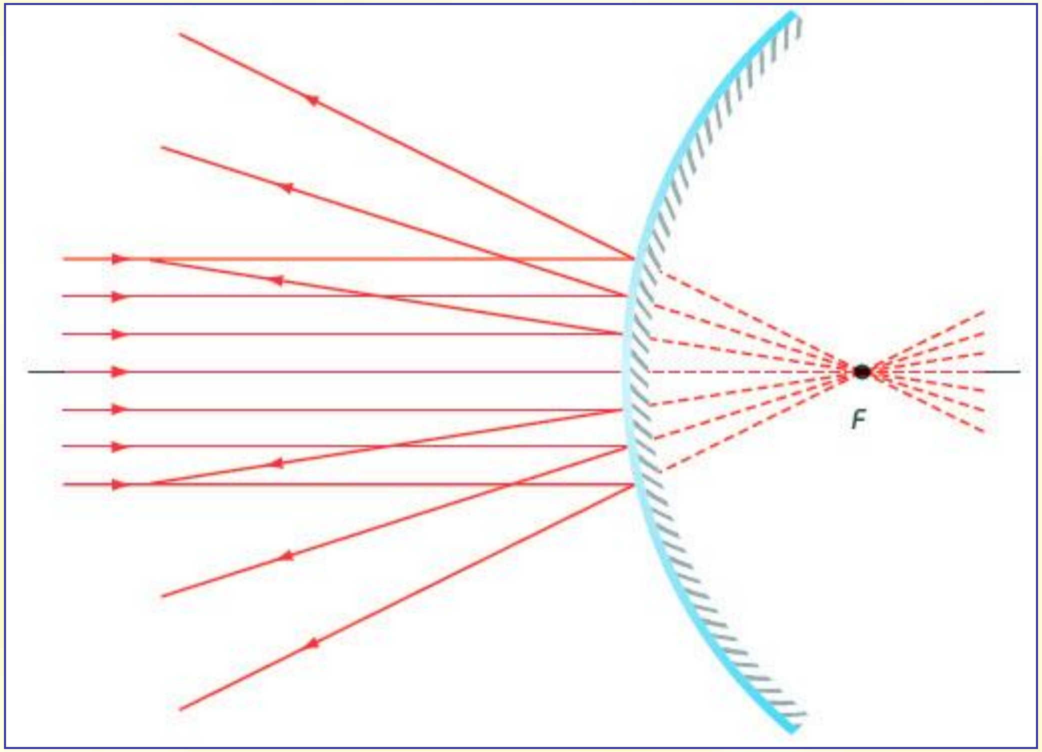
Convex mirrors are mirrors with reflective surfaces that bulge or curve outwards.





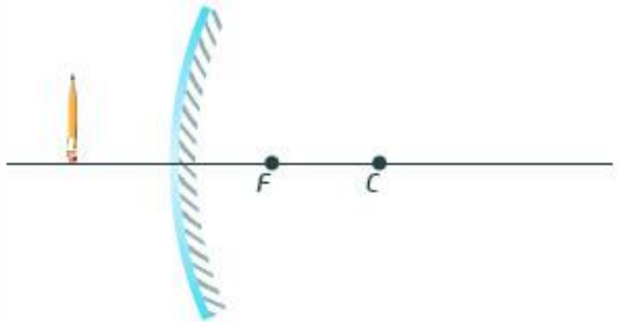
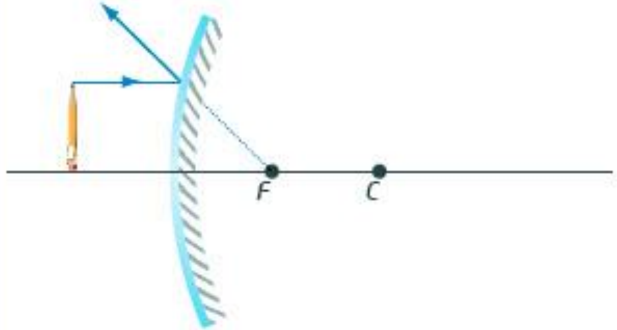
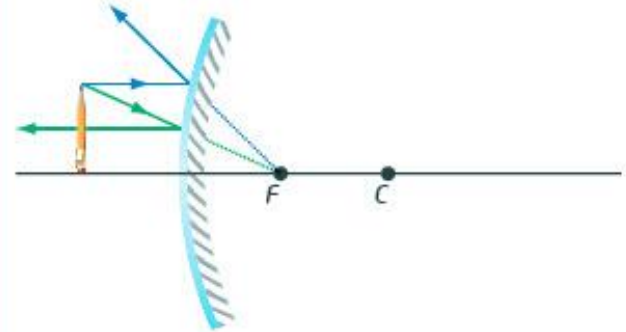
Properties of Convex Mirrors (Page 432)

When parallel rays of light hit a **convex mirror**, the reflected rays travel out and away from each other—they diverge. The focal point is located behind the mirror. Like concave mirrors, convex mirrors have spherical aberration with only a small, centre region giving non-distorted images.



Drawing Ray Diagrams for a Convex Mirror

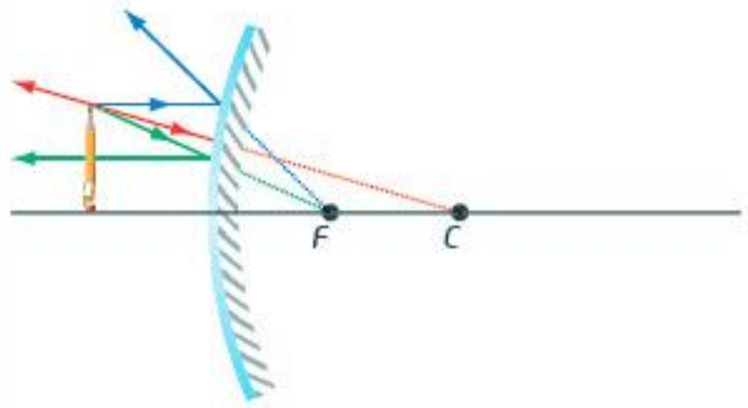
(Page 433)

Directions	Diagram
1. Draw the principal axis and a curve to represent the convex mirror. • Mark a focal point and C. • Draw the object so that the bottom is on the principal axis.	
2. Draw a ray (shown in blue) from the top of the object toward the mirror parallel to the principal axis. Draw the reflected ray back, as though it is coming from the focal point. Draw a dotted line behind the mirror to show that the reflected ray appears to be coming from the focal point.	
3. Draw a ray (shown in green) that is directed toward the focal point, but stop when it reaches the mirror. Draw the reflected ray backward, parallel to the principal axis. Draw a dotted line behind the mirror to show that the incident ray seems to be travelling toward the focal point.	

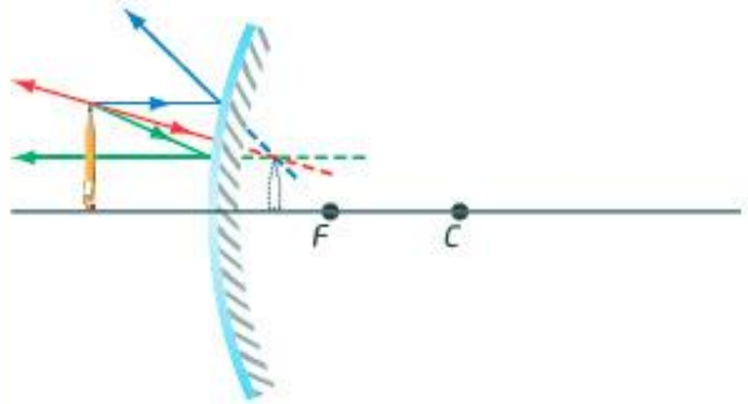
Drawing Ray Diagrams for a Convex Mirror

(Page 433)

4. Draw a ray (shown in red) that is directed toward *C*, but stop when it reaches the mirror. Draw a dotted line behind the mirror to show that the ray seems to be travelling toward *C*. Draw the reflected ray backward, along the incident ray.



5. The reflected rays are directed away from each other, so they will never meet. 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. (Note that the dotted lines are not in this diagram.)



Mirror and Magnification Equations

(Page 434)

The **mirror** and **magnification equations** that are used for concave mirrors can also be used for convex mirrors. Since the focal point is behind the mirror, the **focal length (*f*)** is always **negative**.

Mirror Equation

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

The image distance, d_i, is negative if the image is behind the mirror (a virtual image).

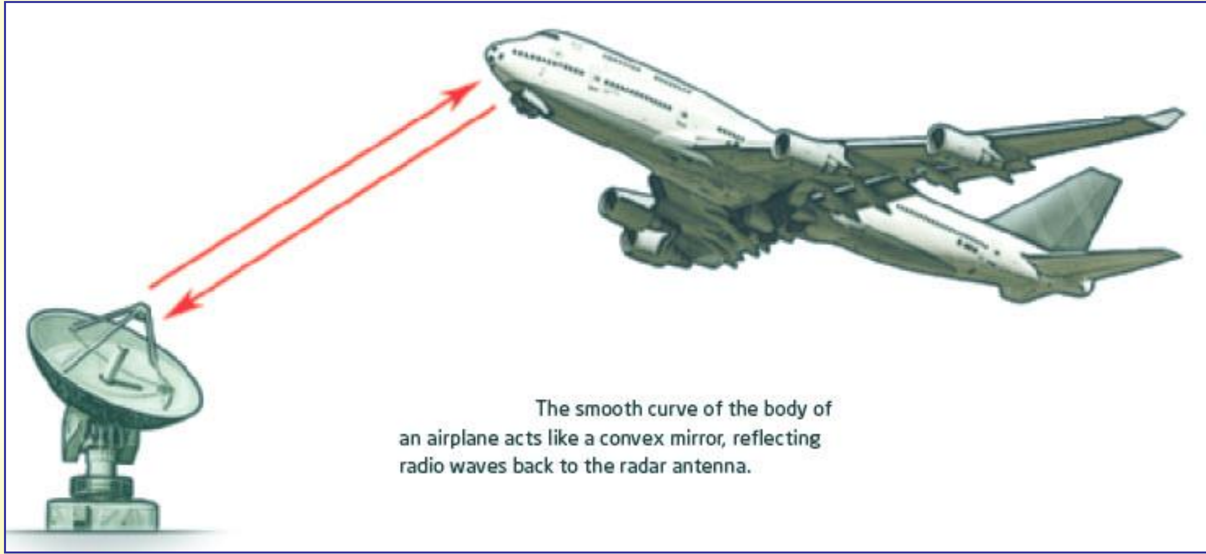
Magnification Equation

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

The image height, h_i, is negative if the image is inverted relative to the object.

Applications of Convex Surfaces (Page 436)

Convex surfaces have many applications, from security mirrors in stores or at border crossings, to automobile side mirrors, to the curved surfaces of aircraft bodies reflecting radar waves.



The smooth curve of the body of an airplane acts like a convex mirror, reflecting radio waves back to the radar antenna.

Section 10.4 Review

(Page 438)

Concepts to be reviewed:

- *the shape and structure of convex mirrors*
- *the behaviour of rays as they reflect off convex mirrors*
- *how to find the focal point for a convex mirror*
- *the characteristics of the virtual image seen in a convex mirror*
- *the use of ray diagrams to predict location and size of an image*
- *using the mirror and magnification equations to calculate image distance and size*
- *practical uses for convex surfaces*

CHAPTER 11 *Refraction*

In this chapter, you will:

- ***explain*** *refraction and the conditions required for partial reflection, partial refraction, and total internal reflection*
- ***identify*** *factors that affect refraction of light as it passes from one medium to another*
- ***explain*** *natural effects of refraction, such as apparent depth, mirages, and rainbows, using the ray model of light*
- ***calculate*** *the velocity of light in a variety of media*
- ***analyze*** *how angles of refraction and incidence change in materials with different indices of refraction*

The Re-appearing Coin

(Page 447)

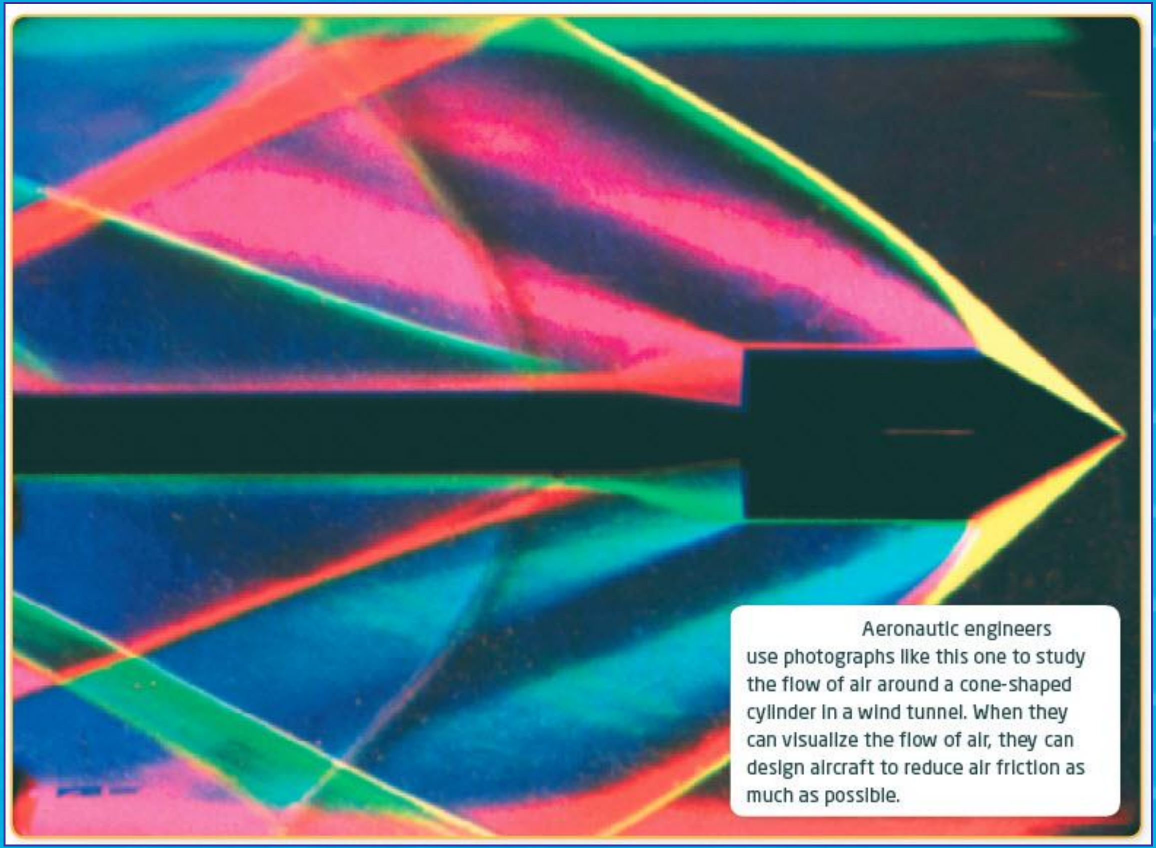
How does adding water to the cup, as pictured below, change your ability to see the coin?

Use your knowledge of the behaviour of light to explain what you have observed.

11.1 Refraction of Light

(Page 449)

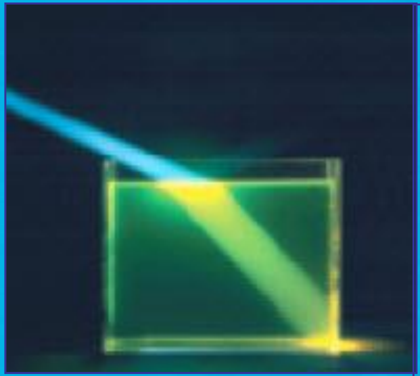
Refraction is the bending of light as it travels, at an angle, from a material with one refractive index to a material with a different refractive index.



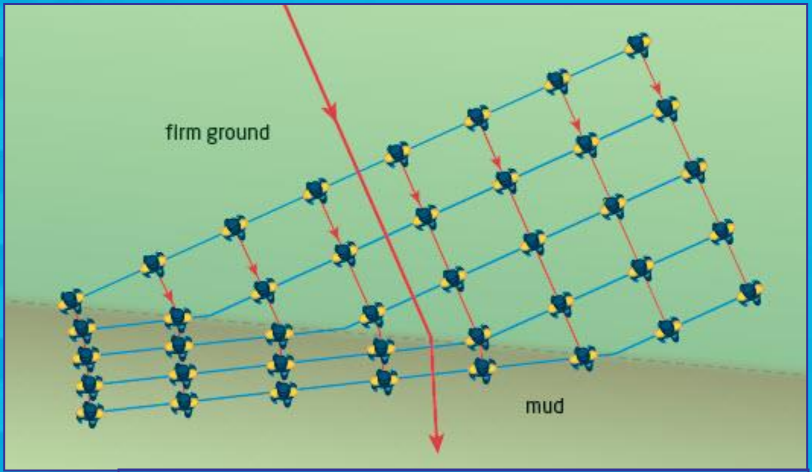
Describing Refraction

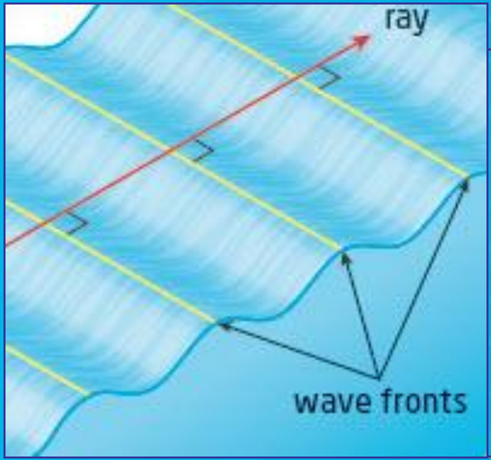
(Page 450)

Light rays bend when they decrease or increase in speed, when they move at an angle from one medium to another.



A beam of light (travelling at an angle) bends as it moves from air to water.





