Waves & Optics

Key words: waves, energy transfer, transverse, longitudinal, frequency, speed, wavelength, amplitude.

By the end of this lesson you will be able to:

State that a wave transfers energy.

Use the following terms correctly in context: wave, frequency, wavelength, speed, amplitude, period.

State the difference between a longitudinal wave and a transverse wave, and give an example of each.

Waves & Energy Transfer

Waves transfer energy.

The energy transferred by waves can be considerable!


Indian Ocean 2004

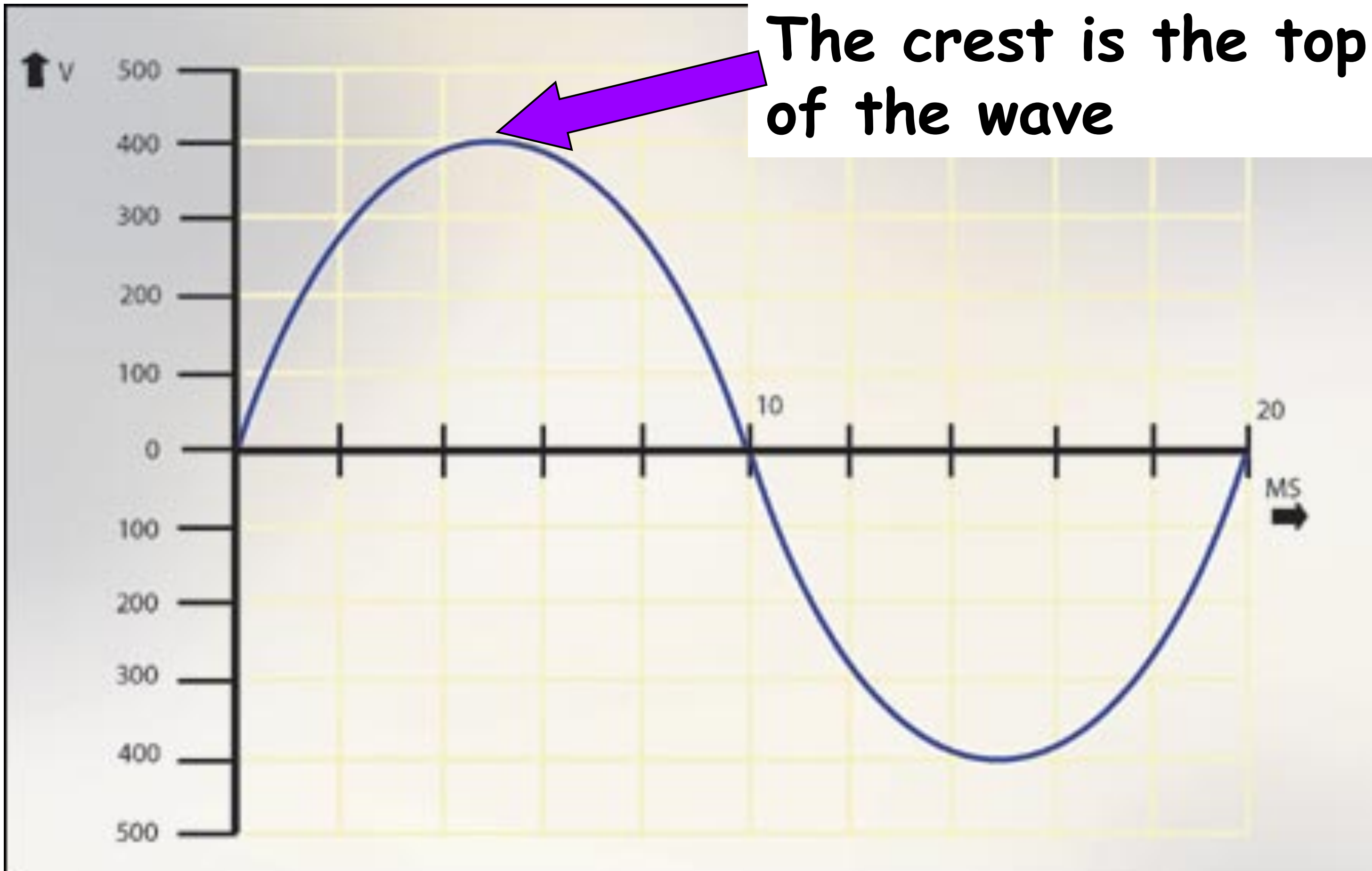
Indonesia 2005

Waves transfer energy…

Waves transfer energy…

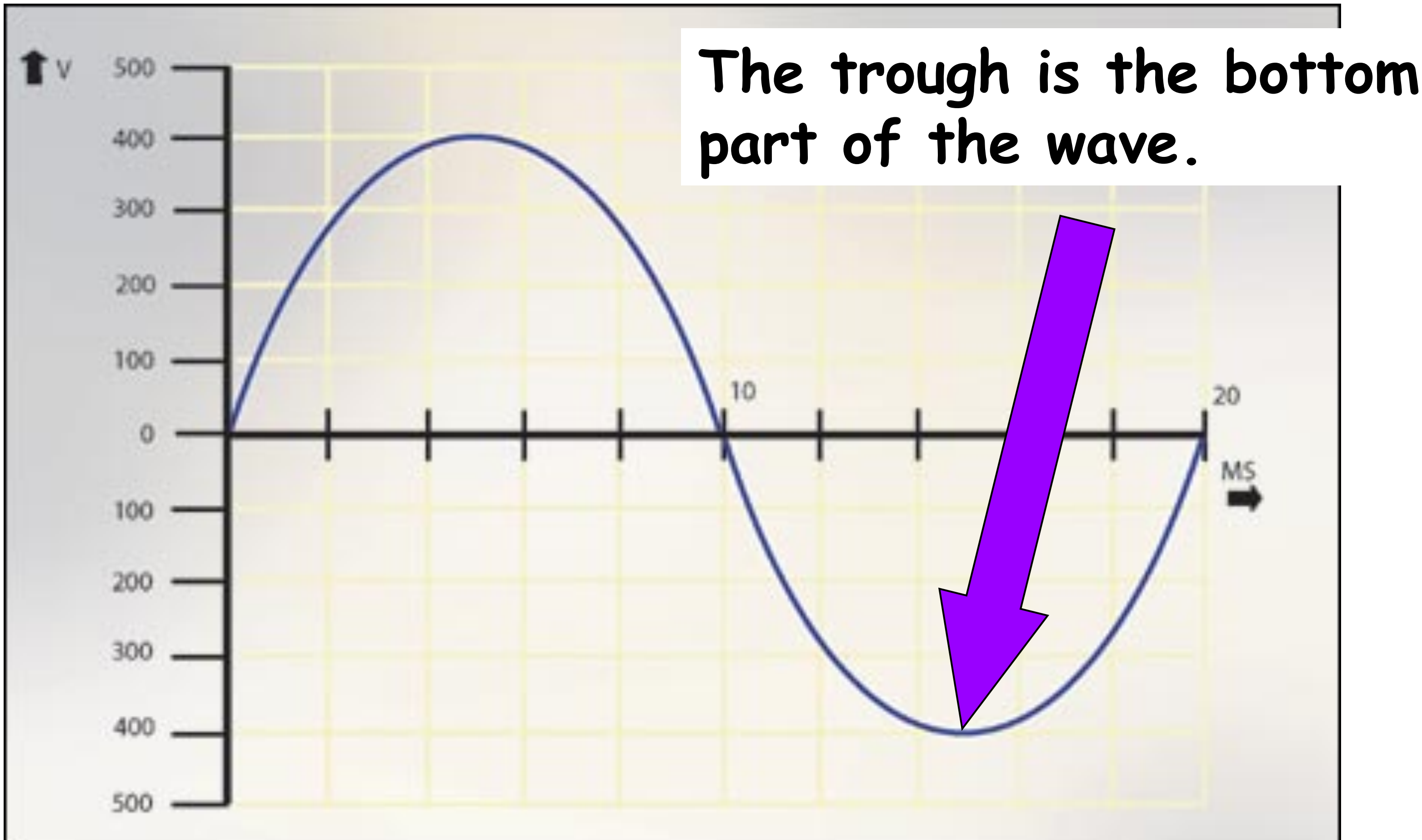
Properties of Waves

What is meant by the crest of the wave?