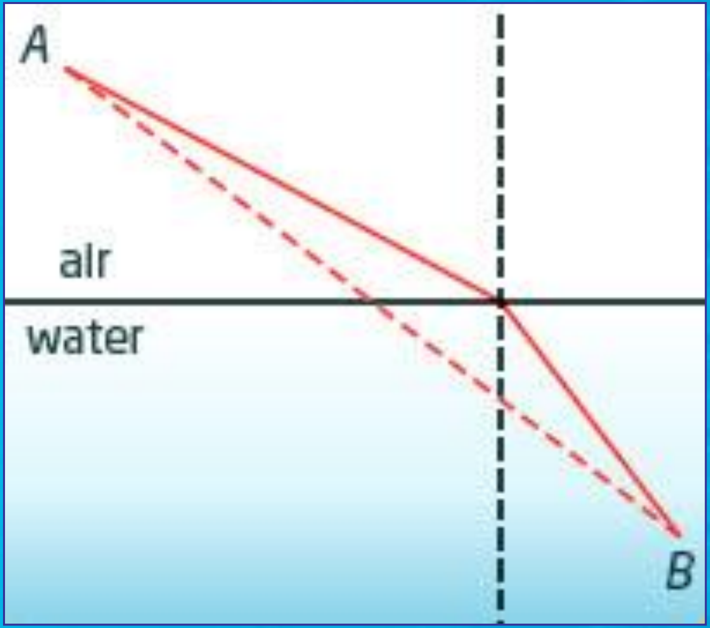
All points in a wave originally move together in the direction the wave is moving.

The part of the wave of marchers that enters the mud (the new medium) first slows down, causing the wave to change direction.

Fermat's Principle

(Page 451)

The exact path that the light will follow as it moves from one medium to another can found by applying **Fermat's Principle.** It states that light will follow the pathway that takes the least amount of time. In a single medium, the pathway is always a straight line. When travelling from one medium to another the fastest pathway is **not** a straight line.



The light travels most quickly from A to B by travelling a greater distance through air (a medium it travels through quickly) and a shorter distance through water (a medium it travels through more slowly).

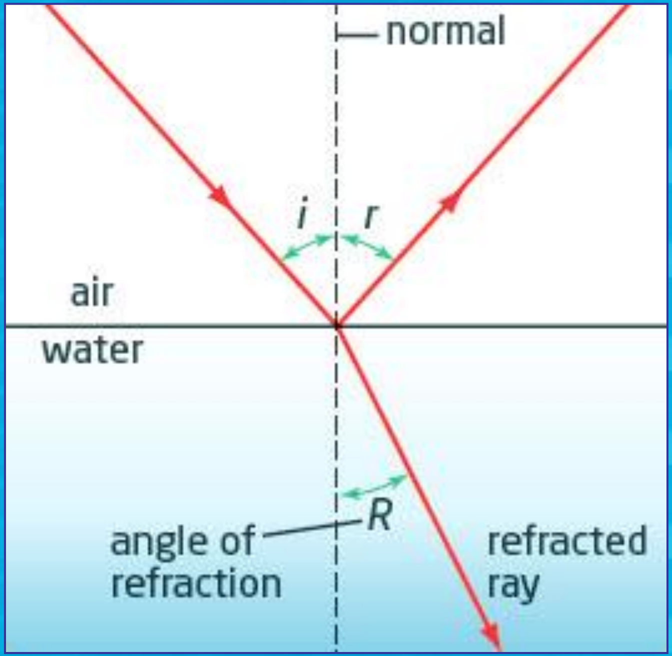
Describing Refraction Using Rays

(Page 451)

When dealing with refraction, two new terms are used to describe the behaviour of light.

1. A **refracted ray** is the ray that is bent upon entering a second medium.

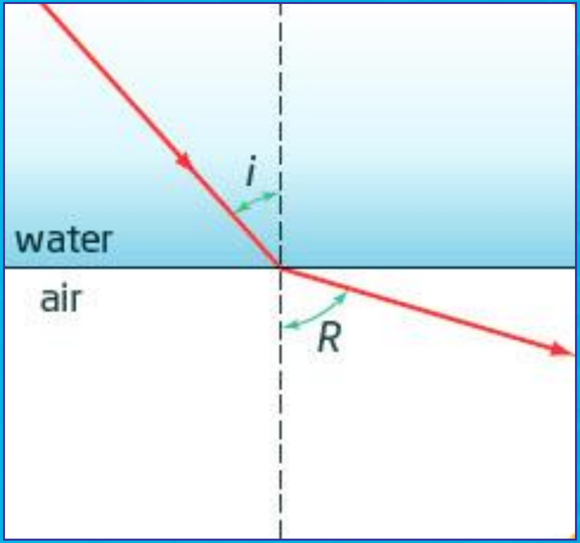
2. The **angle of refraction** is the angle between the normal and the refracted ray.

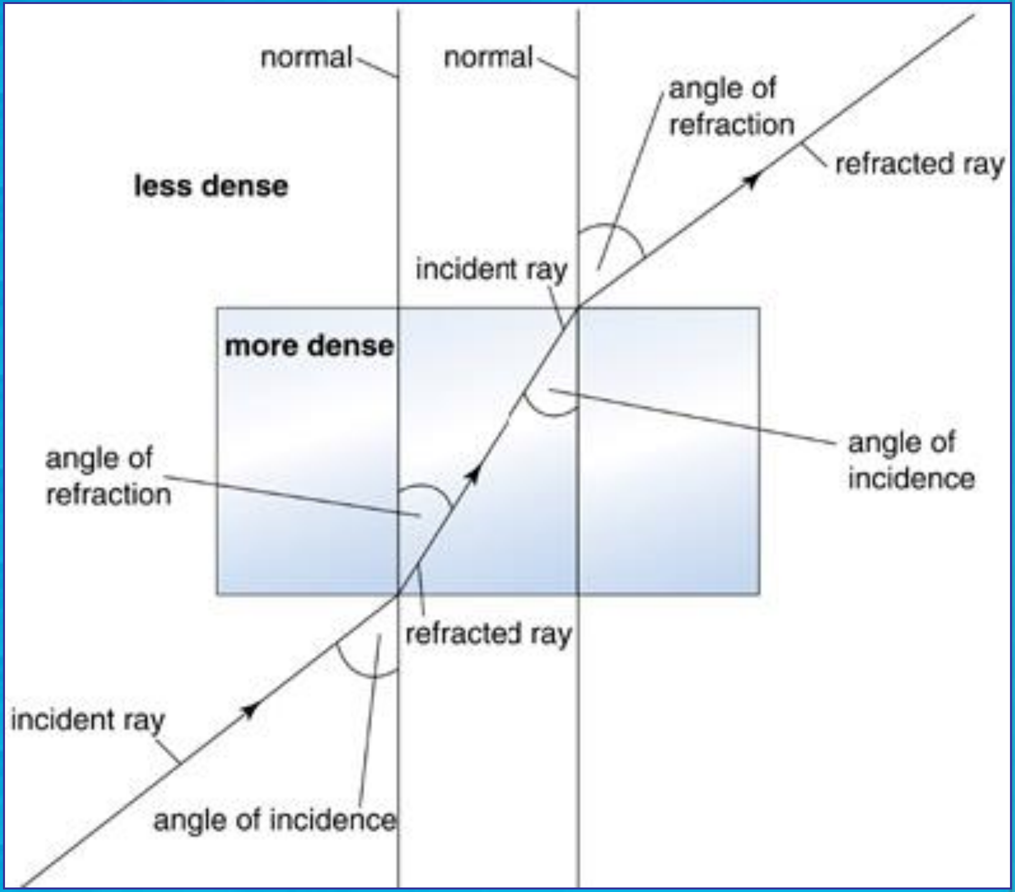


The Direction of the Refracted Ray

(Page 452)

When light travels from a medium in which its speed is faster to one in which its speed is slower, it always **bends toward the normal**.





When light travels from a medium in which its speed is slower to one in which its speed is faster, it always **bends away from the normal**.

Index of Refraction

(Page 452)

The **index of refraction** is the ratio of the speed of light in a vacuum to the speed of light in a given medium.

Index of Refraction

$n = \frac{c}{v}$, where

n is the index of refraction

c is the speed of light in a vacuum

v is the speed of light in a medium

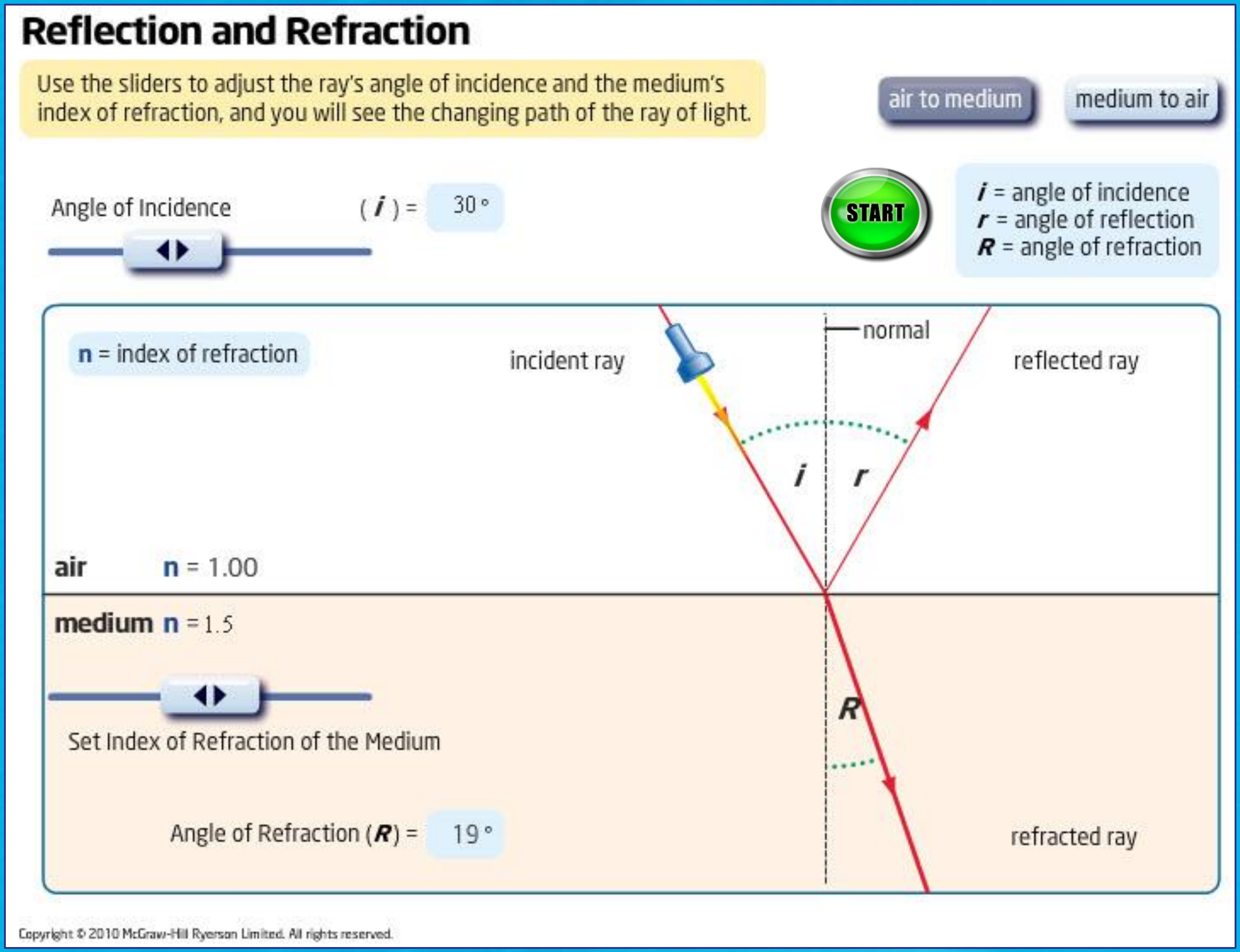
Substance	Index of Refraction (n)
Vacuum	1.000 00
Gases at 0°C and 101.3 kPa	
Hydrogen	1.000 14
Oxygen	1.000 27
Air	1.000 29
Carbon dioxide	1.000 45
Liquids at 20°C	
Water	1.333
Ethyl alcohol	1.362
Glycerol	1.470
Carbon disulfide	1.632

Substance	Index of Refraction (n)
Solids at 20°C	
Quartz (fused)	1.46
Plexiglas™ or Lucite™	1.51
Glass (crown)	1.52
Sodium chloride	1.54
Glass (crystal)	1.54
Ruby	1.54
Glass (flint)	1.65
Zircon	1.92
Diamond	2.42

If you know the **index of refraction** of the substance that is the medium, you can calculate the speed of light in that medium.

Reflection , Refraction, and the Index of Refraction

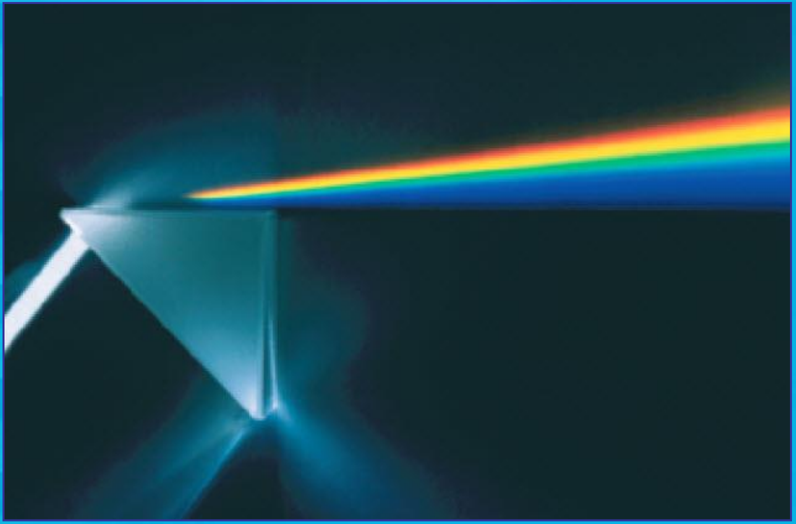
Click the “Start” button to review reflection, refraction, and the index of refraction.

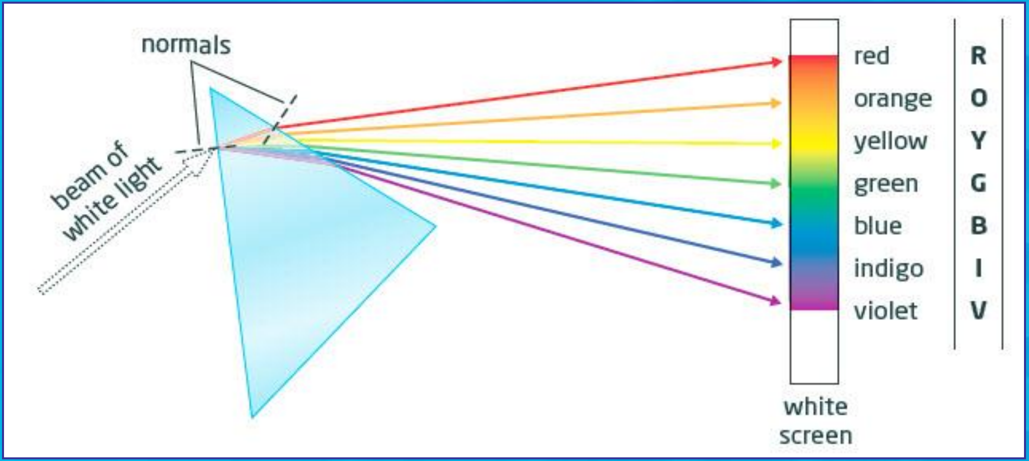


Dispersion

Dispersion is the process of separating colours by refraction.

White light is refracted when it enters a prism and again when it leaves the prism. Since different colours of light travel at different speeds, each refracts a different amount. This is why they separate.





Red light is travelling the slowest, so it refracts the least. Violet light is moving at fastest, so it refracts the most. See below!

BBB (Blue Bends Best) and **RRR** (Red Refracts Rotten)

Section 11.1 Review

Concepts to be reviewed:

- *refraction and why light rays refract*
- *how light bends when the medium changes*
- *the index of refraction of a medium*
- *dispersion and why it occurs*
- *the speed of each wavelength of light in different media*
- *the speed of all wavelengths in a vacuum*

11.2 Partial Refraction and Total Internal Reflection

(Page 457)

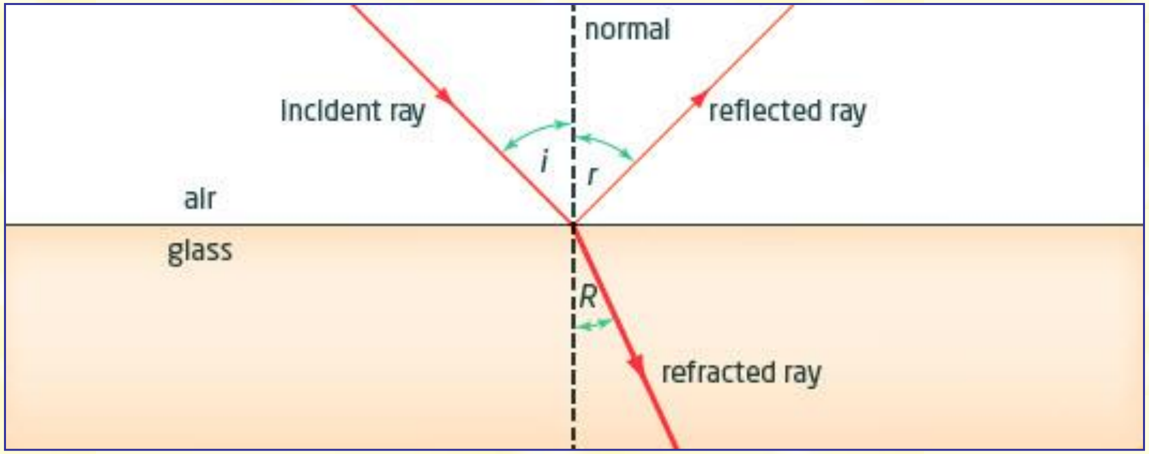
When underwater and looking up, you can only see objects in an area directly above you.

Partial Reflection and Refraction

(Page 458)

Partial reflection and refraction is a phenomenon in which some of the light that is travelling from one medium to another is reflected and some is refracted at the boundary between the media.

Both refraction and reflection occur but not equally.

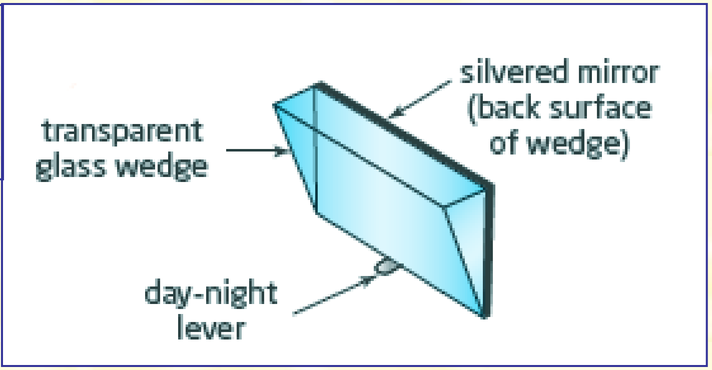


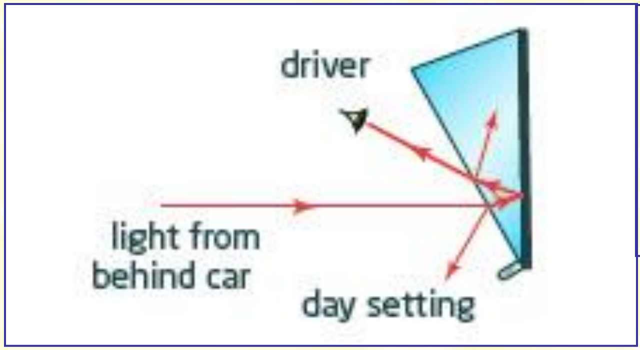
As shown in the images to the right, the reflection of sunlight is far greater when the sun is low in the sky (sunset) than when it is directly overhead (mid day).

Reflection and Refraction in a Rearview Mirror

(Page 460)

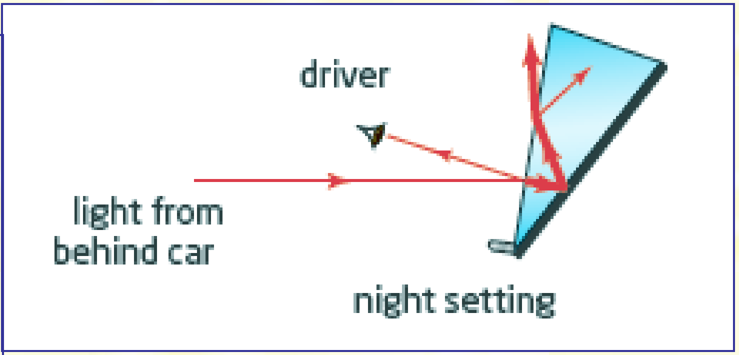
Rearview mirrors are wedge-shaped and silvered on the back.





During daytime driving, the mirror is adjusted so the light that hits the mirror is directed at the driver's eyes.

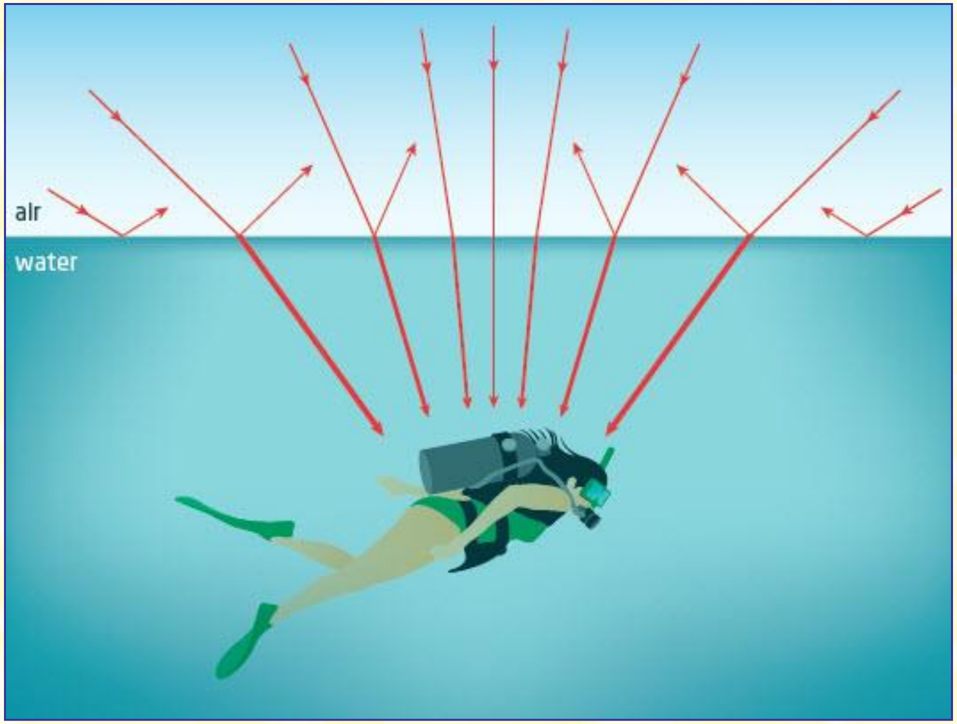
At night, the driver can flip a switch that tilts the mirror, reducing the amount of light directed at the driver's eyes.



Large Angles of Incidence

(Pages 460-461)

Light that reflects off the surface of the water is not visible to the diver below. Light that refracts as it enters the water is visible.



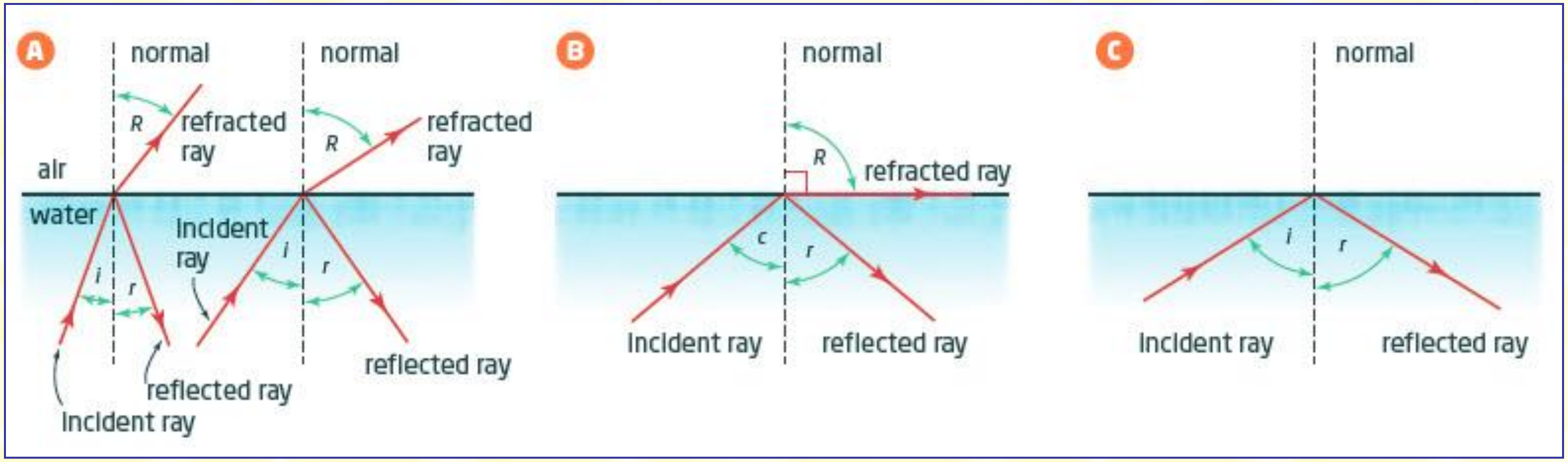
As the angle of incidence of an incoming ray increases, more of the light will be reflected off the surface of the water. This means that less light refracts (and reaches the diver below the surface).

Refraction: Water to Air

(Pages 461-462)

Often, even in very clear water, only nearby underwater objects are visible to an observer.

As the angle of incidence increases, the angle of refraction increases at a faster rate. **(A)**

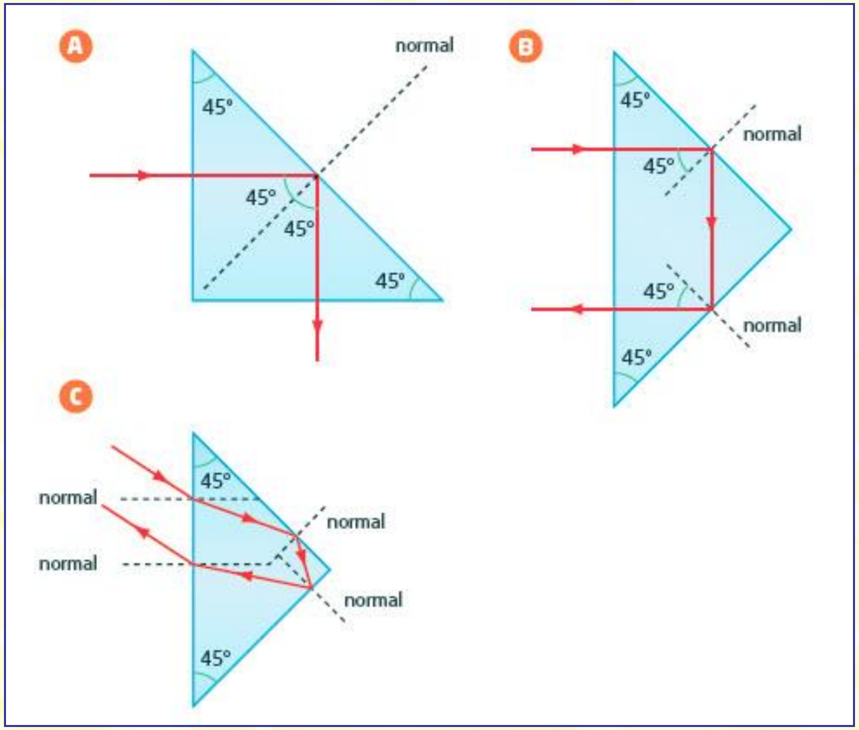


Eventually the **critical angle** is reached when the angle of incidence produces an angle of refraction of 90° **(B)**. When the angle of incidence is larger than the critical angle, all of the light is reflected back into the first medium. This is called **total internal reflection**. **(C)**

Changing the Direction of a Light Ray (Page 464)

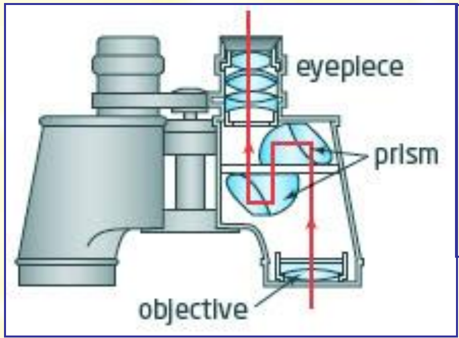
A glass prism can change the direction of a light ray by creating the conditions for **total internal reflection.**

The critical angle between glass and air is less than 45^{o}. Light hitting an inner surface at exactly 45^{o} will be totally reflected inside the glass

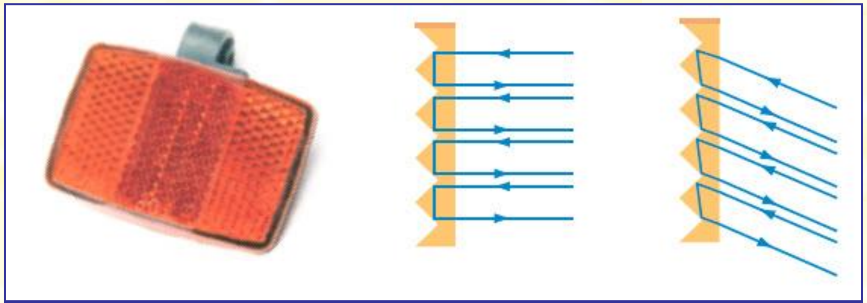


The prisms shown (above, right) change the direction of the incoming ray of light by **90^{o} (A)**, **180^{o} (B)**, and to back in the same direction (regardless of the angle of incidence) **(C)**.

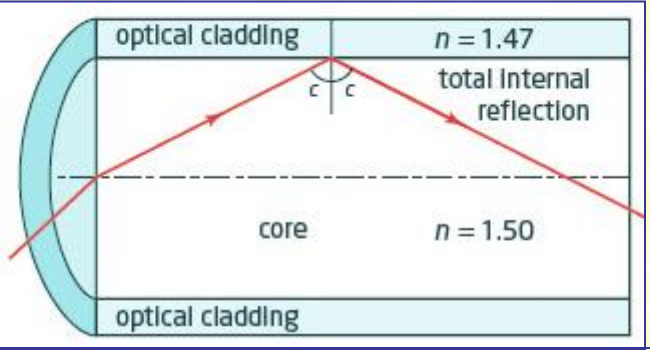
Applications of Total Internal Reflection (Pages 464-466)



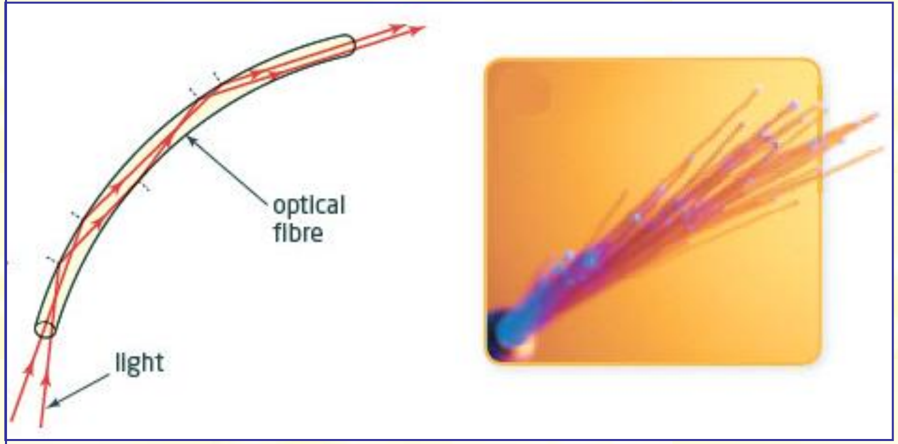
Binoculars use glass prisms to reflect light.



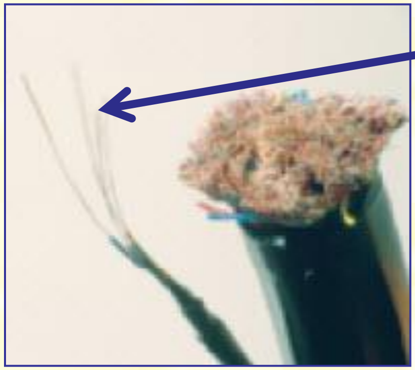
Retroreflectors are small plastic prisms that reflect light directly back in the direction it came from. (For example, in a bicycle reflector)



Optical fibres contain a glass core surrounded by cladding made from another type of glass that has a lower index of refraction. Such fibres achieve total internal reflection, which allows data to be transmitted.



Fibre Optics in Telecommunications / Medicine (Page 466)



Fibre optic cable is superior to the large copper cable shown on its right for the following reasons:

- signals are **not affected by electrical storms**
- **more signals** can be carried with **less energy loss**
- the cables are **smaller and lighter**

Endoscopes are instruments that use optical fibre bundles. One bundle carries light into the area where the test or surgery is to occur, while another bundle carries an image of the area back to a monitor. The endoscope can be inserted through a very small opening.