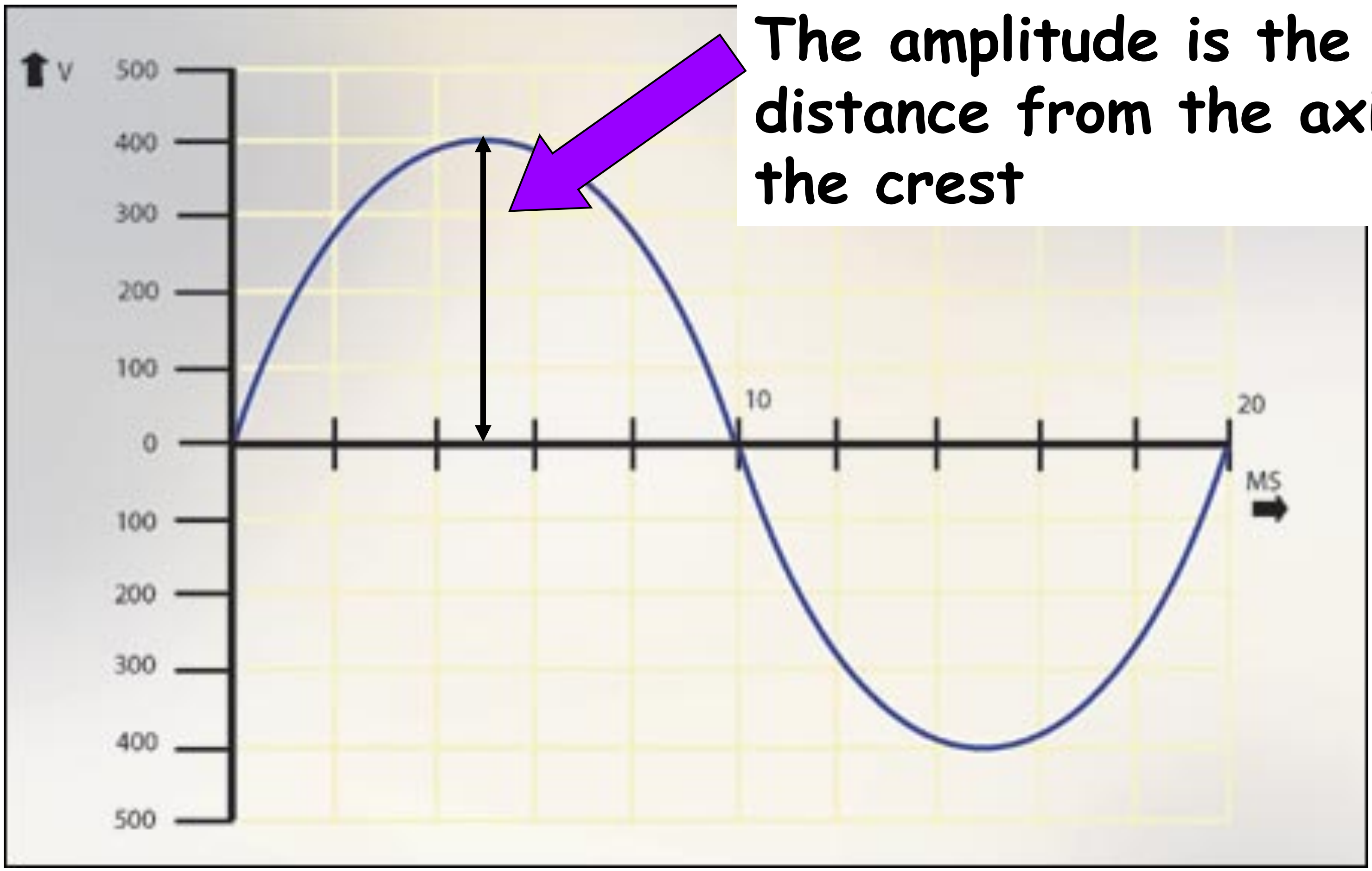


The crest is the top part of the wave

…and the trough?

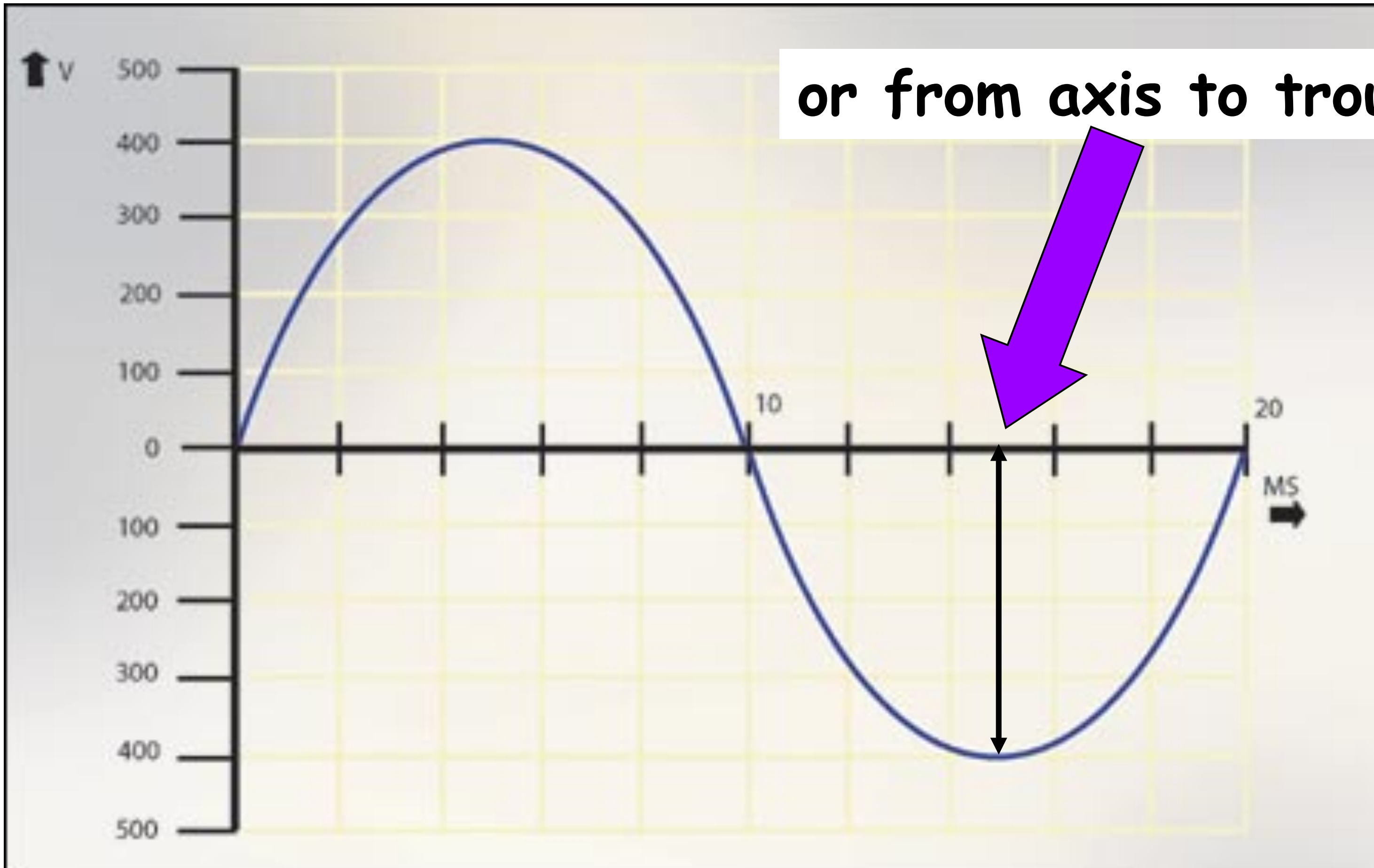


What is the amplitude of the wave?



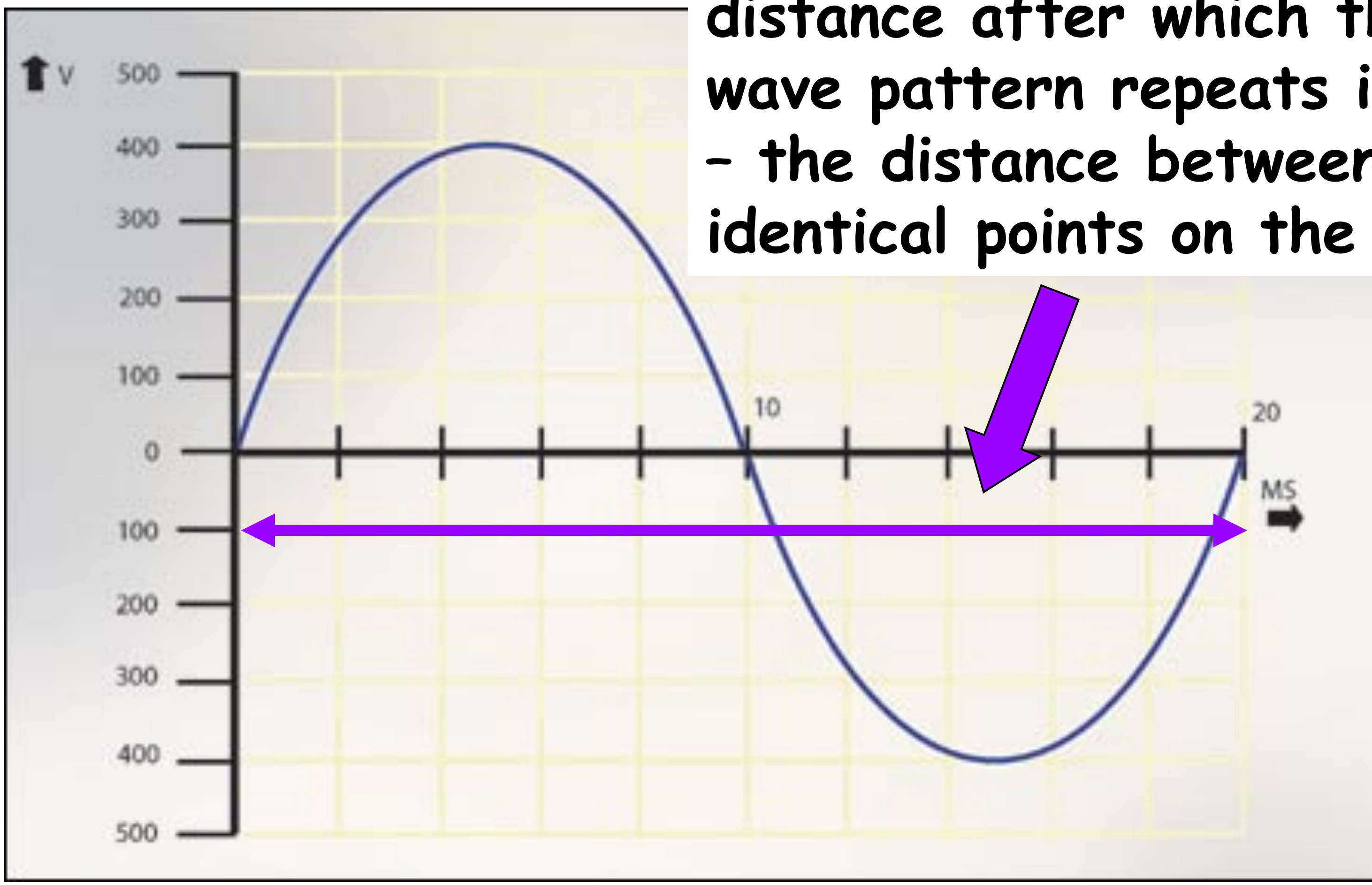
The amplitude is the distance from the axis to the crest

or from axis to trough.

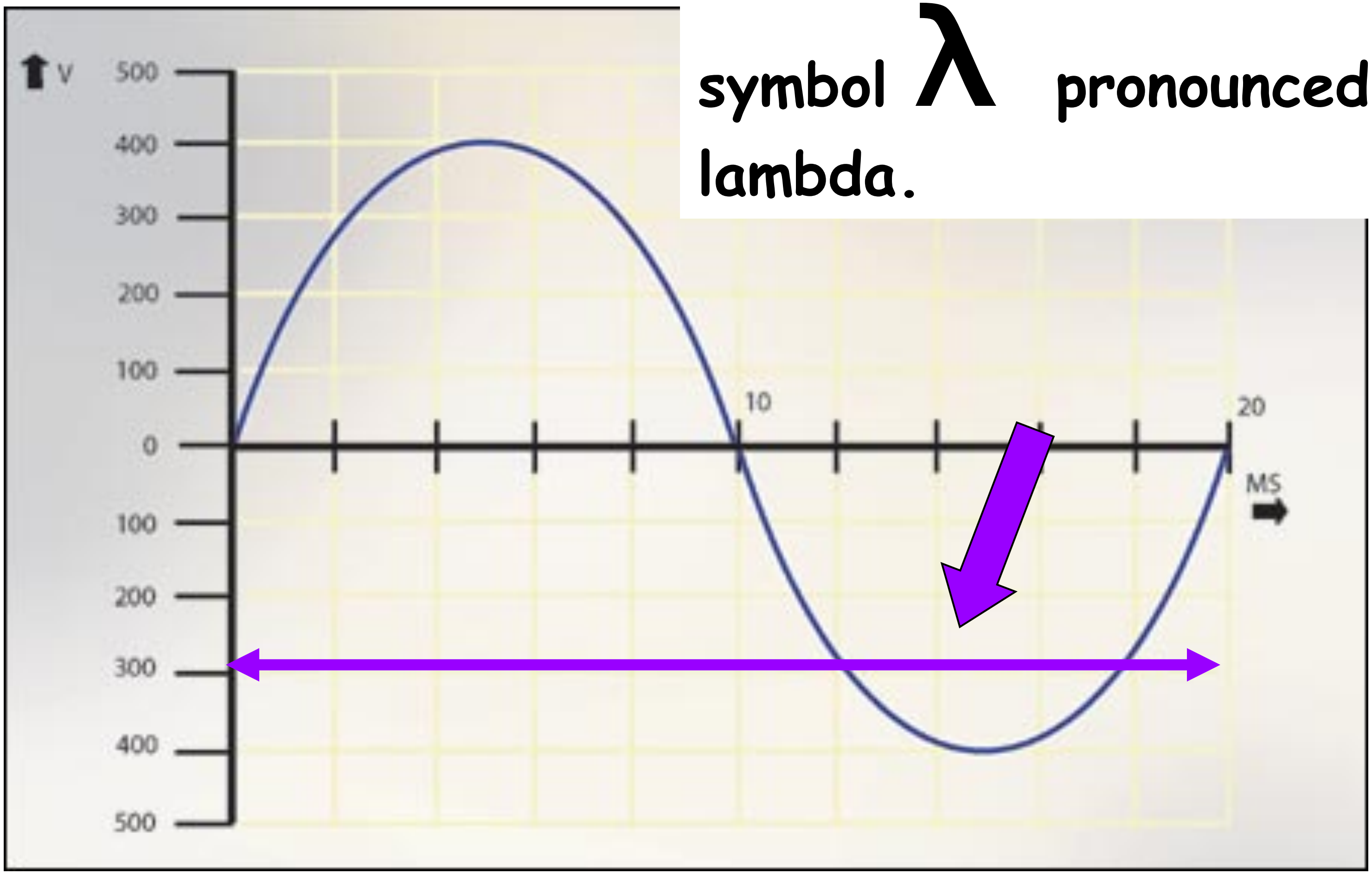


Definition of Wavelength?

The wavelength is the distance after which the wave pattern repeats itself – the distance between two identical points on the wave



Wavelength is given the symbol λ pronounced lambda.



Frequency

The frequency (f) of the wave is the number of waves each second.

Frequency is measured in hertz (Hz) which just means “per second”.

f = number of waves ÷ time in seconds

Frequency

Calculate the frequency of each of the following waves:

125 waves passing a point in 10 seconds.
16 waves passing a point in 24 seconds.
30 waves passing a point in 1 minute.

Frequency

Calculate the frequency of each of the following waves:

125 waves passing a point in 10 seconds

12.5 Hz

16 waves passing a point in 24 seconds.

0.67 Hz (2 sig fig)

30 waves passing a point in 1 minute.

0.5 Hz

Period

The period (T) of a wave is the time taken for one complete wave to pass a point.

It is measured in seconds (s).

Period and frequency are related…

Frequency & Period

The link between the frequency and period of a wave

$$T = \frac{1}{f}$$

Frequency & Period

Rearranging

$$f = \frac{1}{T}$$

Transverse Waves

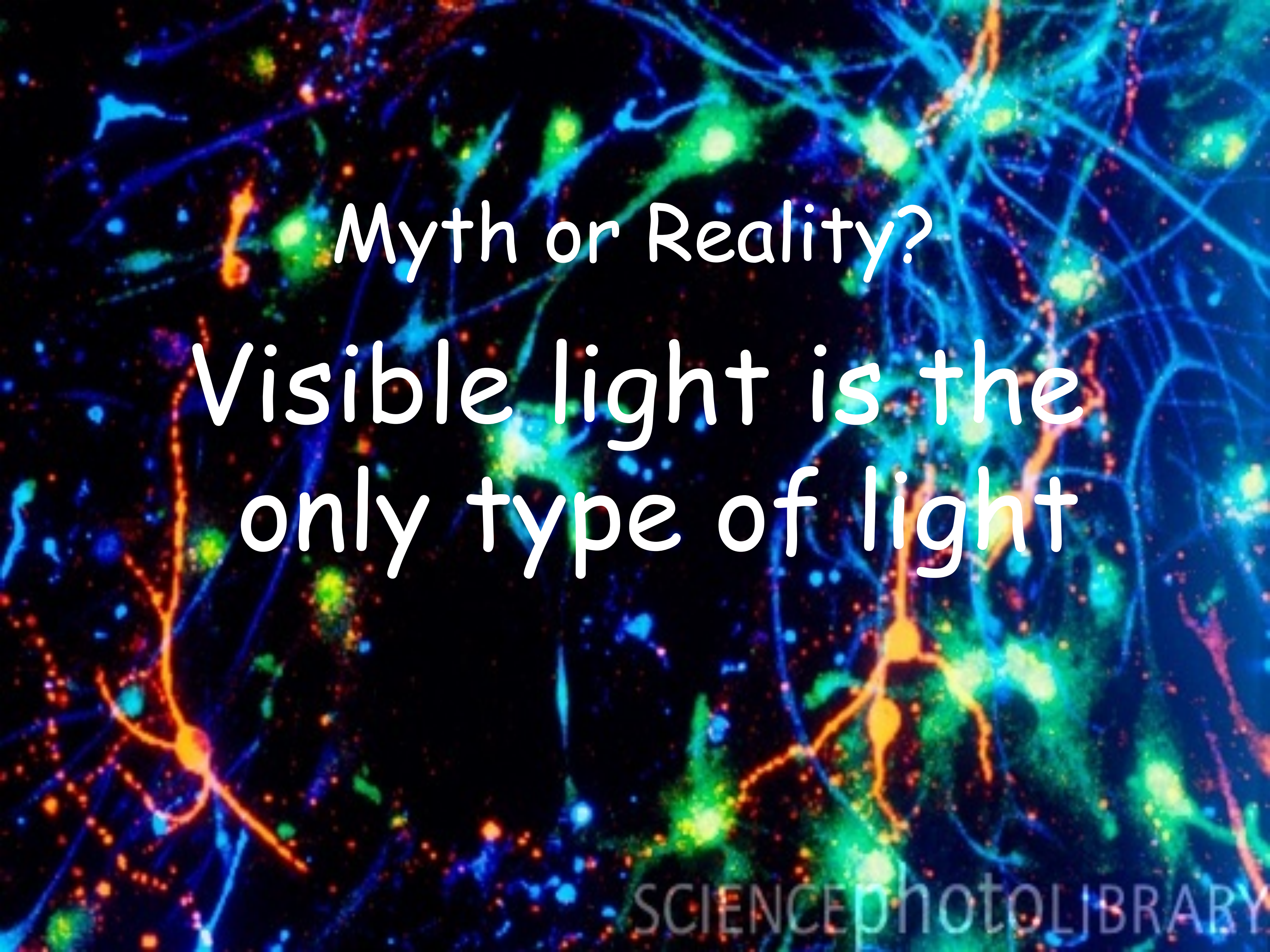
Light, and all forms of electromagnetic radiation, are transverse waves.

Key words: electromagnetic spectrum, wavelength, frequency

By the end of this lesson you will be able to:

State in order of wavelength, the members of the electromagnetic spectrum: gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves , TV and radio.

State that radio and television signals are transmitted through air at 300000000 m/s and that light is also transmitted at this speed.

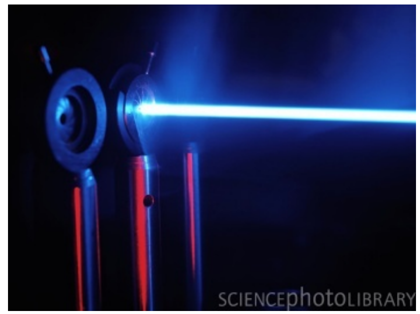

Myth or Reality?
Visible light is the only type of light
SCIENCEphotoLIBRARY

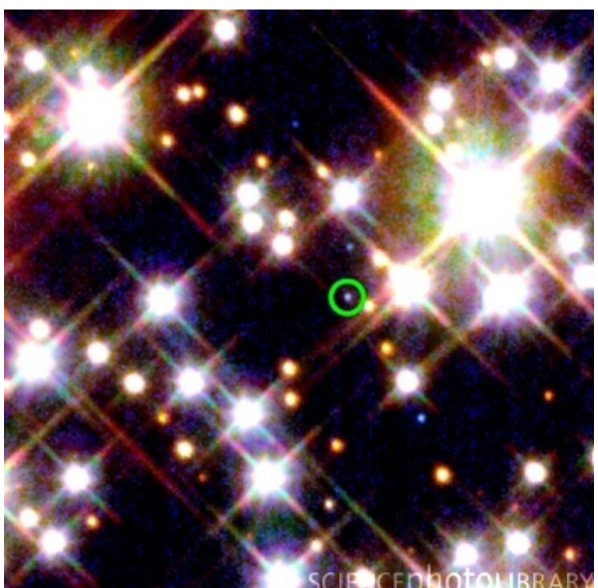
What is radiation?