Section 11.2 Review

(Page 467)

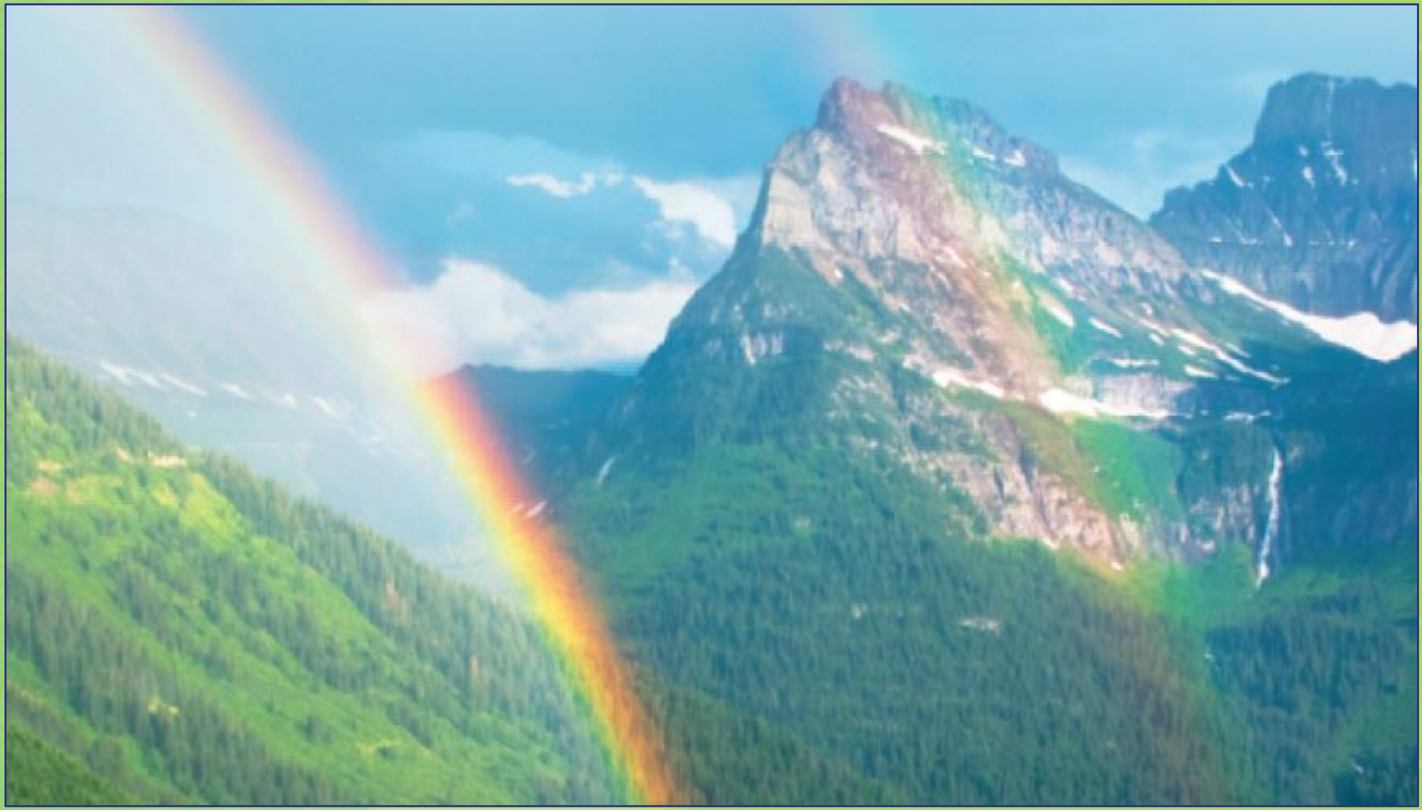
Concepts to be reviewed:

- *partial reflection and refraction, and why and how it occurs*
- *the effect of the size of the angle of incidence on the amount of light that is reflected or refracted*
- *the critical angle and how it can be reached*
- *total internal reflection and why and how it occurs*
- *practical applications for total internal reflection*

11.3 Optical Phenomena in Nature

(Page 468)

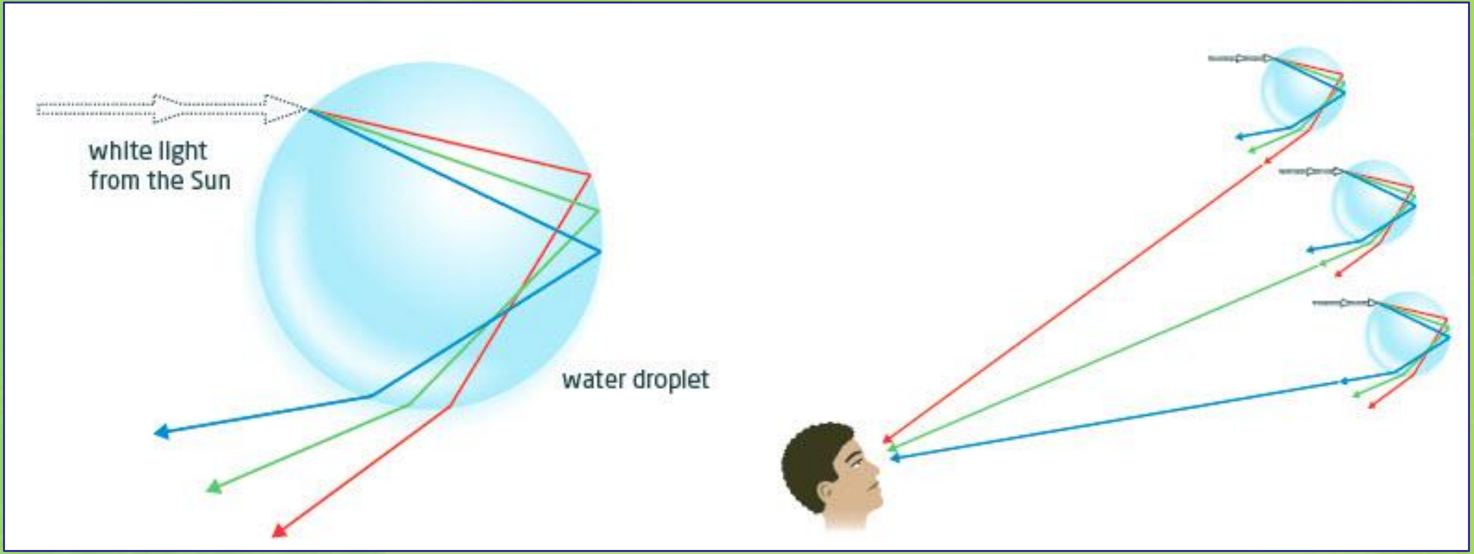
Double rainbows are excellent natural examples of the refraction and dispersion of light.



In order to see a rainbow, the Sun must be behind you. The light must reflect off something in order for it to return to your eyes.

Formation of Rainbows and Sundogs (Page 469)

A **rainbow** is an arc of colours of the visible spectrum that appears opposite the Sun. It is caused by the reflection, refraction, and dispersion of the Sun's rays as they pass through raindrops.

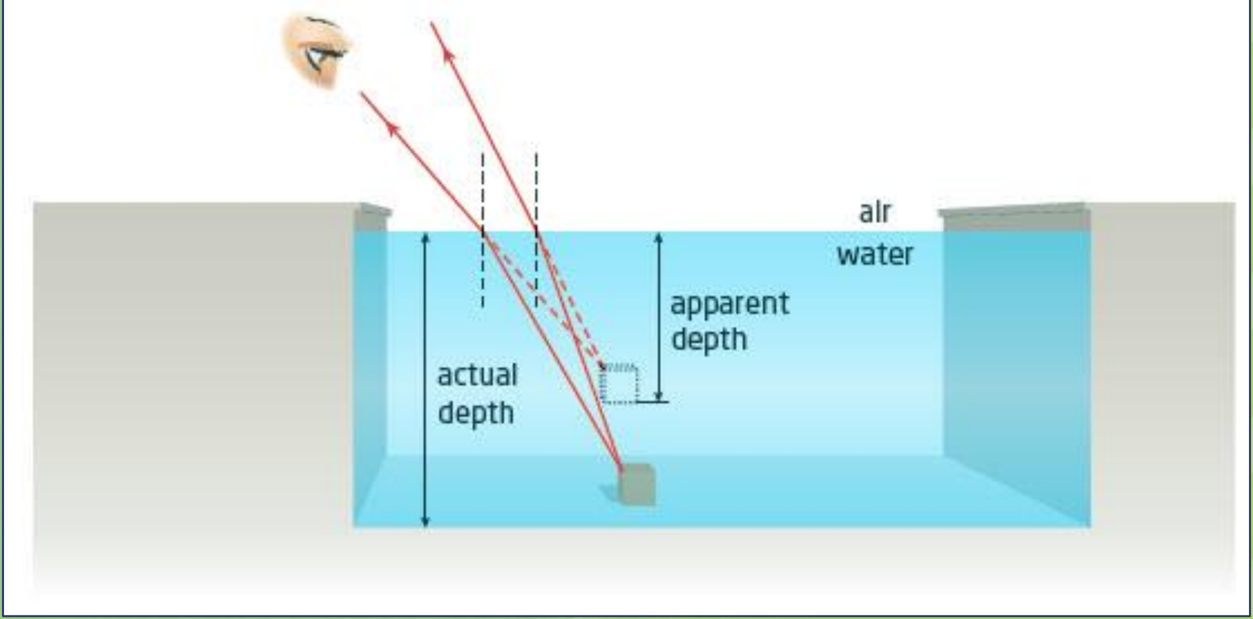


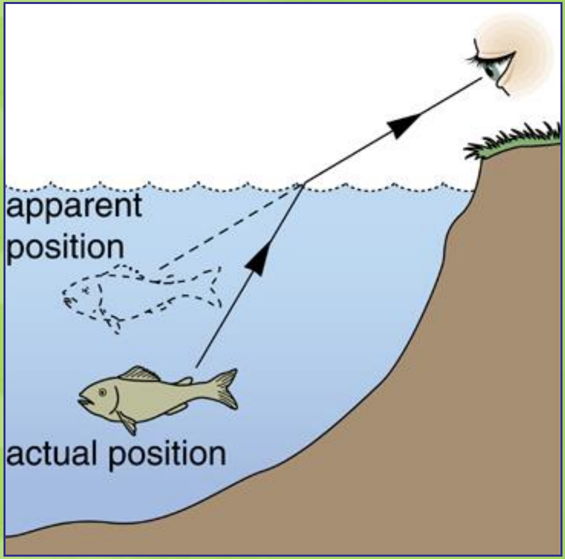
A **sundog** (*parhelia*) occurs when ice crystals in the atmosphere refract sunlight. Sundogs are usually visible on cold, clear mornings or evenings when there are ice crystals in the air.

The Illusion of Apparent Depth

(Page 470)

Apparent depth is an optical effect in which the image of an object appears closer than the object actually is.





The rays of light from the object being observed have been refracted when they move from the water into the air on their way to the observer's eyes. This is what causes the illusion of apparent depth.

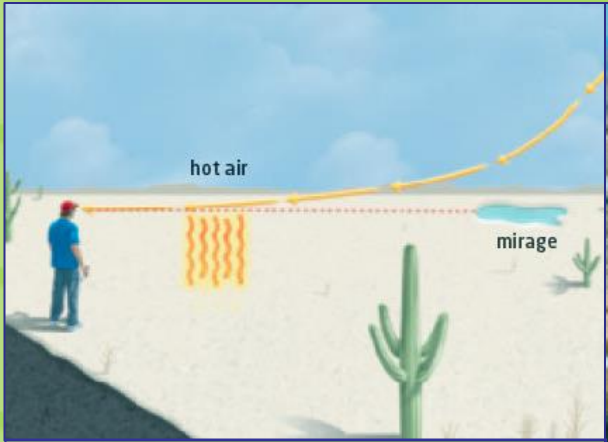
Shimmering and Mirages

(Pages 471-472)

Shimmering and **mirages** are caused by the refraction of light in unevenly heated air.

Shimmering is the apparent movement of objects in hot air over objects and surfaces.

A **mirage** is an optical effect caused by the refraction of light rays passing through layers of air that have very different temperatures.



Mirages are most often seen in a very hot desert or on a highway.

Mirages and Temperature Inversions

Although less common, mirages can be caused by a combination of opposite temperatures. The images seen can be from objects that are actually beyond the horizon and/or the images may also appear to be upside down.

These mirages can be caused by light from distant objects reflecting off warmer air aloft and back to the observer or by light rays crossing on their way to the observer, causing the image to be inverted.

Section 11.3 Review

(Page 475)

Concepts to be reviewed:

- *rainbows and how they are formed*
- *the phenomenon known as apparent depth*
- *shimmering and what causes it*
- *mirages and what causes them*

CHAPTER 12 *Lenses and Lens Technologies*

In this chapter, you will:

- ***describe*** *the characteristics of images formed by lenses*
- ***identify*** *ways in which lenses are used in optical instruments such as microscopes*
- ***describe*** *a technological device and a procedure that use the properties of light*
- ***predict*** *the characteristics of images formed by lenses using ray diagrams and algebraic equations and test the prediction through inquiry*
- ***analyze*** *and* ***evaluate*** *the effectiveness of a technological procedure related to human sight*
- ***evaluate*** *the benefits to society of a technological device that uses properties of light*

The Disappearing Finger

(Page 485)

How far to each side does your field of view extend?

12.1 Characteristics of Lenses

(Page 487)

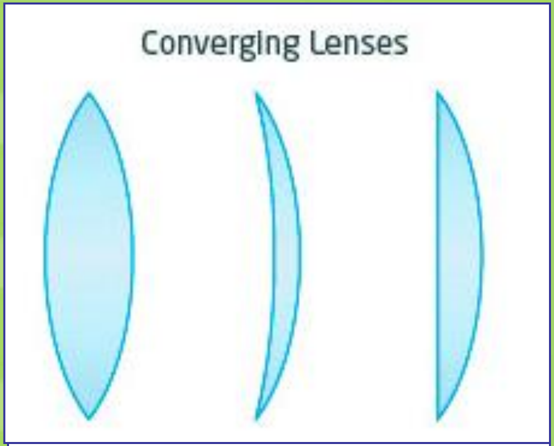
A **lens** is a transparent object with at least one curved side that causes light to refract.

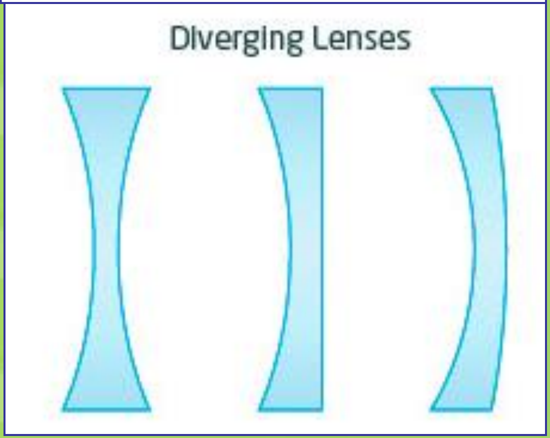
Modern lenses come in many sizes and have a variety of uses.

Reading stones made from transparent pieces of quartz or glass were the earliest type of lens used to magnify written text.

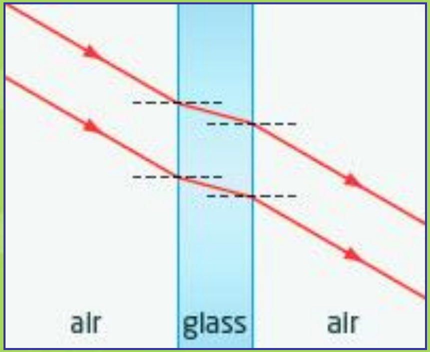
Describing Lenses

The terms **plane** (or **plano**), **concave**, and **convex** are used to describe the shape of lenses as well as mirrors. Unlike mirrors, lenses have two sides, either of which can be plane, concave, or convex in shape. The combination of shapes that are present in a lens determines whether the lens causes parallel light rays to **diverge** (spread out) or **converge** (come together) and by how much.





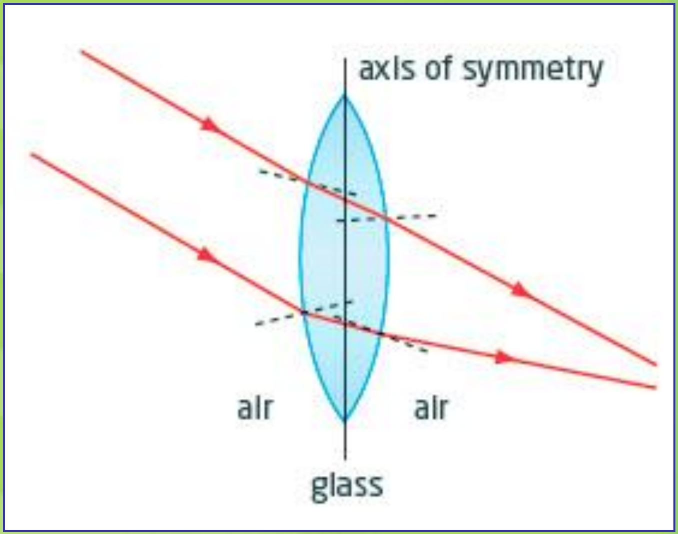
A window pane causes light rays to shift to the side (**lateral displacement**) but not change their direction relative to each other.



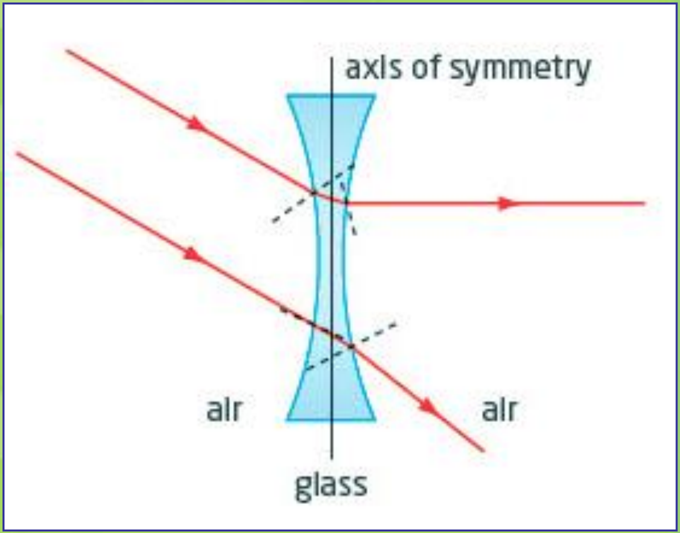
Converging and Diverging Lenses

(Page 489)

A **converging lens** brings parallel light rays toward a common point. A lens that is **convex** on both sides (biconvex or double convex) best illustrates convergent behaviour. The convergence is caused by rays first refracting toward the normal when light enters the glass and then refracting away from the normal when they leave.



A **diverging lens** spreads parallel light rays away from a common point. A lens that is **concave** on both sides (biconcave or double concave) best illustrates divergent behaviour.

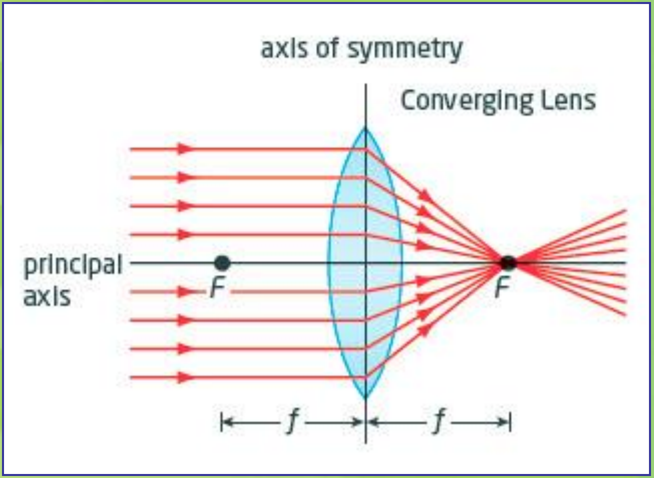


Focal Point and Focal Length of Lenses

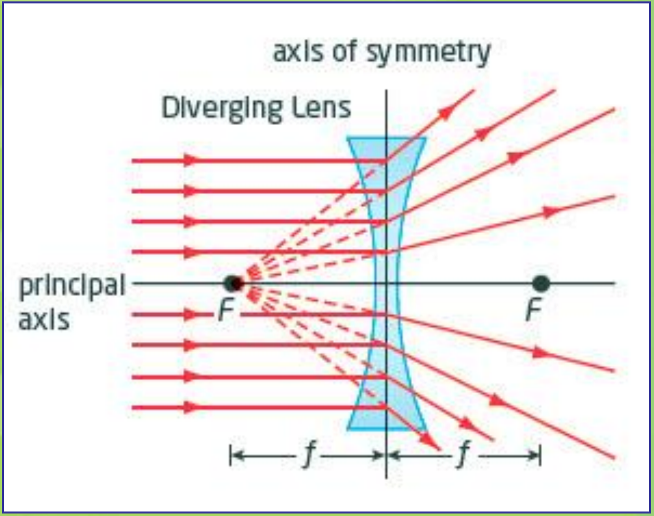
(Page 490)

The **principal axis** of a lens is a straight line that passes through the centre of the lens, normal to both surfaces (sides) of the lens.