Myth or Reality?

All radiation is harmful.

Where does light come from?



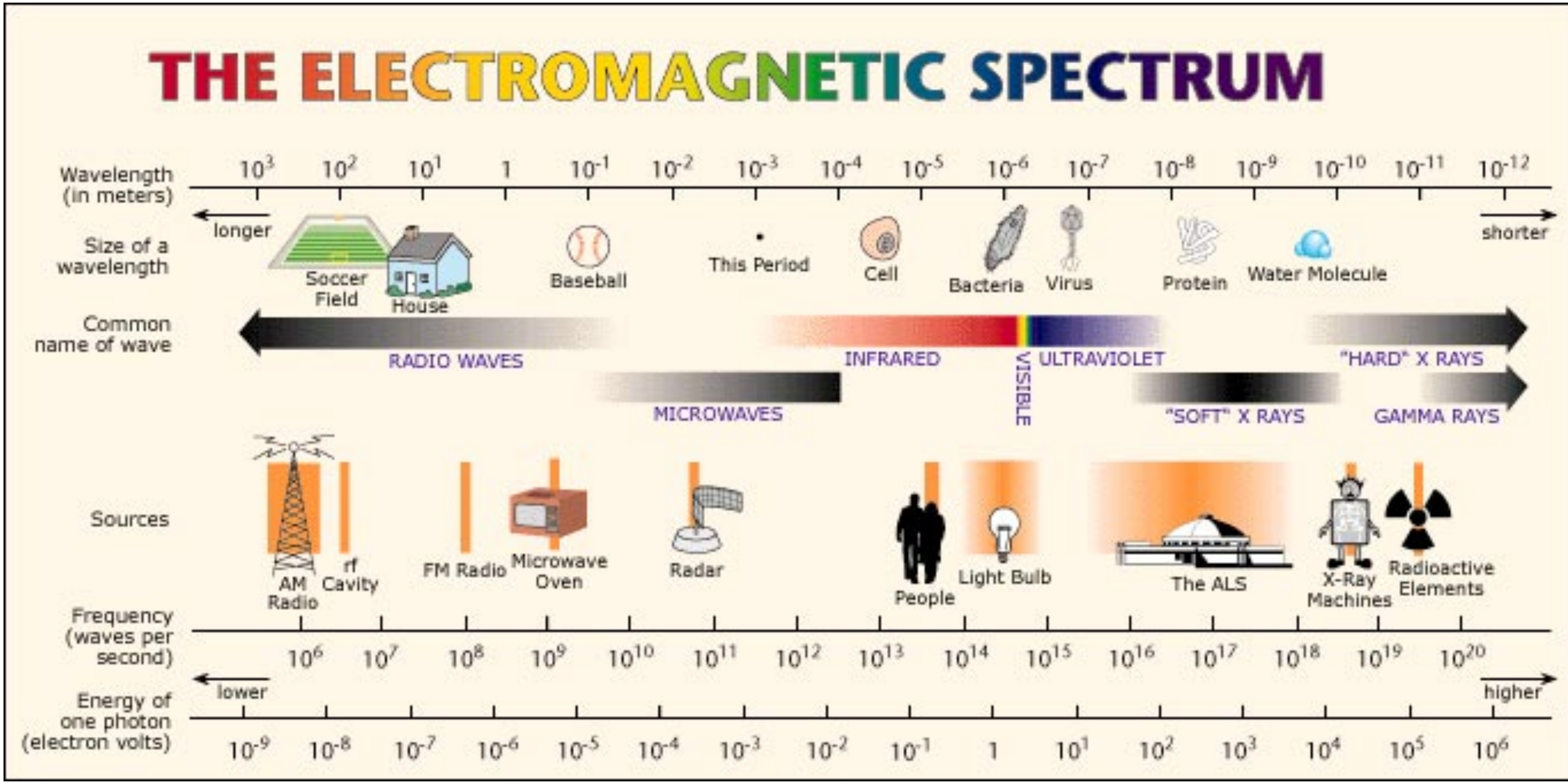


What is a light wave?

Light is a disturbance of electric and magnetic fields that travels in the form of a wave.

Like all waves it can be described as having peaks, troughs, frequency, wavelength, amplitude and it transfers energy.

What is the electromagnetic spectrum?



The electromagnetic spectrum consists of all the different wavelengths of electromagnetic radiation, including light, radio waves, and X-rays.

All travel at 3×10^8 m/s

Radio Waves

The longest wavelength and lowest frequency.

Radio waves are longer than 1 mm.

Radio wavelengths are found everywhere: in the background radiation of the universe, in interstellar clouds, and in the cool remnants of supernova explosions.

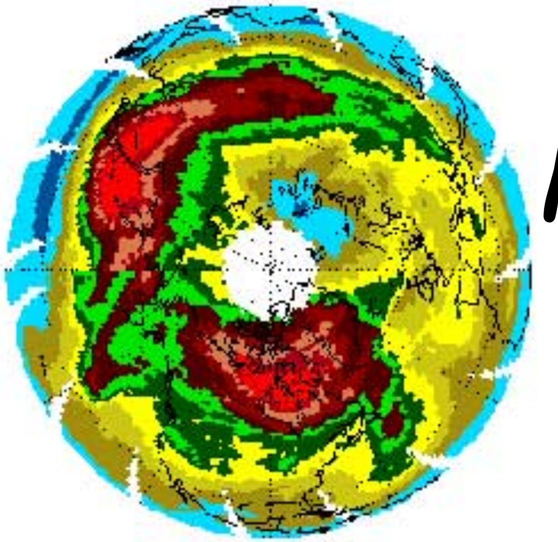
Radio Waves

Radio stations use radio wavelengths (10 cm – 1000 m) of electromagnetic radiation to send signals that our radios then translate into sound.

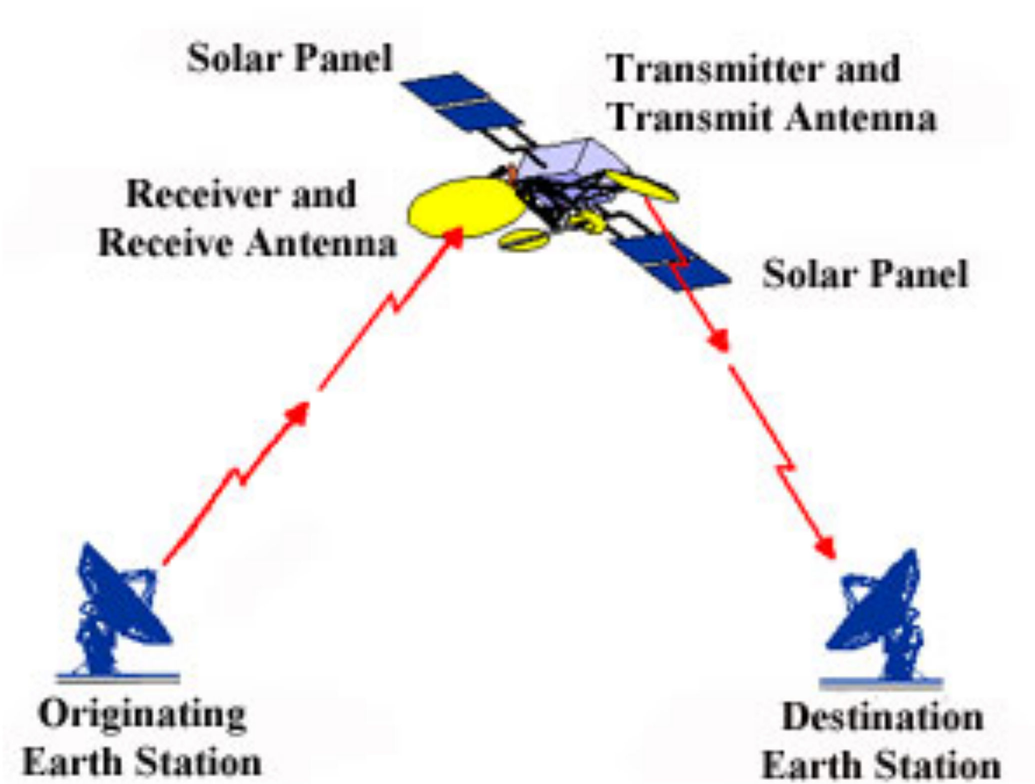
These wavelengths are typically 1 m long in the FM band.

Radio Waves

Radio stations transmit em radiation, not sound. The radio station encodes a pattern on the em radiation it transmits, and then our radios receive the em radiation, decode the pattern and translate the pattern into sound.

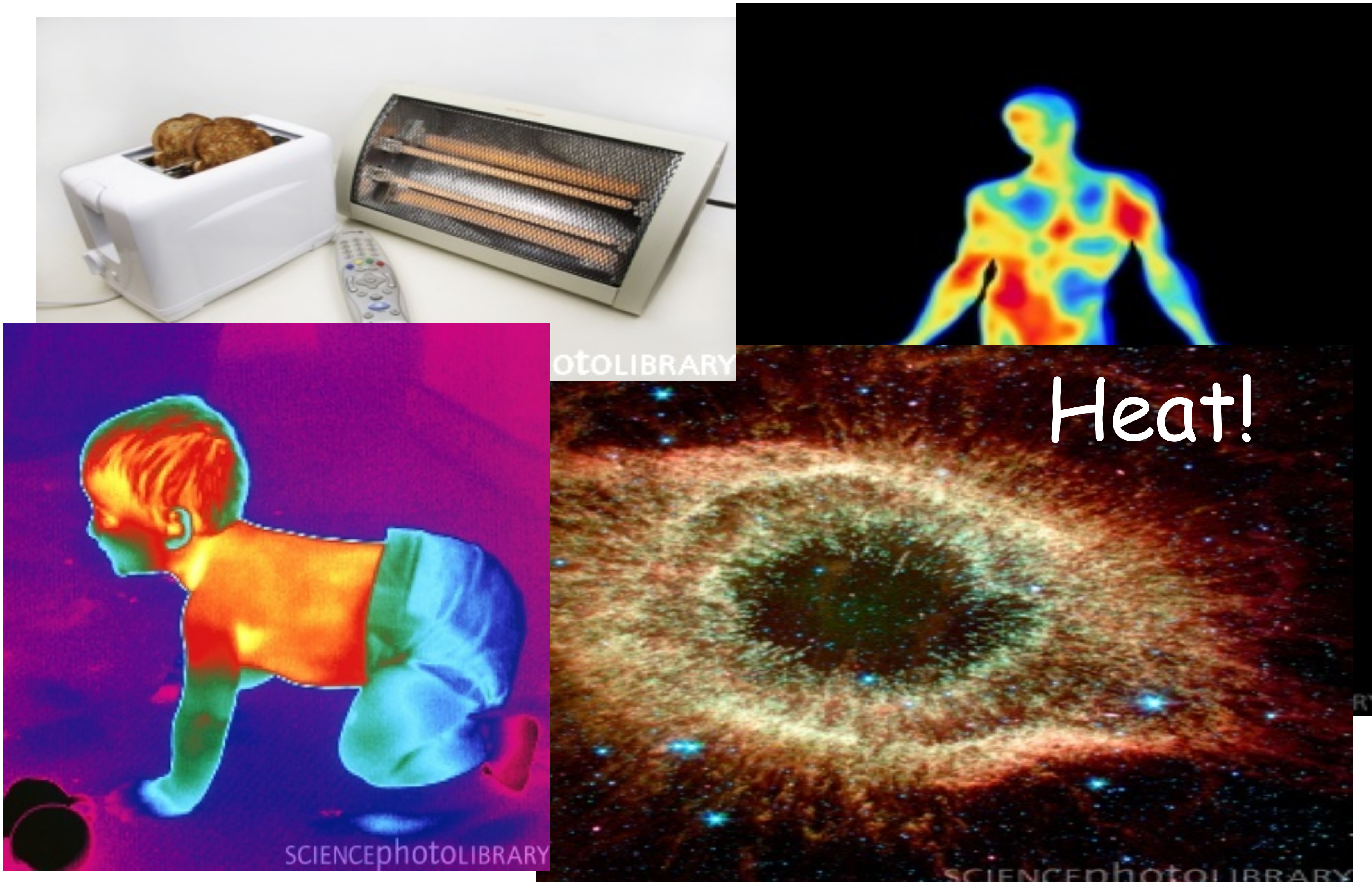


Microwaves 0.1 – 10 cm

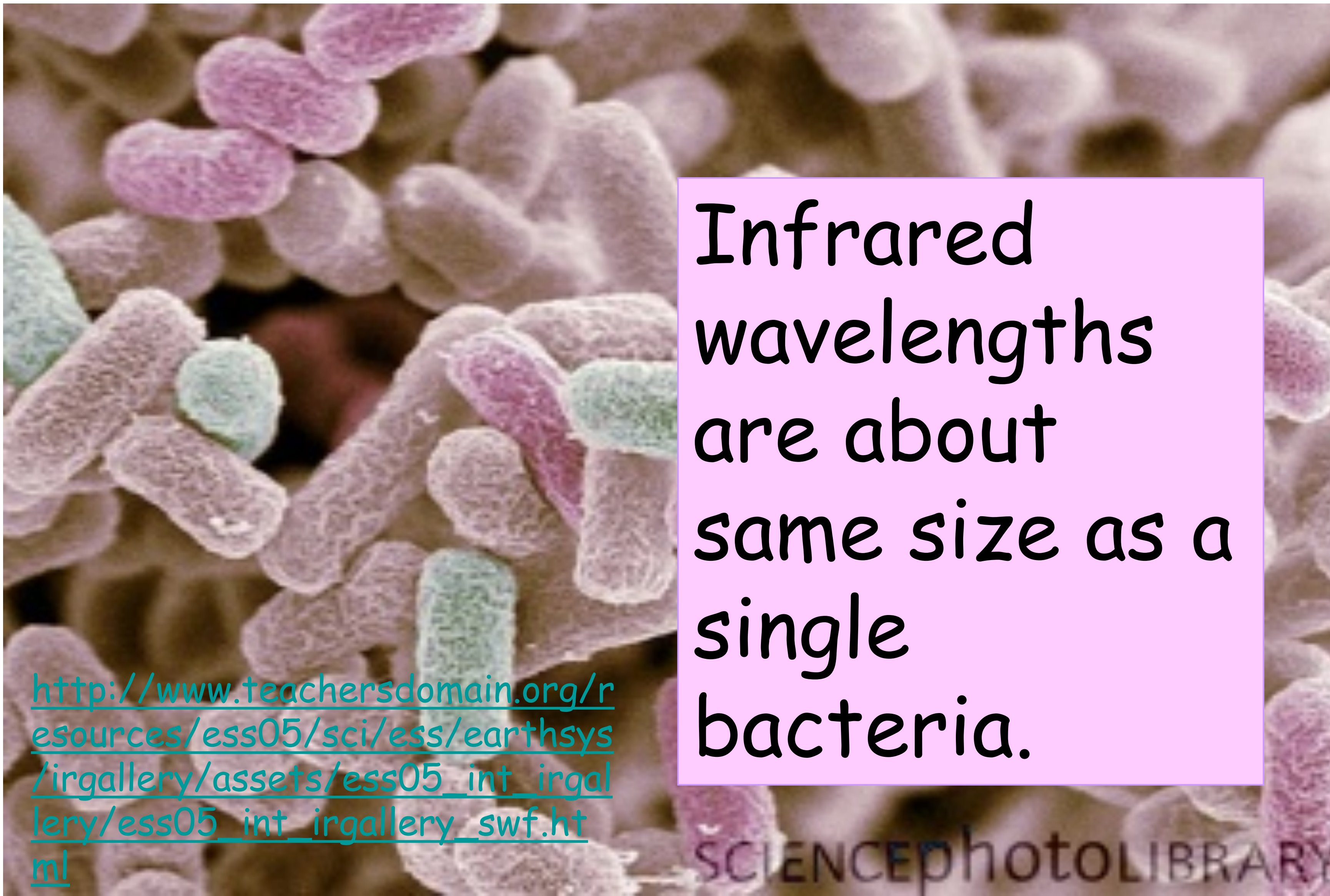


Basis of almost all space communications.

Infrared 0.1 cm to 0.00007 cm



Infrared 0.1 cm to 0.00007 cm



Infrared wavelengths are about same size as a single bacteria.

http://www.teachersdomain.org/resources/ess05/sci/ess/earthsys/irgallery/assets/ess05_int_irgallery/ess05_int_irgallery_swf.html

Visible Light

Visible light covers the range of wavelengths from 400 to 700 nm.

Our eyes are sensitive only to this small portion of the electromagnetic spectrum.

Visible Light

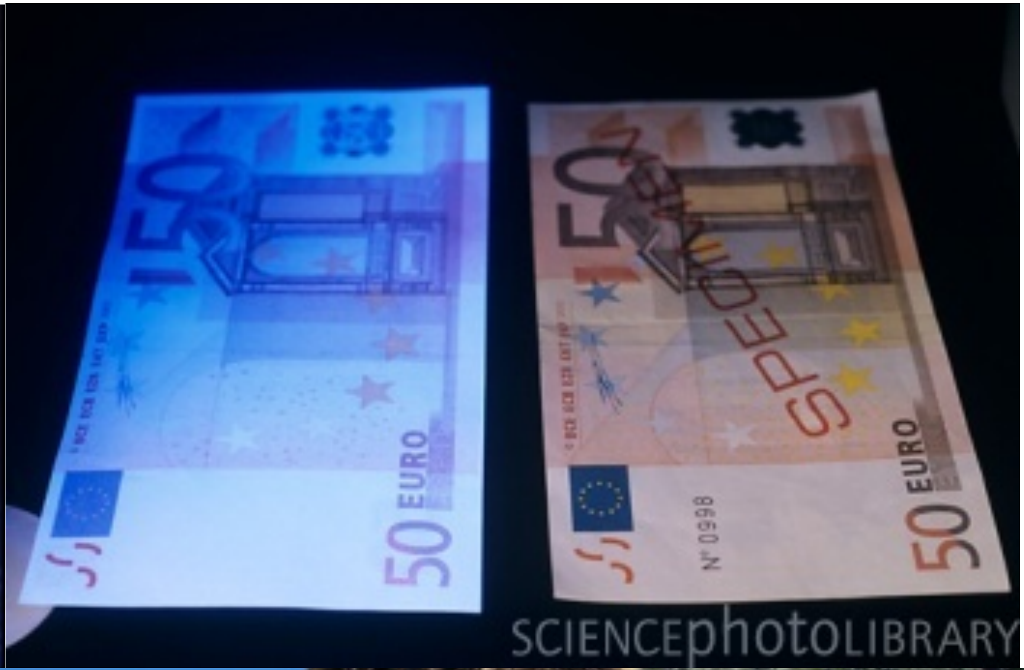
The Sun emits most of its radiation in the visible range, which our eyes perceive as the colours of the rainbow.