When rays that are parallel to the principal axis pass through a converging lens, the rays intersect at a point called the **focal point** (***F***). The distance from the focal point to the centre of the lens is called the **focal length** (***f***).

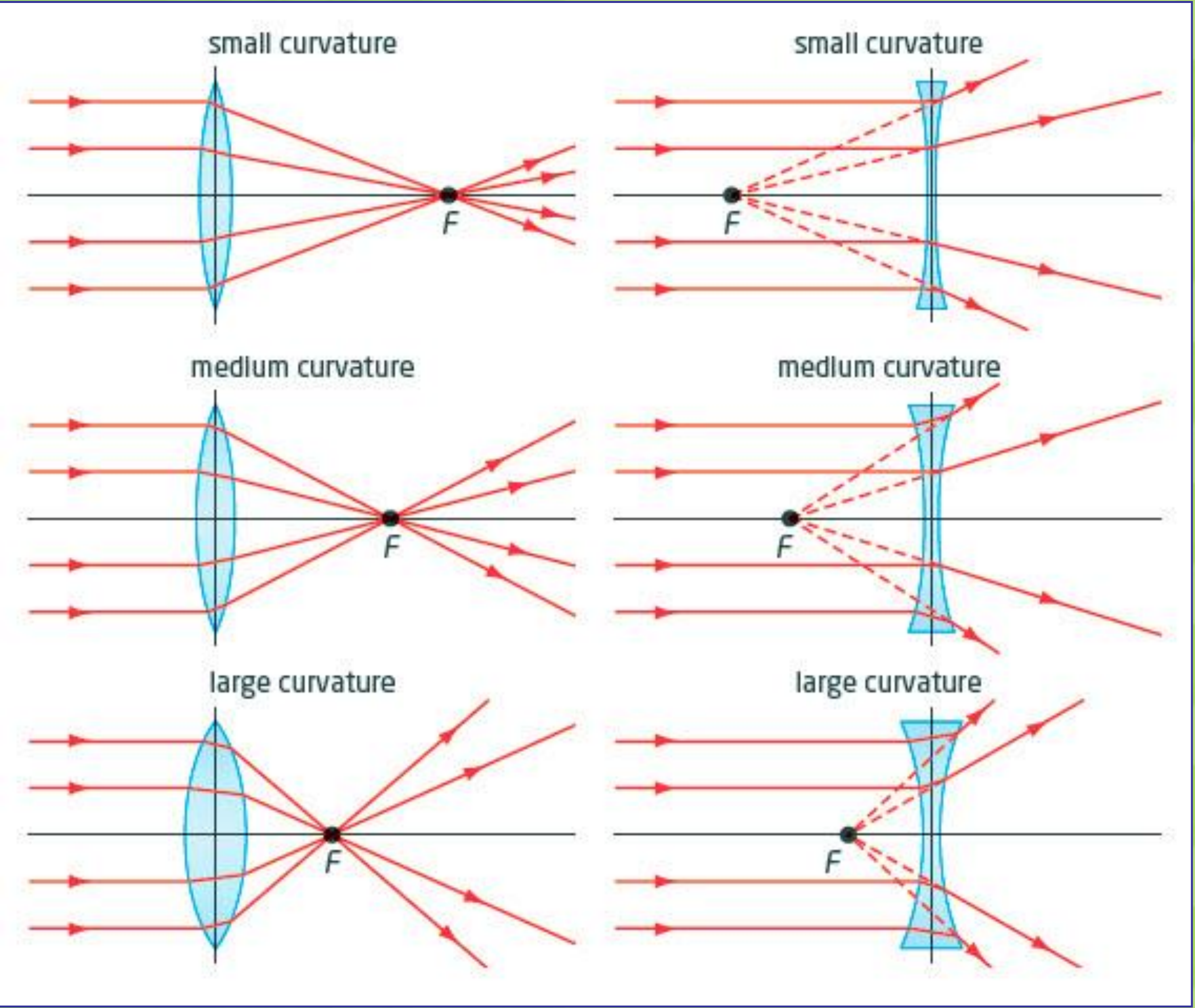


To find the **focal point** (***F***) for a diverging lens you must extend the rays behind the lens, finding the **virtual focus** (virtual focal point). As with the converging lens, the **focal length** (***f***) is the distance between the centre of the lens and ***F***.



Focal Point and Focal Length of Lenses (Page 490)

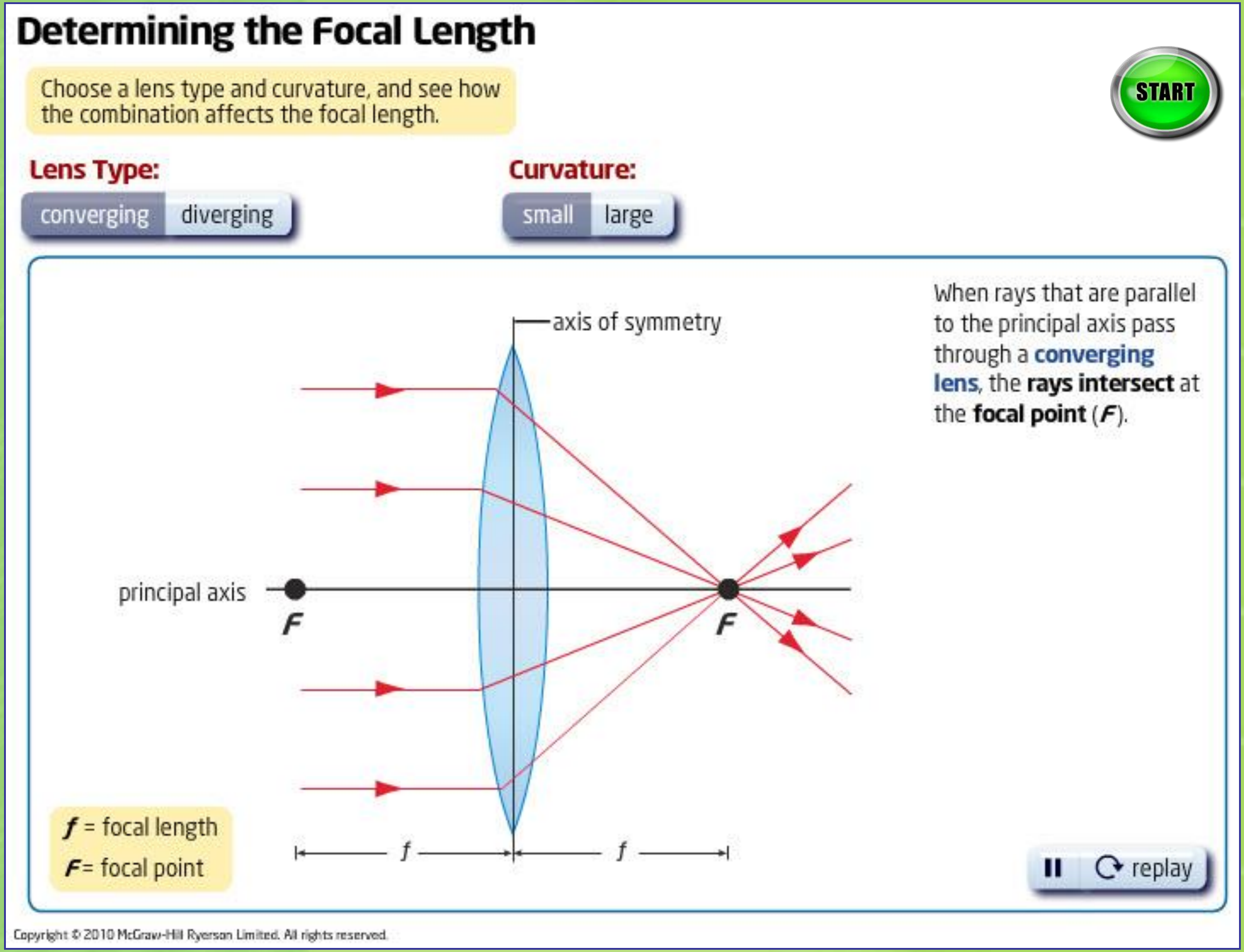
The position of the **focal point** for a lens depends on both the index of refraction of the lens material and the curvature of the lens.



A **larger curvature** in either a converging or a diverging lens results in the **rays bending more**.

Focal Point and Focal Length of Lenses

Click on the "Start" button to review how lens curvature affects the position of the focal point and focal length.

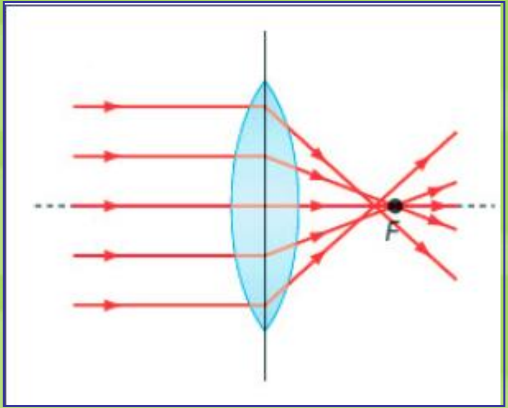


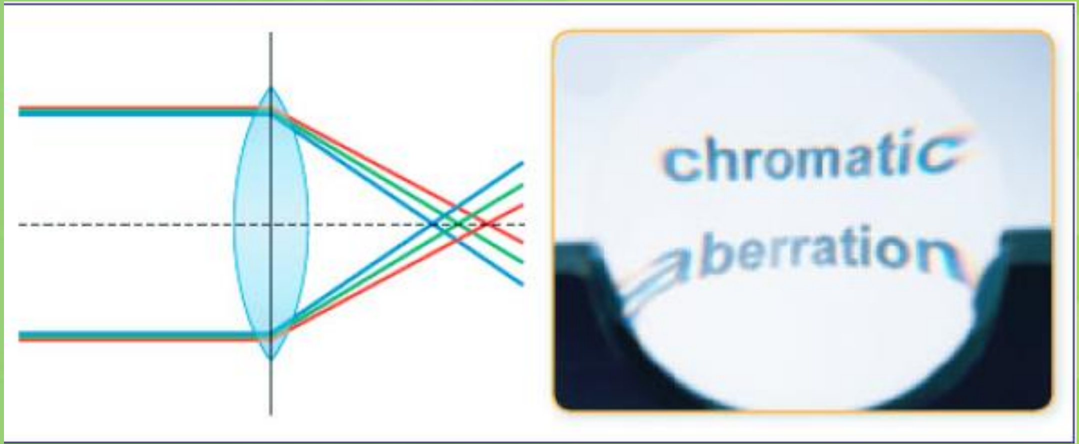
Thick and Thin Lenses and Chromatic Aberration

(Pages 491-492)

For thick lenses, only light rays that pass through the lens near the principal axis meet at the focal point and give a sharp image.

A fish-eye lens drastically distorts the image, but it brings a much larger area into view. It is an example of **spherical aberration**.

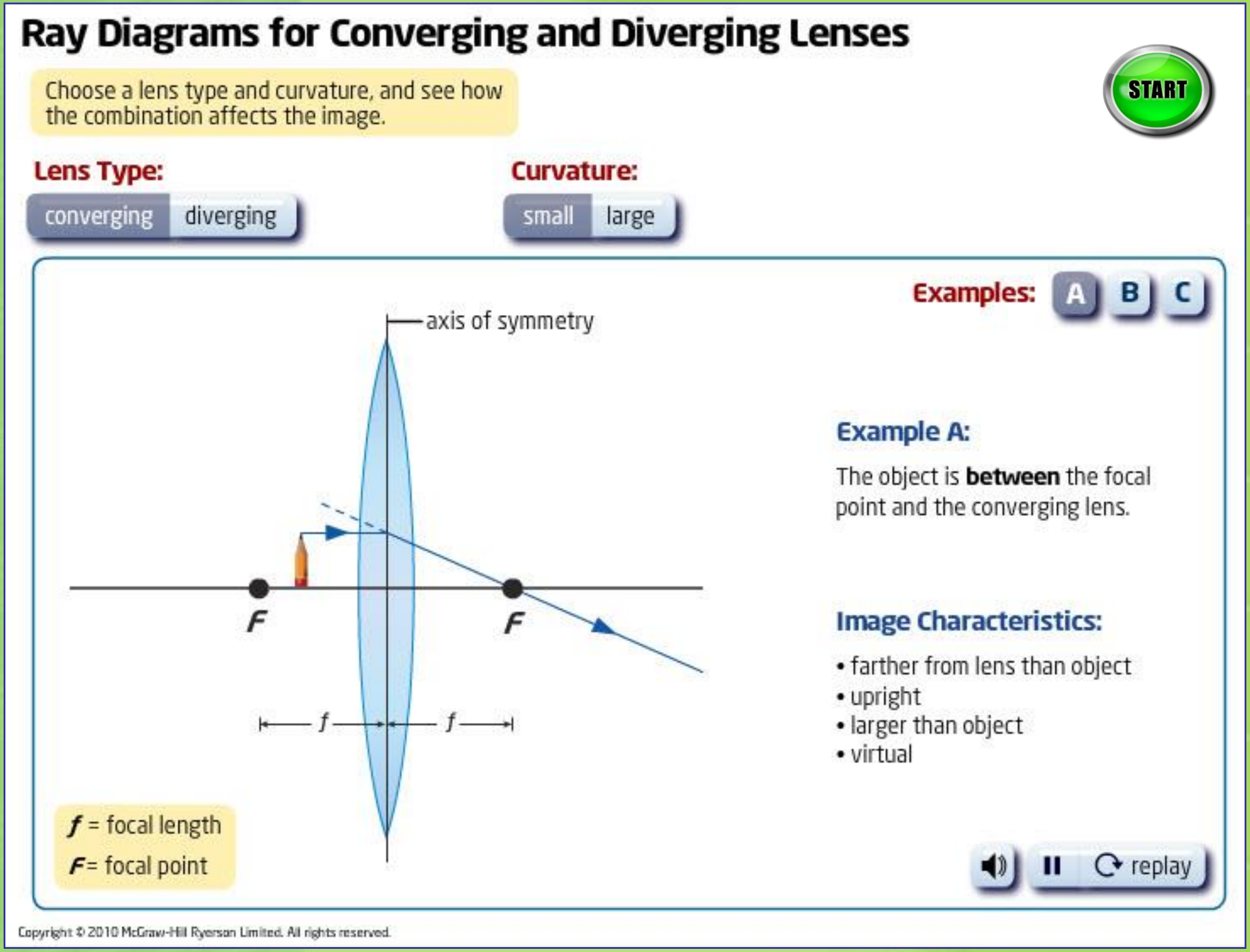




Chromatic aberration is the dispersion of light through a lens. The edges of lenses act as prisms, splitting light into colours.

Drawing Ray Diagrams for Converging and Diverging Lenses

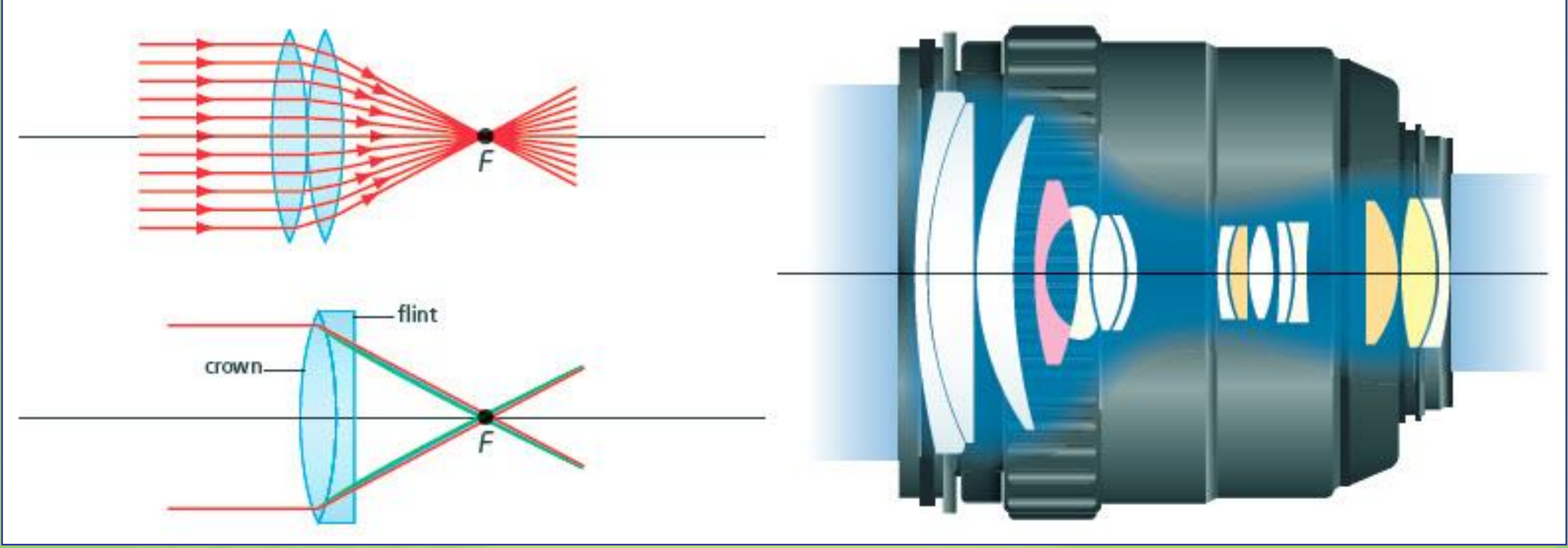
Click the “Start” button to review how to draw ray diagrams for converging and diverging lenses.



Correcting Chromatic Aberration

(Page 492)

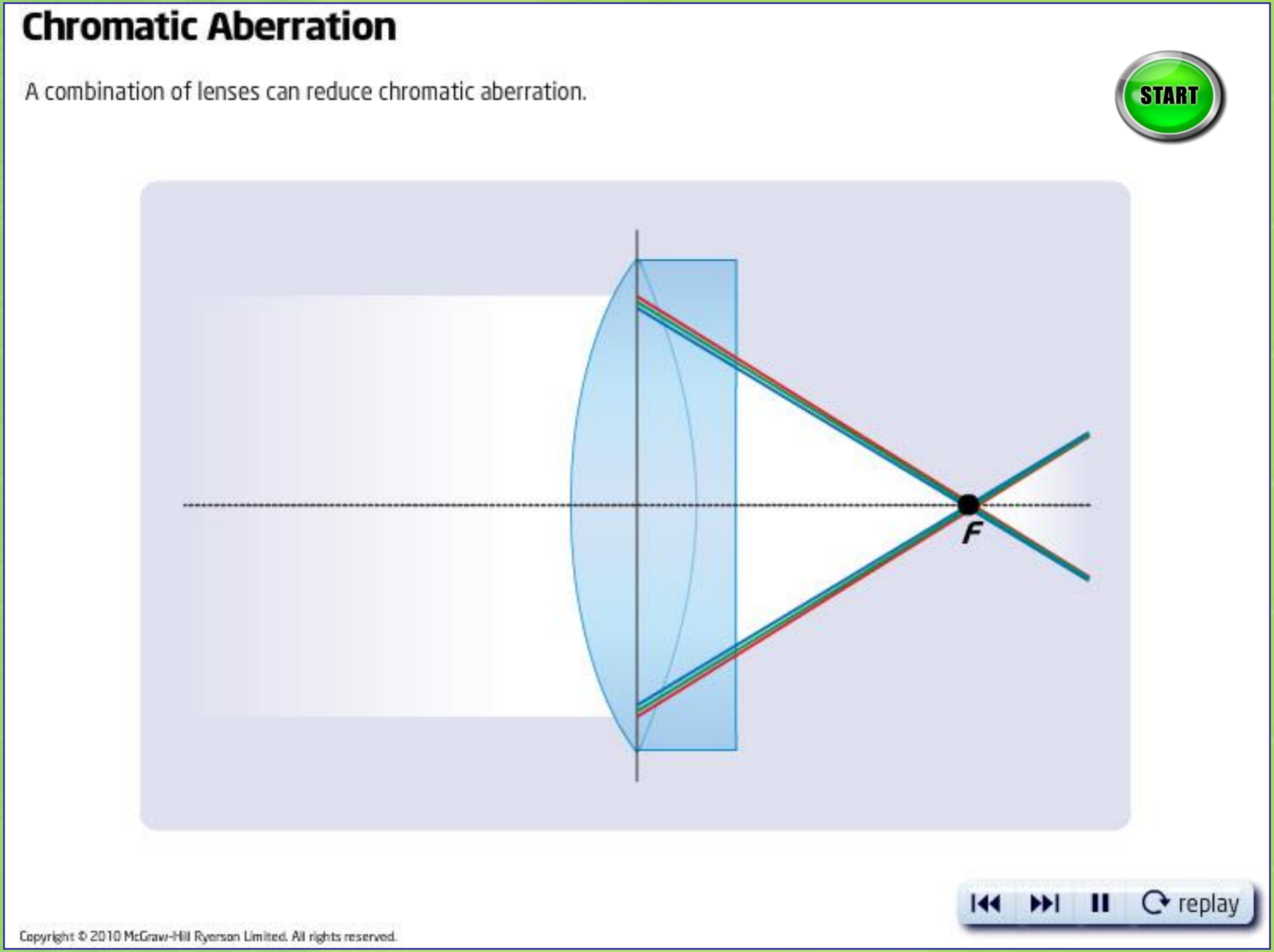
Spherical and chromatic aberration can be partially corrected by combining one or more lenses, especially if the lenses are made of materials with different indices of refraction.



Strategies that can be used to reduce chromatic aberration include: using two thinner lenses instead of one thick one; combining lenses made of different materials; or combining many lenses.

Reducing Chromatic Aberration

Click the "Start" button to review methods for reducing chromatic aberration.



Concepts to be reviewed:

- *different types of lenses and how they are classified*
- *the design and function of converging and diverging lenses*
- *determining the location of the focal point in converging and diverging lenses*
- *thick lenses and chromatic aberration*

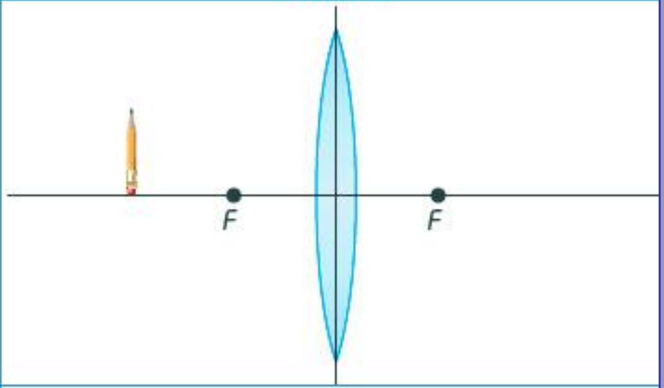
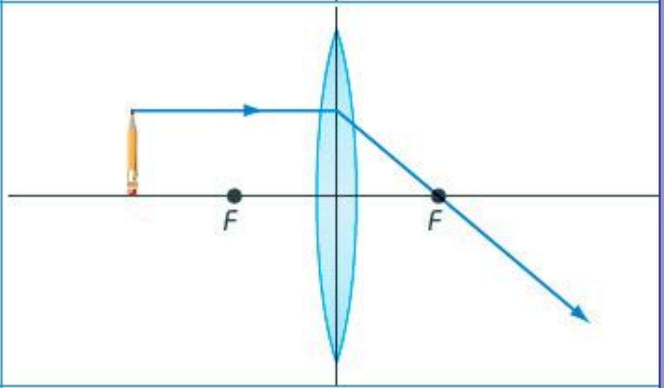
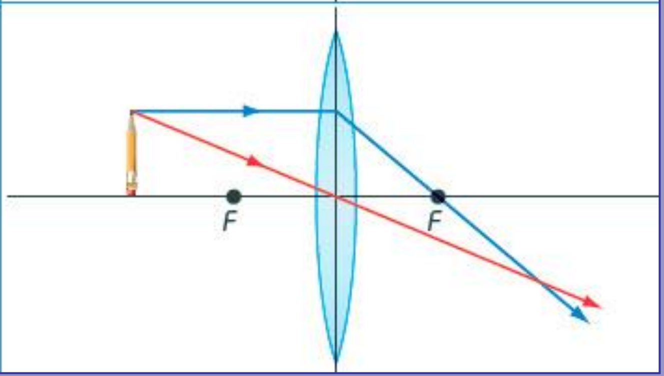
12.2 Images Formed by Lenses

(Page 494)

Lenses and combinations of lenses can be used to make images appear to be larger or smaller than the actual object. Ray diagrams can be used to determine the location, orientation, size, and type of image as it appears through a lens.

Drawing Ray Diagrams for Converging Lenses

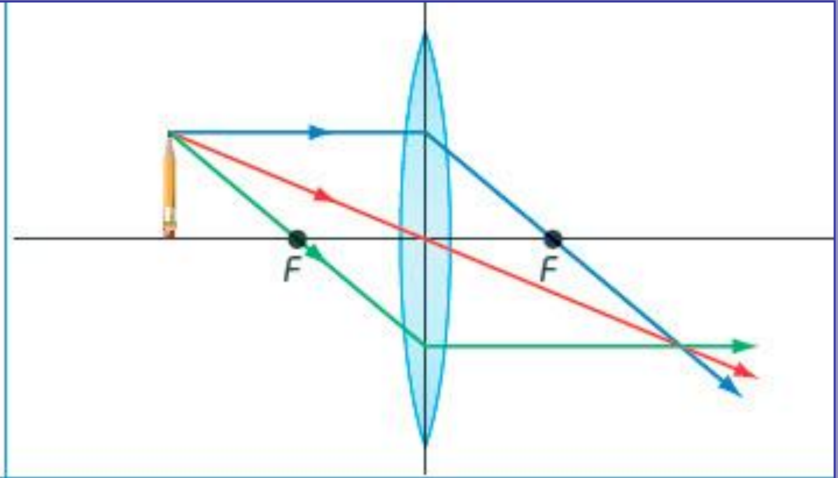
(Page 495)

Directions	Diagram
1. Draw the principal axis and a vertical line through the centre of the axis representing the axis of symmetry 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.	
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 axis of symmetry. *All rays that enter a converging lens parallel to the principal axis leave through the focal point.* Therefore, draw the ray from the lens through the focal point on the opposite side of the lens.	
3. Draw the second ray (shown in red). It goes from the top of the object directly through the centre of the lens. *The centre of the lens acts like a flat piece of glass, so rays leave in the same direction that they entered.* In reality, the ray would shift to the side. (Review **Figure 12.4**.) However, for thin lenses, the shift is not noticeable. Therefore, continue the ray with no change in direction.	

Drawing Ray Diagrams for Converging Lenses

(Page 495)

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, to the axis of symmetry. *Any ray that enters a converging lens from the focal point leaves the lens parallel to the principal axis.* Therefore, continue the ray horizontally until it meets the other rays.



5. Draw the real 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.

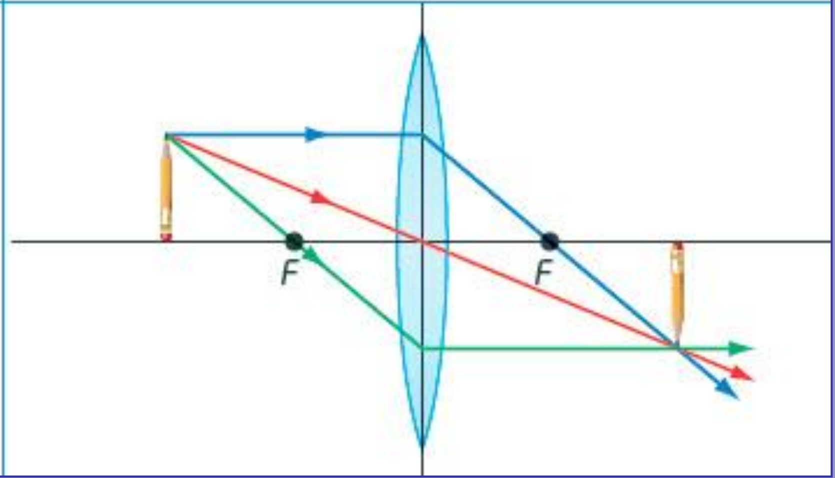
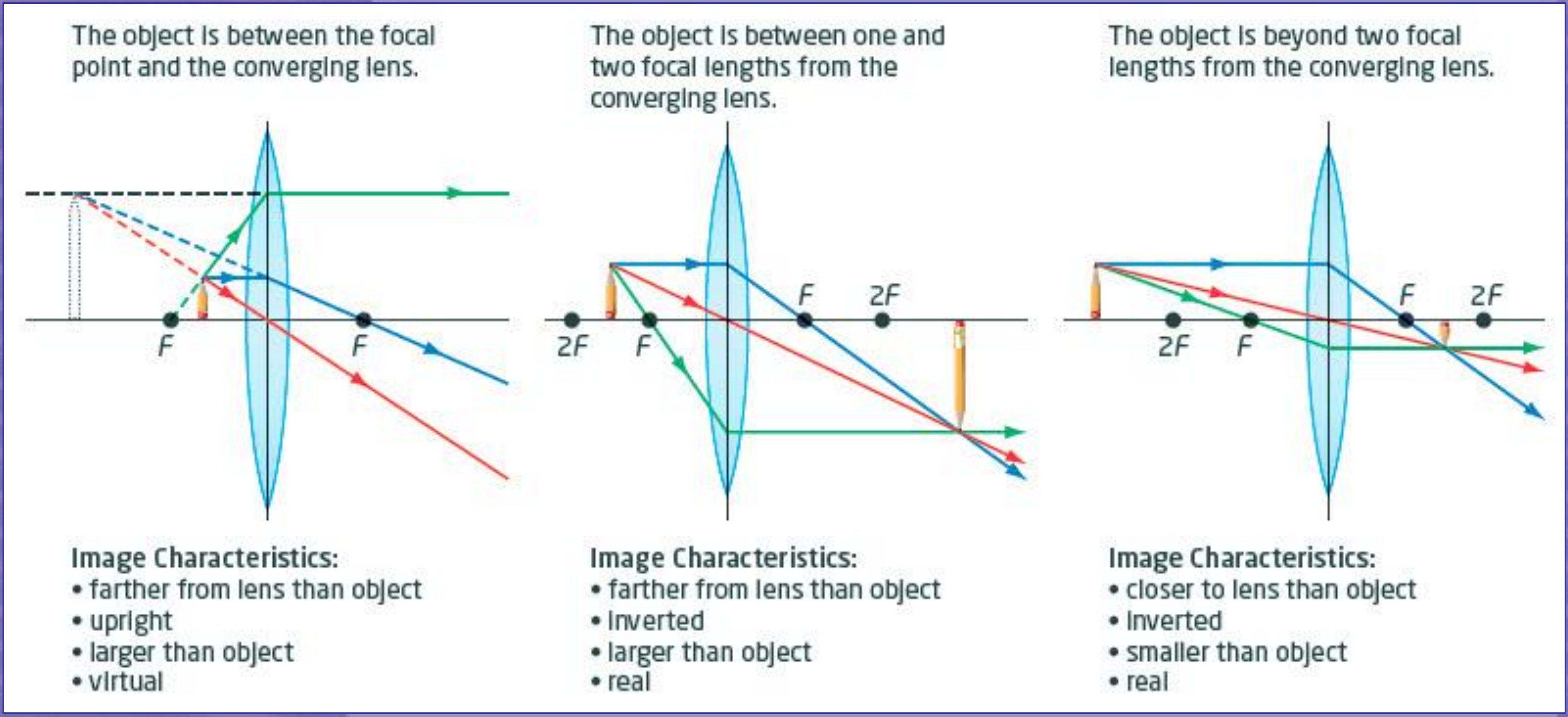


Image Characteristics in Converging Lenses

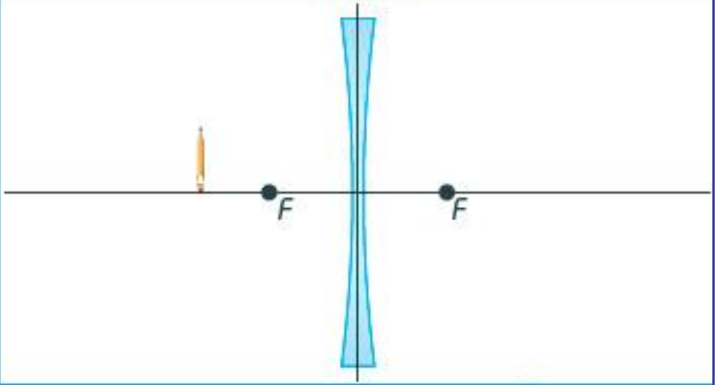
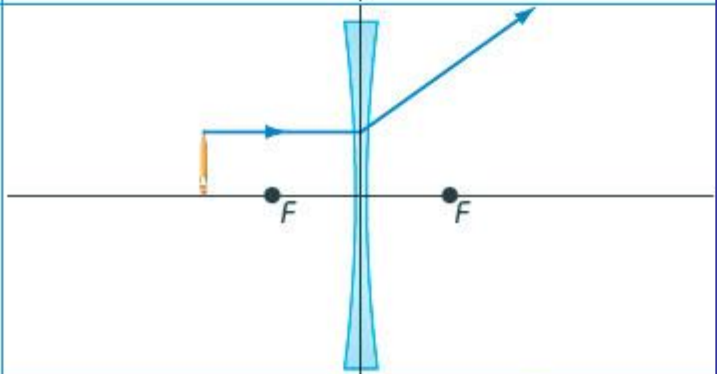
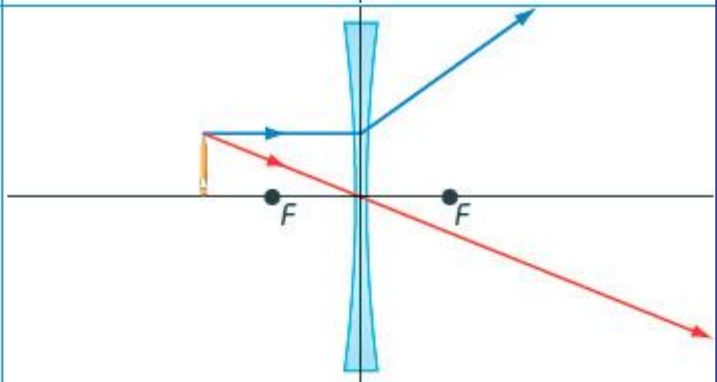
(Page 496)

Images seen through a converging lens may be inverted (upside down) or upright. Ray diagrams drawn with the object in different positions relative to the lens and focal point can be used to determine the orientation of the image.



Drawing Ray Diagrams for Diverging Lenses

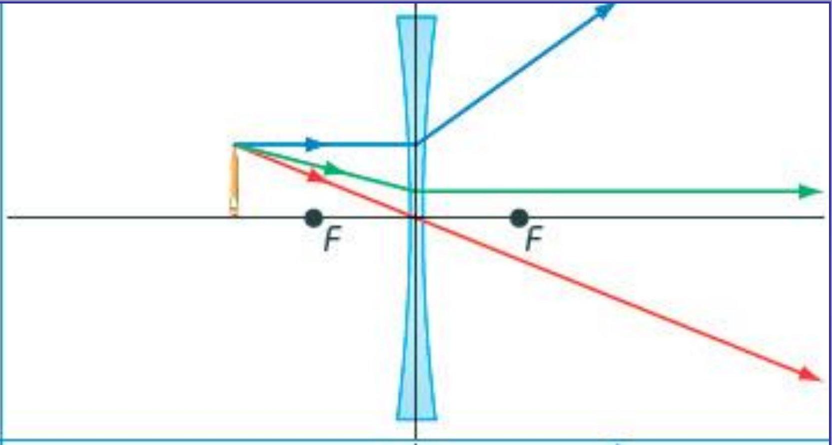
(Page 497)

Directions	Diagram
1. Draw the principal axis and the axis of symmetry of the diverging 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.	
2. Draw the first ray (shown in blue) from the top of the object parallel to the principal axis until it reaches the axis of symmetry. *All rays that enter a diverging lens parallel to the principal axis leave as though they were coming from the virtual focal point on the object side.*	
3. Draw the second ray (shown in red) from the top of the object directly through the centre of the lens. *The centre of the lens acts like a flat piece of glass, so rays leave in the same direction that they entered.* Therefore, continue the ray with no change in direction.	