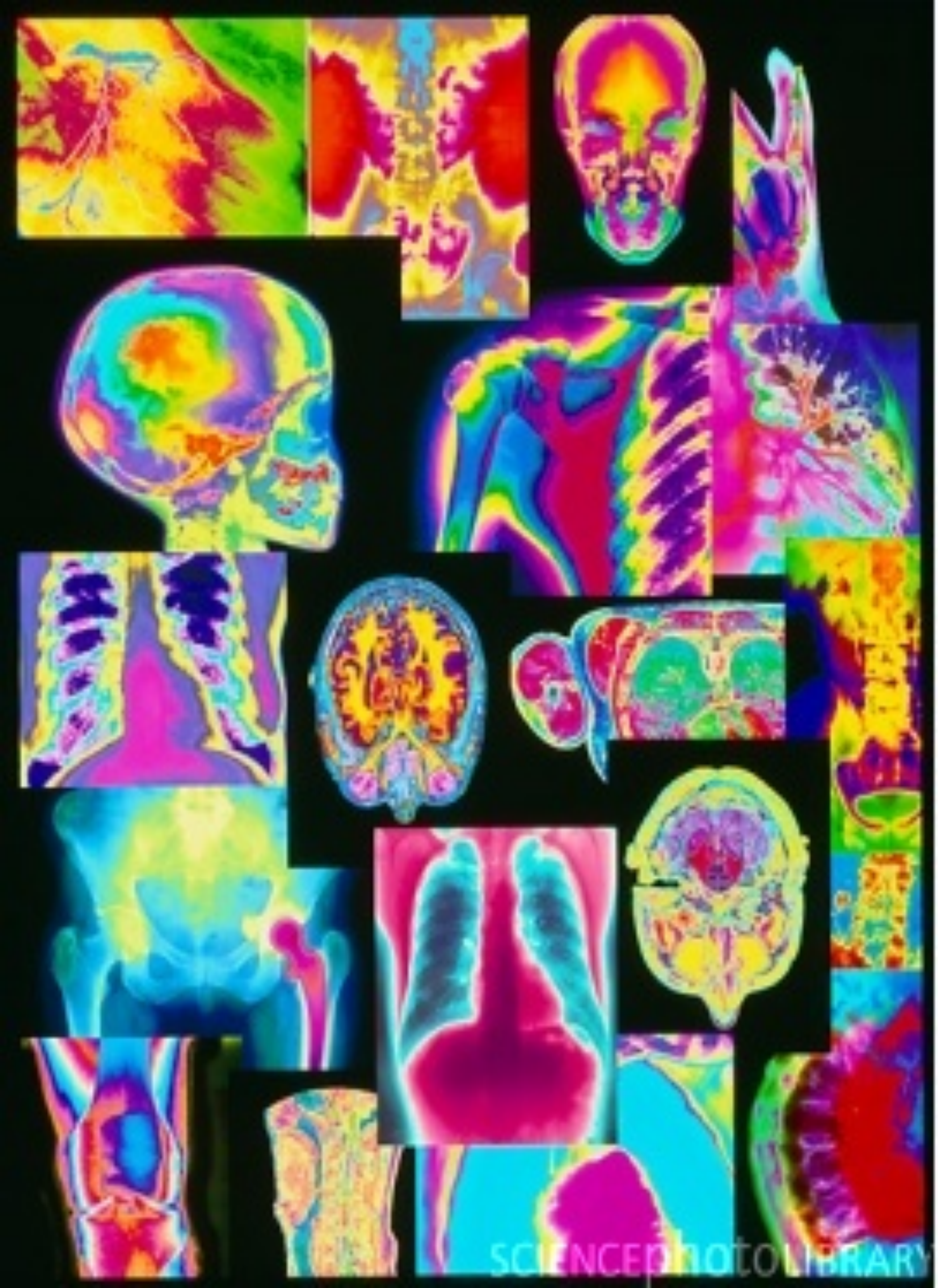
Ultraviolet

Ultraviolet radiation has wavelengths of 10 to 310 nm (about the size of a virus).

Young, hot stars produce a lot of ultraviolet light and bathe interstellar space with this energetic light.

Ultraviolet

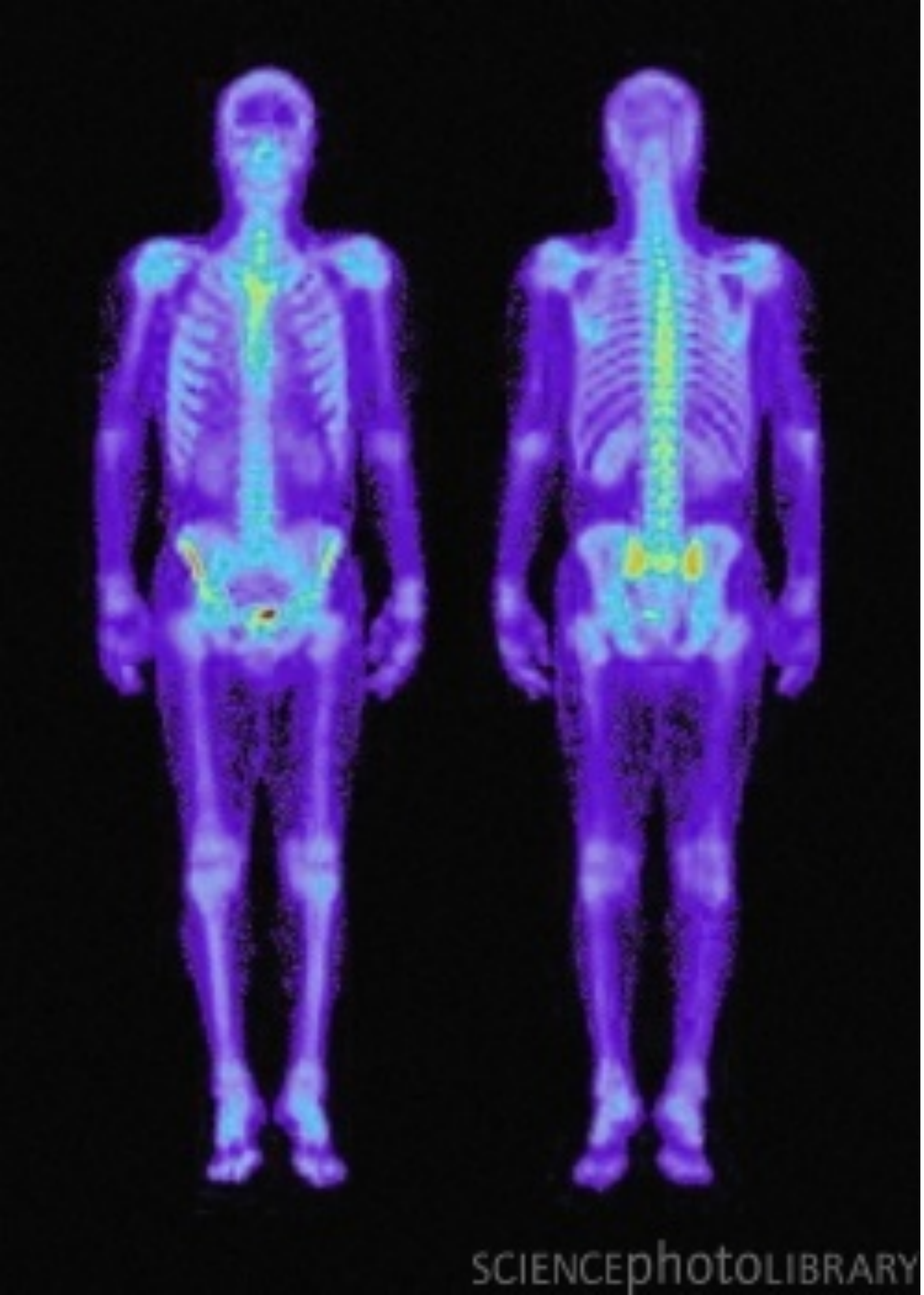




X-rays

X-rays range in wavelength from 0.01 to 10 nm (about the size of an atom).

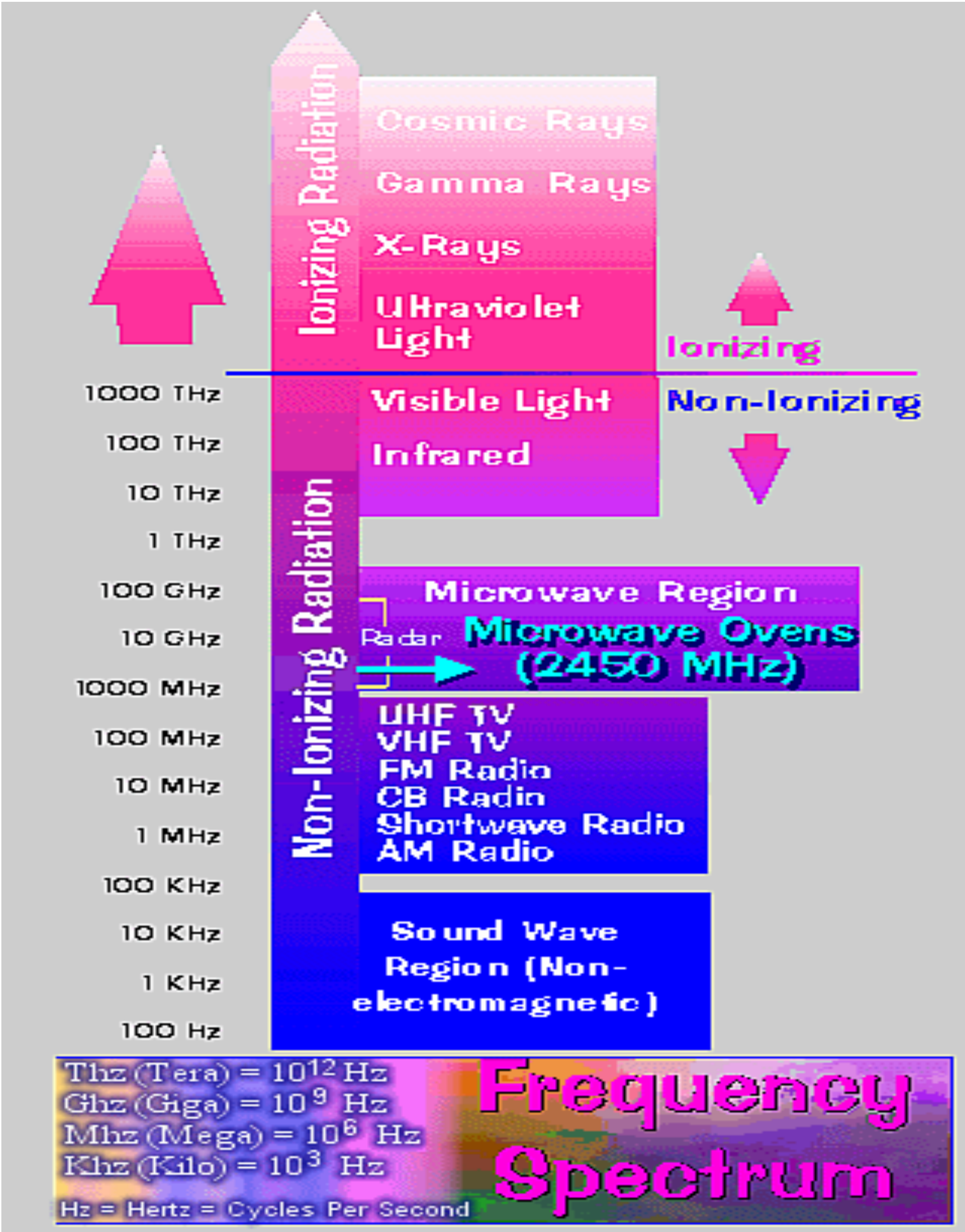
They are generated, for example, by super heated gas from exploding stars and quasars, where temperatures are near a million to ten million degrees.