Drawing Ray Diagrams for Diverging Lenses

(Page 497)

4. Draw the third ray (shown in green). It goes from the top of the object as though it were going to the focal point on the opposite side of the lens. Stop at the axis of symmetry. *Any ray that is directed toward the focal point on the opposite side of the diverging lens leaves the lens parallel to the principal axis.* Therefore, continue the ray horizontally.



5. Notice that the rays diverge after leaving the lens. Because the rays do not meet, you extend the blue and green rays backward with dashed lines until they meet to identify the location of the image point. The red line that runs through the centre of the lens is a straight line, so you do not have to draw it backward. Draw the image, outlined with dots, with the top of the image at the point where the three rays meet. The bottom of the image is on the principal axis.

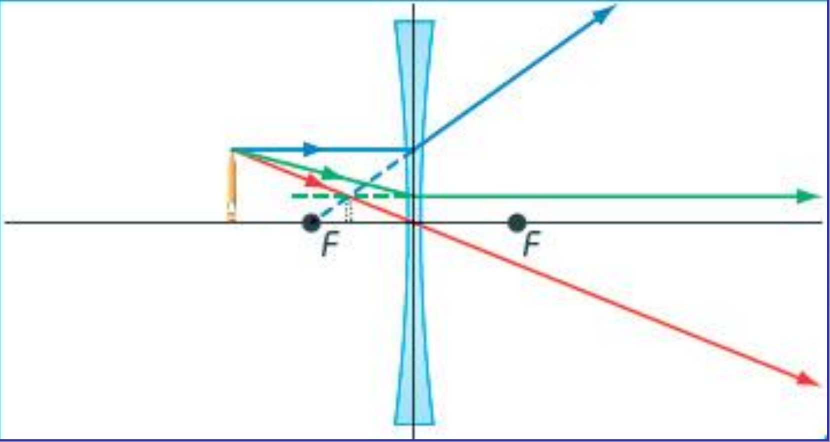


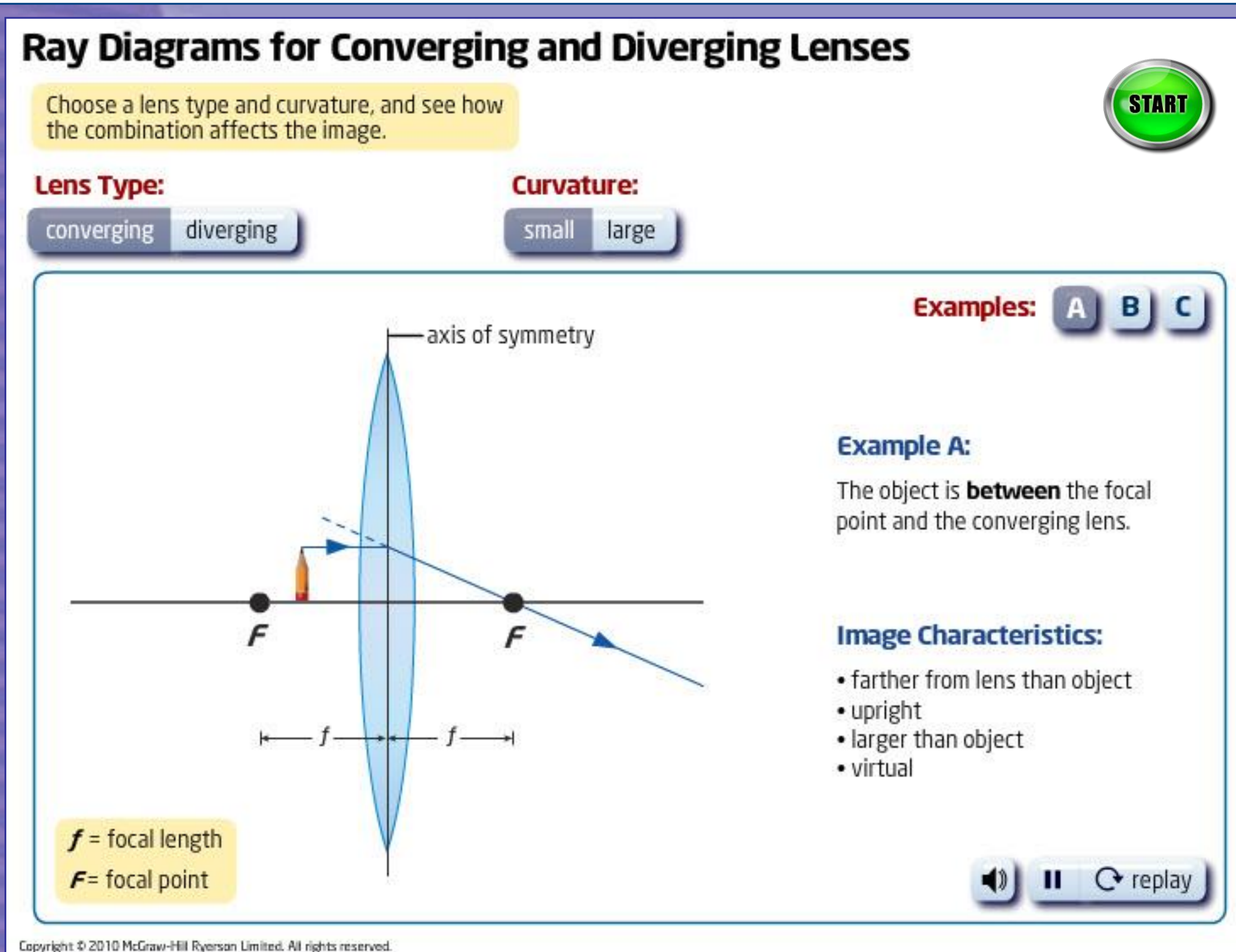
Image Characteristics in Diverging Lenses

(Page 498)

Images seen through a diverging lens are **always** upright, virtual, closer to the lens than the object, and smaller than the object, regardless of the location of the object. As the object moves farther from the lens, the image becomes smaller.

Ray Diagrams for Converging and Diverging Lenses

Click the “Start” button to review how to draw ray diagrams for converging and diverging lenses.



The Thin Lens and Magnification Equations (Pages 498-500)

Algebraic equations can be used to predict the position and size of the images formed by lenses, just as you did with mirrors.

Thin Lens Equation

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

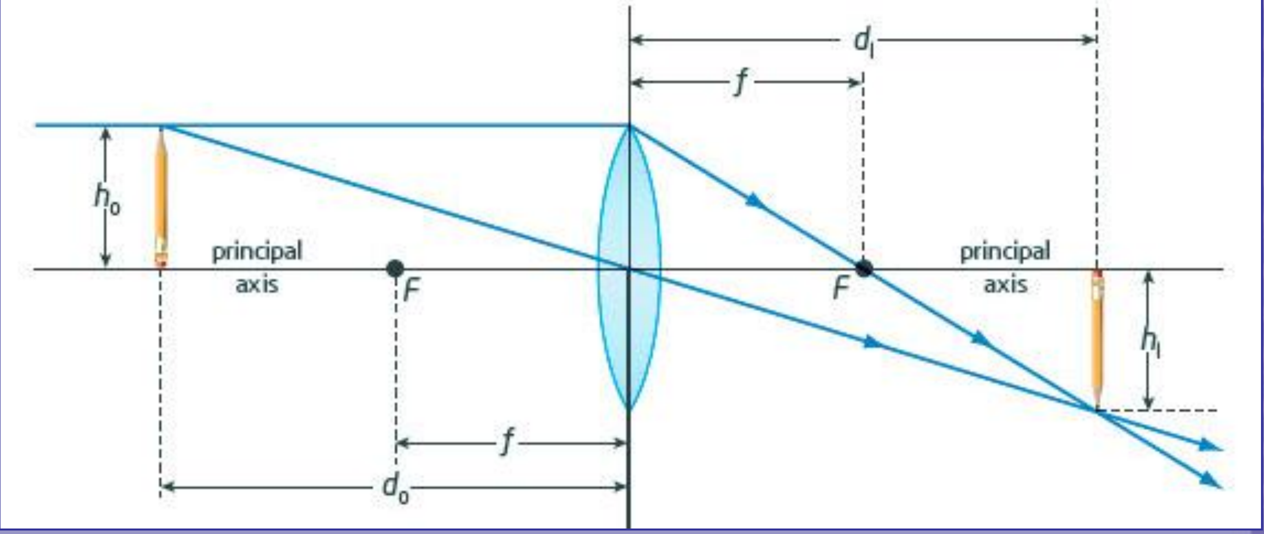
Magnification Equation

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

The negative sign means that real images are inverted. For virtual images, the image distance is negative. So the negative sign ensures that the image distance will be positive and the image will be upright.

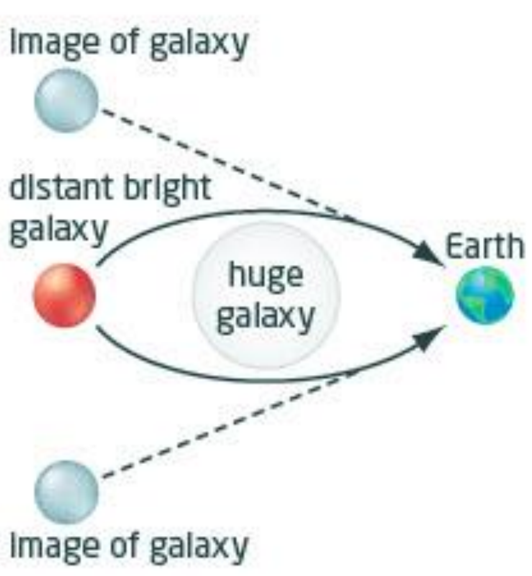
Remember that:

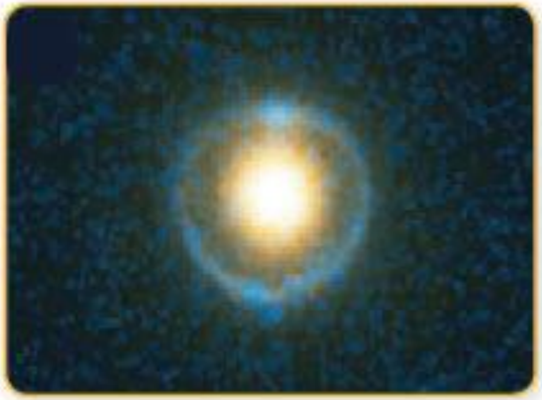
- ***f*** is the focal length
- d_o is the distance from the lens to the object
- d_i is the distance from the lens to the image
- h_o is the height of the object
- h_i is the height of the image



Gravitational Lenses

(Page 500)





Albert Einstein proposed that gravity can bend light much like a lens does. According to Einstein, if there were an extremely bright galaxy directly behind a huge galaxy, relative to Earth, the light from the bright galaxy would be bent around the huge galaxy. An observer would see the light as a ring around the huge galaxy. This process is known as **gravitational lensing**.

Section 12.2 Review

(Page 501)

Concepts to be reviewed:

- *drawing ray diagrams to determine the characteristics of images formed by lenses*
- *the type of image produced when an object is between a converging lens and the focal point*
- *the type of image produced when an object is beyond the focal point of a converging lens*
- *the type of image formed by a diverging lens*
- *using thin lens and magnification equations to determine characteristics of an image*

12.3 Lens Technologies and the Human Eye

(Page 502)

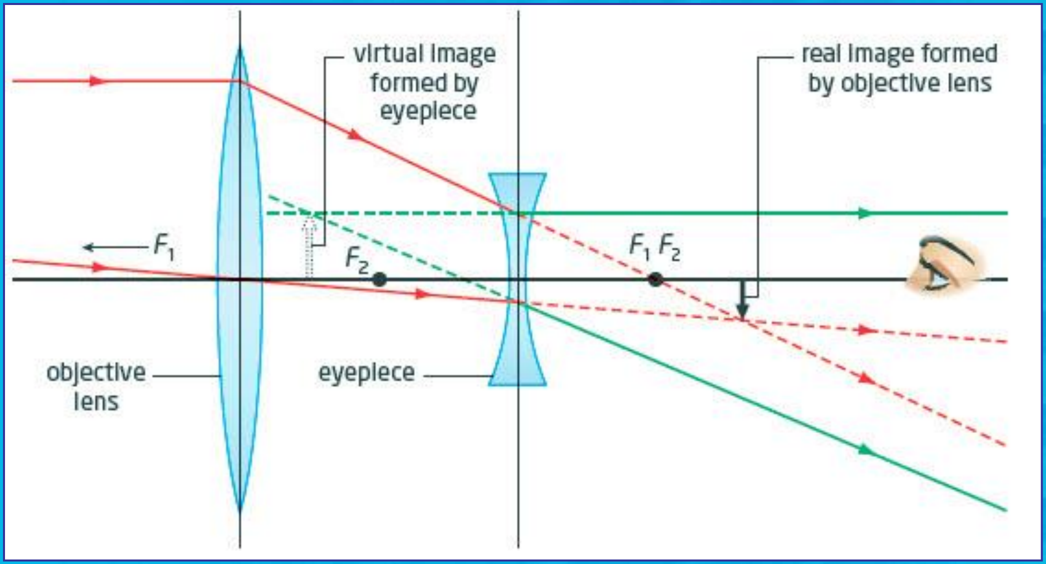
Early **refracting telescopes** such as the ones built by Galileo allowed scientists to view distant objects in much more detail. Galileo's telescope had two lenses: a converging lens and a diverging lens. The converging lens was used as the telescope's objective lens.

Galileo made some remarkable discoveries in astronomy using a telescope like this one.

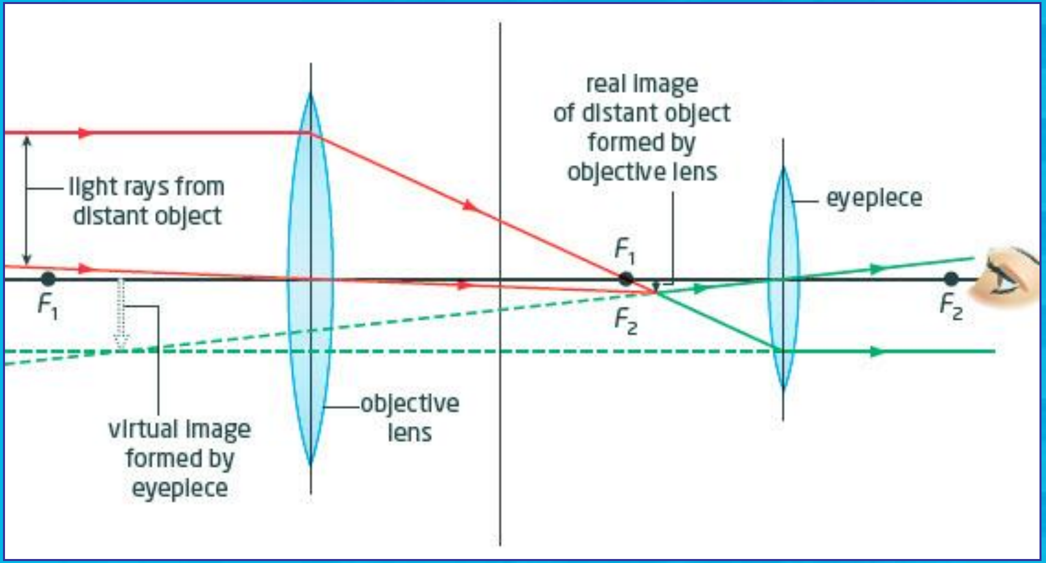
The **objective lens** is the lens through which light from an object enters a telescope. The **eyepiece** is the lens through which an observer views the object. Light leaves the telescope through the eyepiece.

Ray Diagrams for Telescopes

(Page 503)



The ray diagram for **Galileo's telescope** shows how the lenses were positioned so that the focal points for both lenses (***F*₁** and ***F*₂**) are the same. A virtual upright image of the object is formed.

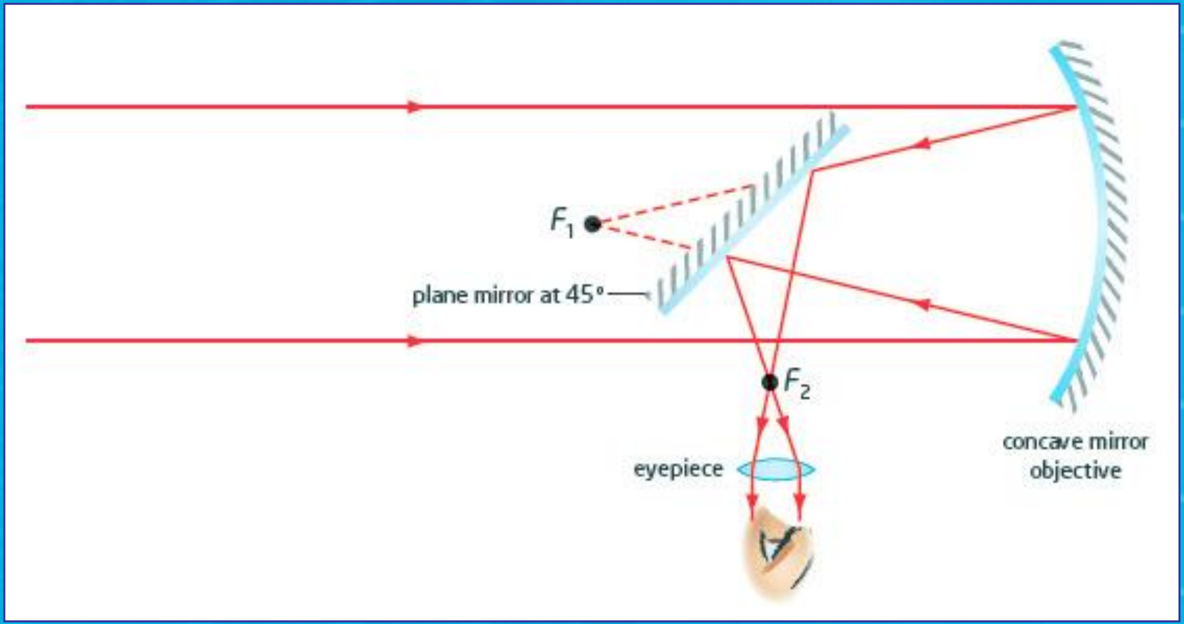


The ray diagram of **Kepler's telescope** shows how the focal points of the two lenses are at the same point between the lenses. The final image is larger but inverted.

Newton's Innovation

(Page 504)

Sir Isaac Newton reduced the chromatic aberration produced by Galileo's and Kepler's telescopes by using a concave mirror as the objective. The eyepiece magnified the image collected by the objective mirror.



Modern Telescopes

Although tremendous advances have been made, all modern telescopes are based on the designs of Galileo, Kepler, and Newton. Telescopes based on Galileo's and Kepler's designs are called **refracting telescopes** because they contain only lenses. Those based on Newton's design are called **reflecting telescopes** because they include mirrors.

http://hubblesite.org/

SPITZER SPACE TELESCOPE

http://www.spitzer.caltech.edu/

http://en.wikipedia.org/wiki/File:Astroscan.jpg

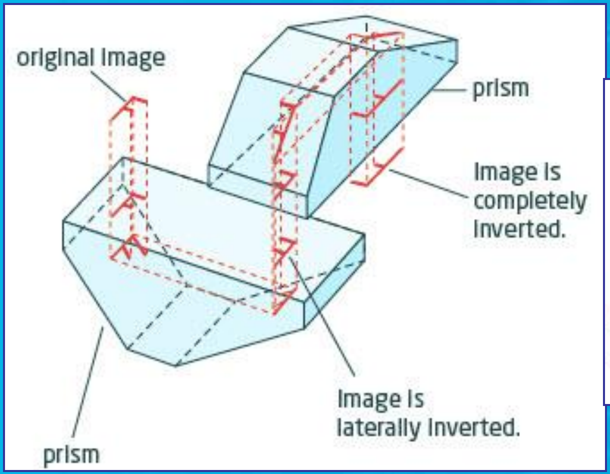
http://en.wikipedia.org/wiki/File:Kecknasa.jpg

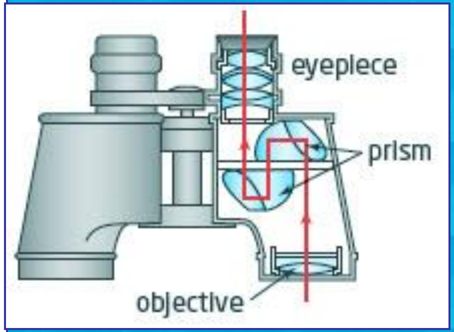
http://en.wikipedia.org/wiki/File:Telescope.jpg

http://en.wikipedia.org/wiki/File:100inchHooker.jpg (from Wikimedia Commons)

Binoculars and Microscopes

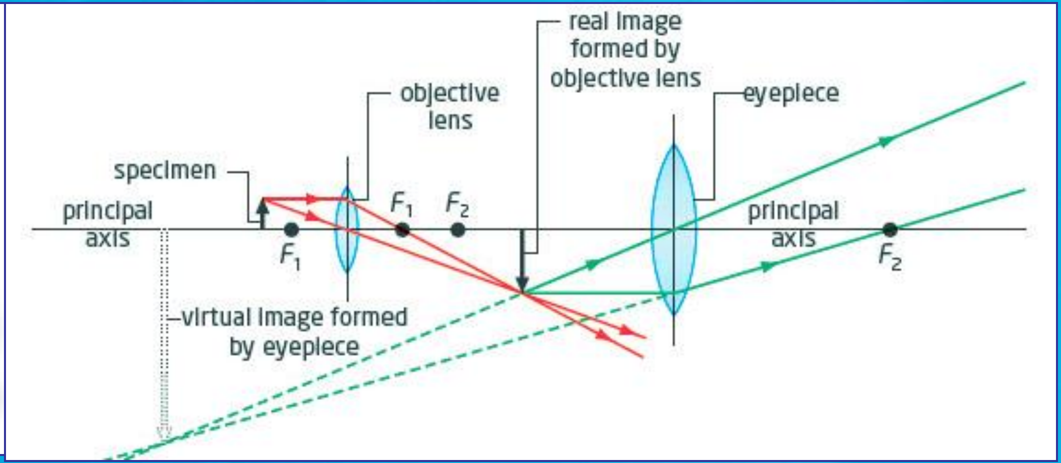
(Pages 504-505)





Binoculars are really just two refracting telescopes that are attached so that both eyes can see the same image. Two prisms on each side act as mirrors.

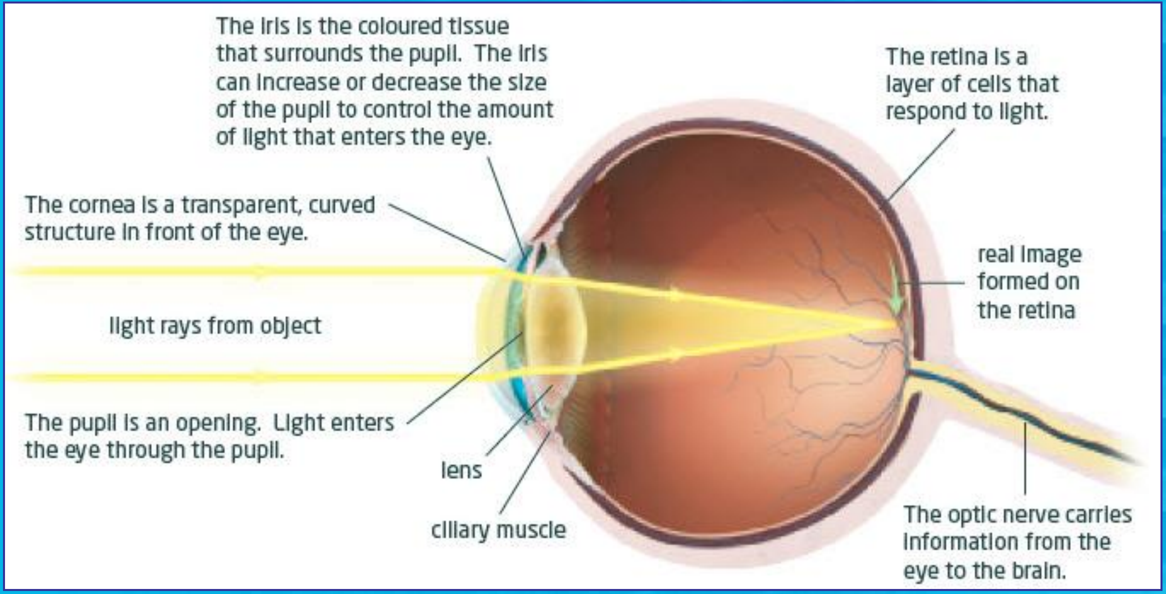
Microscopes are designed to make a tiny specimen appear larger. Similar to Kepler's refracting telescope, microscopes produce an inverted image that has been magnified many times.



Sight and the Human Eye

(Page 506)

The human eye allows us to focus on objects at different distances, record images, and detect subtle changes in colour and brightness. The focussing happens at the front of the eye, and everything else happens at the back of the eye and in the brain.



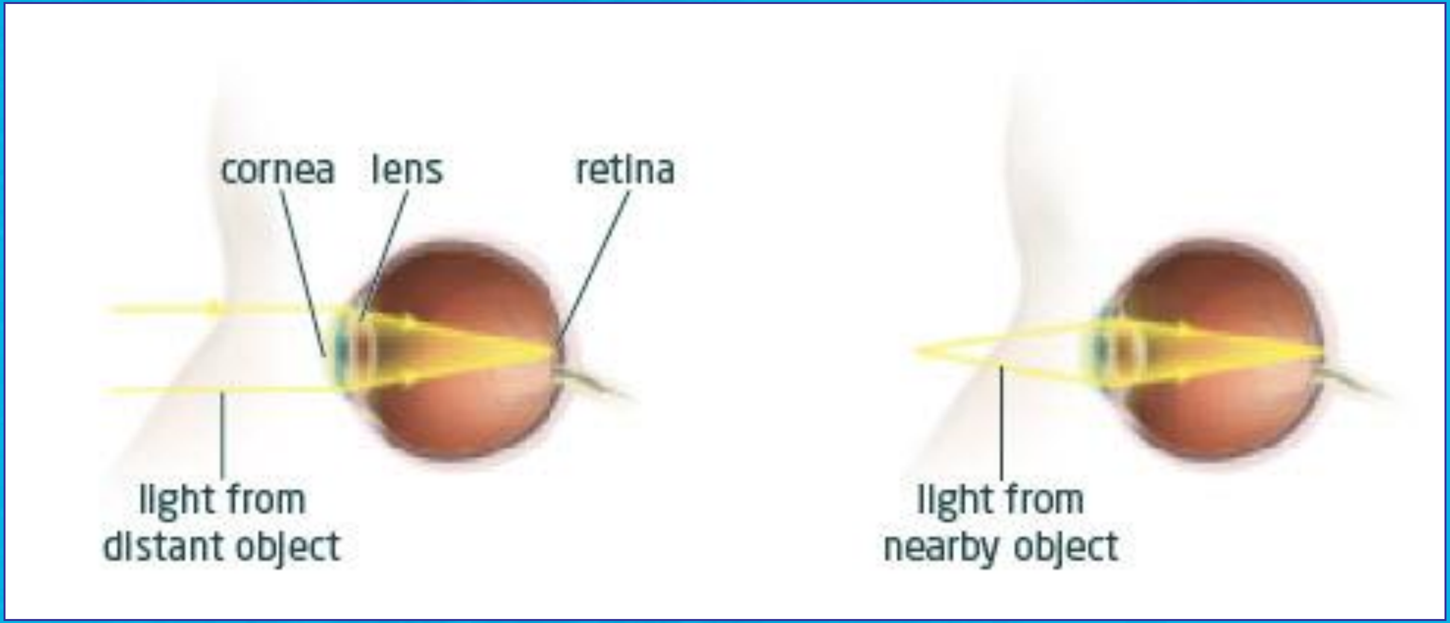
The **cornea** is the tissue that forms a transparent curved structure in the front of the eye. It refracts light before it enters the eye.

Located at the back of the eye, the **retina** is a layer of rod and cone cells that respond to light and initiate nerve impulses. The rod cells are sensitive to light, and the cone cells detect colour.

How the Human Eye Focusses

(Page 506)

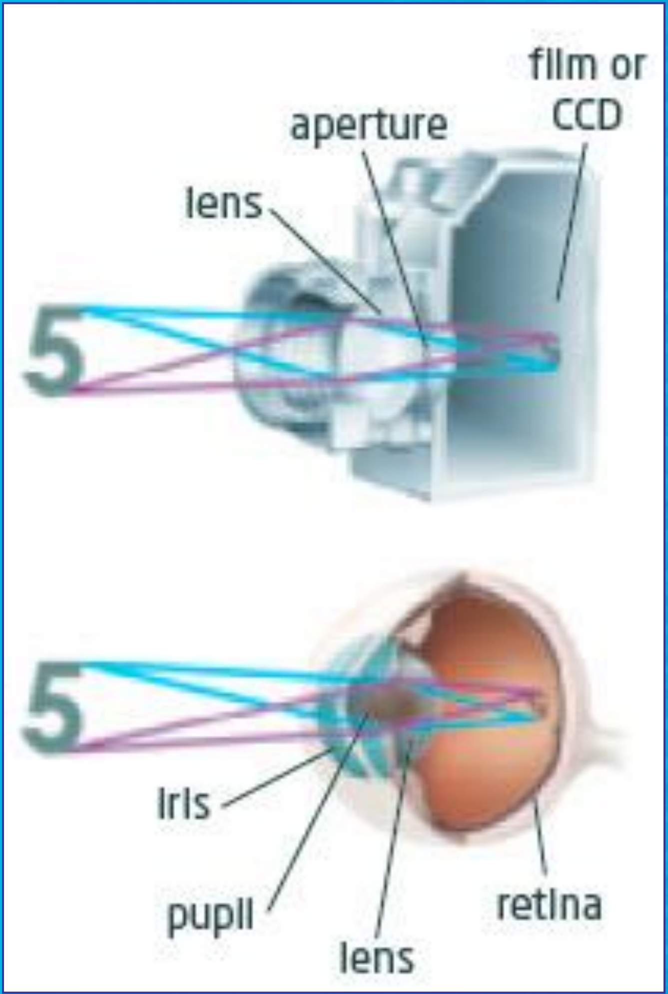
The lens inside the eye can change shape and thus refract light to a different extent, allowing it to focus light from both nearby and distant objects on the retina. The ciliary muscles change the shape of the lens by making the lens shorter and thicker.



The lens must be thicker (more curved) to focus on closer objects.

Comparing the Eye and the Camera

(Page 507)



Both eyes and cameras have lenses that focus light on a light-sensitive material.

The **lens** of the eye changes in shape in order to focus on objects at different distances. In cameras, the **lens** moves in and out to focus on objects at different distances.

The light sensitive material in an eye is the **retina**. In a camera, the **film** or **CCD**s (charge-coupled devices) are sensitive to light.

Cameras have an **aperture** that controls the amount of light that can enter. In eyes, the **pupil** carries out the same function.

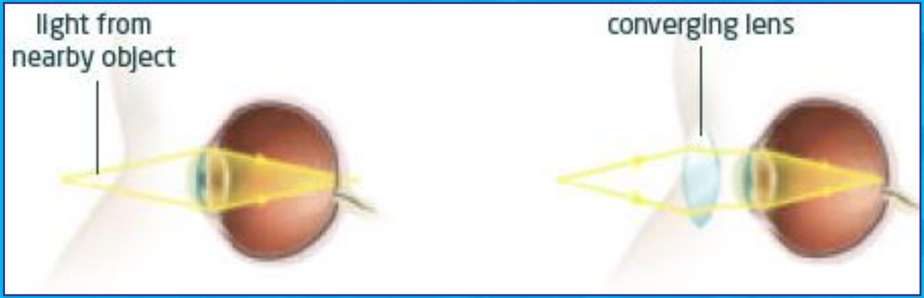
Correcting Vision Using Lenses

(Pages 507-508)

Common causes of poor vision are a incorrect shape of the eyeball, an incorrect shape of the cornea, and hardening of the lens. Each condition can be corrected by wearing glasses or contact lenses.

Myopia (near-sightedness) is the inability to focus on distant objects. It is caused by the eyeball being too long. The image forms in front of the retina. This condition can be corrected by wearing glasses or contacts with diverging lenses.

Hyperopia (far-sightedness) is the inability to focus on nearby objects. The eyeball is too short, and the incoming rays do not meet before they reach the retina. This can be corrected with glasses or contacts with converging lenses.



Correcting Vision Using Lenses

(Pages 507-508)

Presbyopia is a condition in which lenses of the eyes become stiff, and the ciliary muscles can no longer make the lenses change shape. People with this condition cannot focus on nearby objects. If a person is also near-sighted, they are not able to focus on near or far objects. This condition can be corrected by wearing **bifocals** (lenses with two parts). The top part of the lens corrects for near-sightedness and the bottom part helps eyes focus on nearby objects.

Bifocal lenses

Astigmatism is blurred or distorted vision, usually caused by an incorrectly shaped cornea. Corrective lenses or laser eye surgery can be used to correct astigmatism.

Laser Eye Surgery

(Pages 508-509)

Laser eye surgery involves using a laser to remove (vaporize) parts of the cornea, changing its shape and thus the way it refracts light. The surgery involves the following:

• a flap is cut in the cornea and then pulled back

• the cornea surface is shaped with the laser

• the flap is replaced

Although considered quite safe, risks involved in laser eye surgery can include:

• dry eyes

• oversensitivity to light

• poor perception of contrast

• double vision

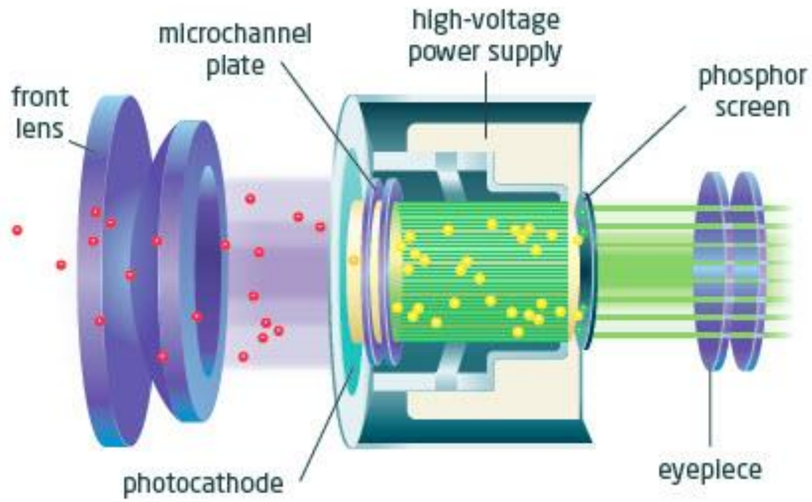
• perception of ghosted images, starbursts, or halos around light sources

Halo seen in low light

Enhancing Human Vision

(Page 510)

When light becomes extremely dim, the human eye can no longer perceive images. **Night-vision devices** allow people to see when only a very small amount of light is available. These devices are very useful to law enforcement and military forces, as well as people studying wildlife at night.



Night-vision devices use an image-intensifier tube that uses a high-voltage power supply to increase the amount of light reaching an observer's eye.

Section 12.3 Review

(Page 511)

Concepts to be reviewed:

- *technologies making use of lenses, and how they use them*
- *parts of the eye and how these parts allow people to see*
- *the various conditions that affect people's ability to see objects clearly, and how these conditions can be corrected using lenses and surgery*
- *how night-vision devices help people see in very low light situations*