Gamma rays

Gamma rays have the shortest wavelengths, of less than 0.01 nm (about the size of an atomic nucleus).

This is the highest frequency and most energetic region of the em spectrum.
Gamma rays can result from nuclear reactions taking place in objects such as pulsars, quasars, and black holes.


Ionizing Radiation
Cosmic Rays
Gamma Rays
X-Rays
Ultraviolet Light
Ionizing
Non-Ionizing
Visible Light
Infrared
1000 THz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1000 MHz
100 MHz
10 MHz
1 MHz
100 KHz
10 KHz
1 KHz
100 Hz
Non-Ionizing Radiation
Microwave Region
Radar
Microwave Ovens (2450 MHz)
UHF TV
VHF TV
FM Radio
CB Radio
Shortwave Radio
AM Radio
Sound Wave Region (Non-electromagnetic)
Thz (Tera) = 10^12 Hz
Ghz (Giga) = 10^9 Hz
Mhz (Mega) = 10^6 Hz
Khz (Kilo) = 10^3 Hz
Hz = Hertz = Cycles Per Second
Frequency Spectrum

Low frequency

Long wavelength

Rabbits
Mambo
In
Very
Unusual
eXpensive
Gardens

Radio
Microwaves
Infrared
Visible Light
UV
X-rays
Gamma Rays

High frequency

Short wavelength

All e-m waves travel at the speed of light!

Ultrasound

What is the normal range of human hearing?

What is ultrasound?

Ultrasound

What is the normal range of human hearing?

20 Hz – 20,000 Hz (20 kHz)

What is ultrasound?

Sound with frequency > 20,000 Hz

Imaging with Ultrasound

Medical ultrasound used for imaging a foetus is between 1 and 20 MHz (10000000 and 20000000 Hz!)

How is ultrasound used for imaging?

http://www.layyous.com/ultasound/ultrasound_video.htm

Imaging with Ultrasound

http://www.mayoclinic.com/health/ultrasound/MM00084

A handheld transducer is held on the stomach. This changes electrical energy to sound energy which is transmitted in waves into the body.

Imaging with Ultrasound

The waves are reflected off the boundaries between materials which have different sound properties (e.g. the amniotic fluid and the foetus). The transducer also acts as a receiver – detecting the echo and turning sound into an electrical signal.

Imaging with Ultrasound

By recording the time taken for the echo to be detected, and the intensities of the echoes, and using the speed of sound in tissue, a computer can build up a detailed image of the foetus.

Imaging with Ultrasound

The skin is covered in jelly during the ultrasound procedure. Why is this?

Imaging with Ultrasound

The skin is covered in jelly during the ultrasound procedure. Why is this?

Good contact is important. Otherwise the ultrasound waves will simply reflect off the outer skin and no image will be obtained. It makes movement of the transducer easier. It ensures a clearer picture is obtained.

Imaging with Ultrasound

Why is ultrasound used instead of X-rays?

Imaging with Ultrasound

Why is ultrasound used instead of X-rays?

Ultrasound causes no harmful effects to the foetus. It is low power so can be used safely to image the foetus.

Other Uses of Ultrasound

Doppler ultrasound is a newer technique which can be used to measure blood flow.

Ultrasound can also be used to break up kidney stones – faster and safer than surgical removal.

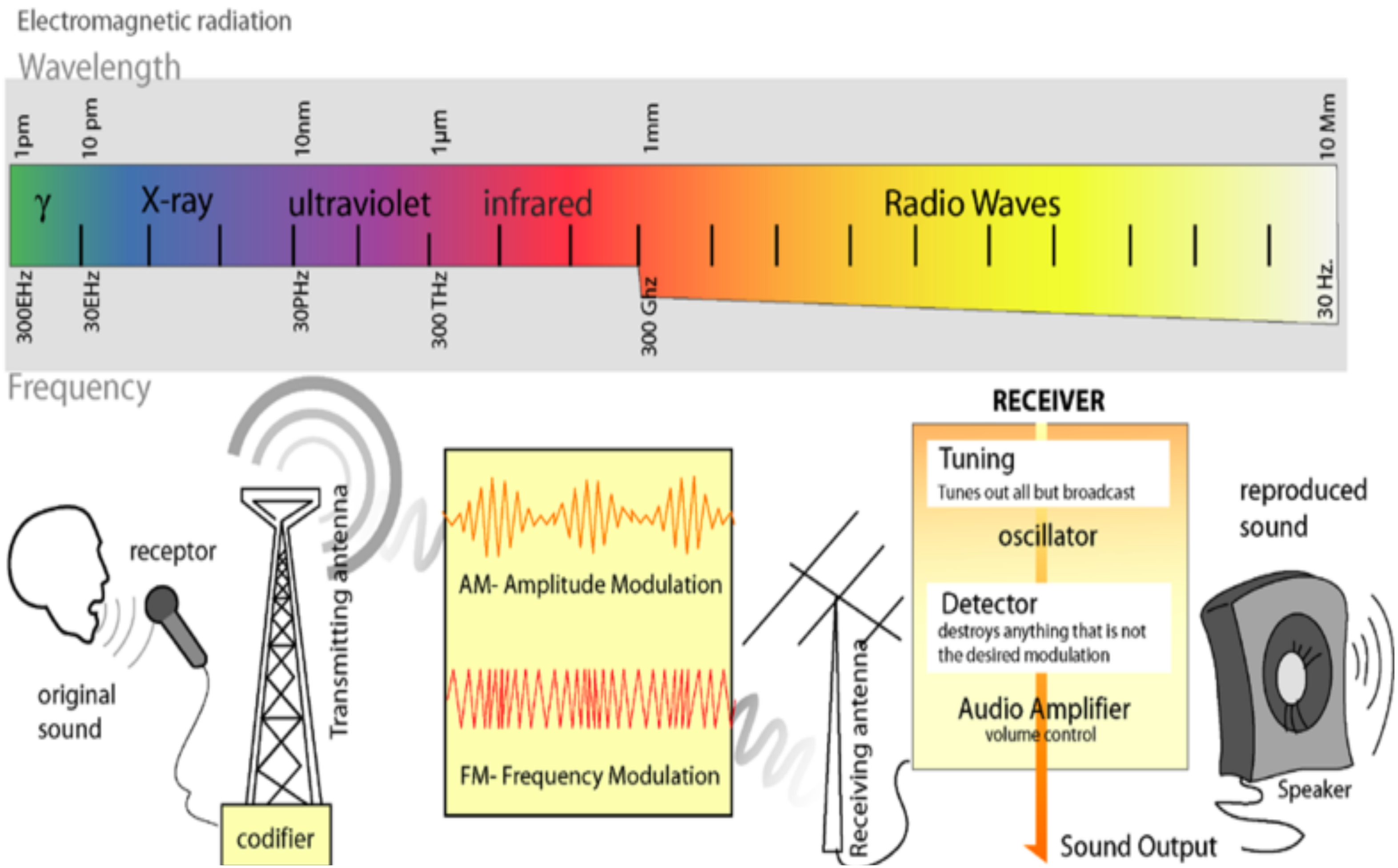
Using Sonar

SOund NAvigation and Ranging

Used for underwater ranging - first patented in 1913 - prompted by Titanic disaster.

Sonar Use

Radio Communication



What are radio (and TV) waves?

Radio Communication

What are radio (and TV) waves?

They are a type of electromagnetic radiation that travel through air at 3×10^8 m/s.

Note: TV waves are not a separate part of the electromagnetic spectrum, they are just higher frequency radio waves.

Each radio station broadcasts with a different frequency or wavelength - remember the speed is always the same.

The frequency of radio waves is much higher than the frequency of sound waves.

Key words: reflection, angle of incidence, angle of reflection, light rays

By the end of this lesson you will be able to:

State that light can be reflected.

Use the terms angle of incidence, angle of reflection and normal when a ray of light is reflected from a plane mirror.

State the principle of reversibility of a ray path.

Reflection of Light

Watch the demonstration with the laser optics kit.

What is meant by the normal?

What is meant by the angle of incidence?

What is meant by the angle of reflection?

What do you notice about the angles of incidence and reflection? How do they compare?

Virtual Int 2 Physics -> Waves & Optics -> Reflection -> Reflection from a Plane Mirror

The normal, angle of incidence and angle of reflection

Complete the sentences:

The normal is

The angle of incidence is

The angle of reflection is

The normal, angle of incidence and angle of reflection

The normal is **an imaginary line drawn perpendicular to the reflecting surface**

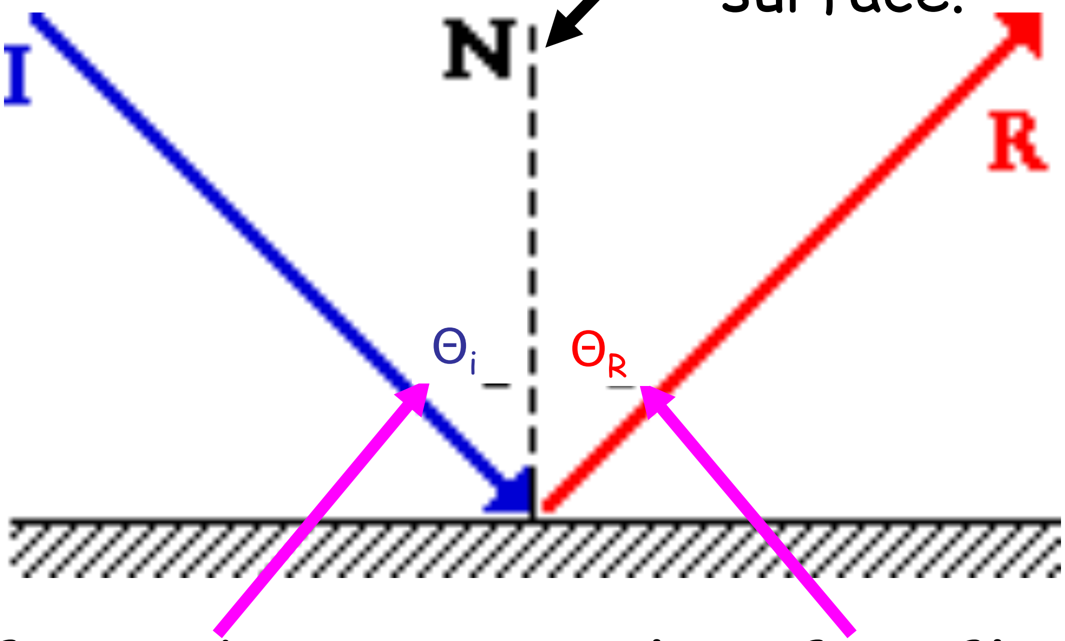
The angle of incidence is **the angle between the incident ray and the normal**

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

Reflection of Light

Law of Reflection

The normal is at a right angle (90°) to the surface.



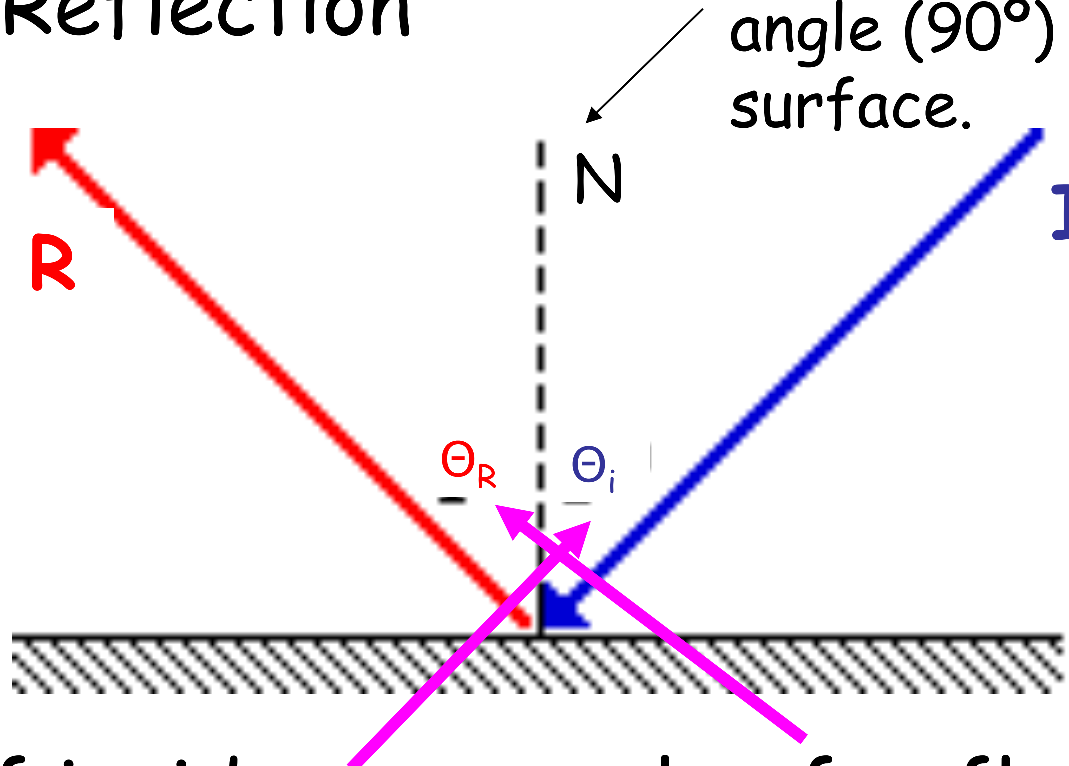
angle of incidence = angle of reflection

Flash animation - reflection

Reversibility of Rays

Law of Reflection

The normal is at a right angle (90°) to the surface.



angle of incidence = angle of reflection

Flash animation - reflection

Key words: refraction, incidence, normal

By the end of this lesson you will be able to:

State what is meant by the refraction of light.

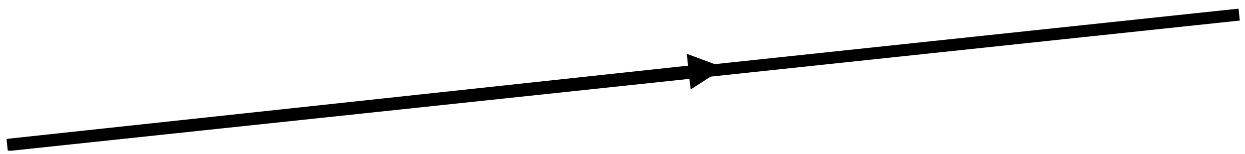
Use the terms angle of incidence, angle of refraction and normal.

Draw diagrams to show the change of direction as light passes from air to glass and glass to air.

Rays of Light

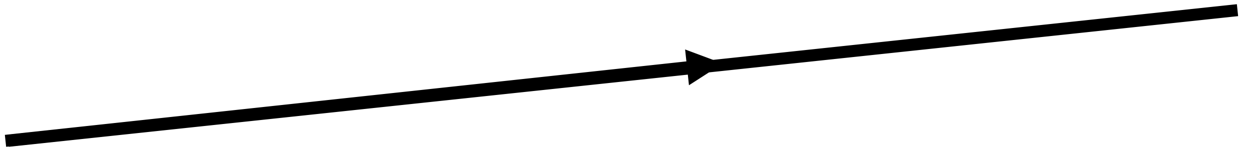
In any material (air, glass, water) light will travel in a straight line.

We represent light using ray diagrams.



Drawing Light Rays

We represent light using ray diagrams.



What two things must you remember when drawing light rays?

Drawing Light Rays

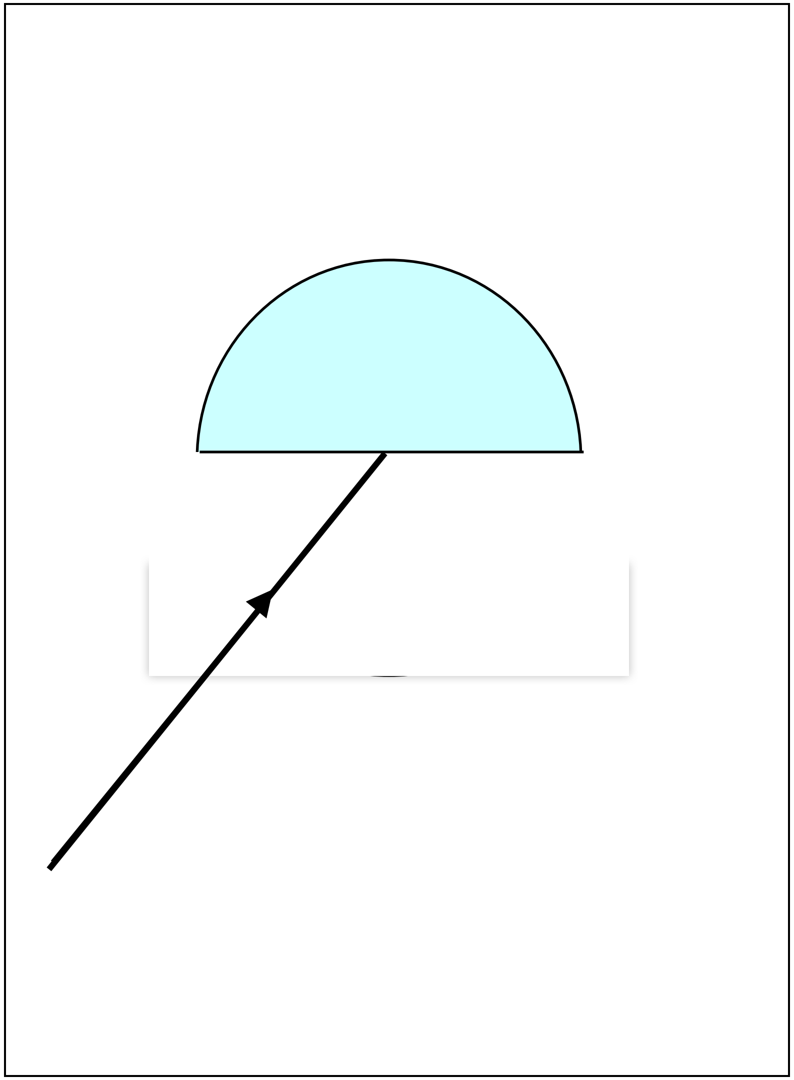
What two things must you remember when drawing light rays?

1. Use a ruler so the ray is a straight line
2. Include an arrow to show the direction of travel

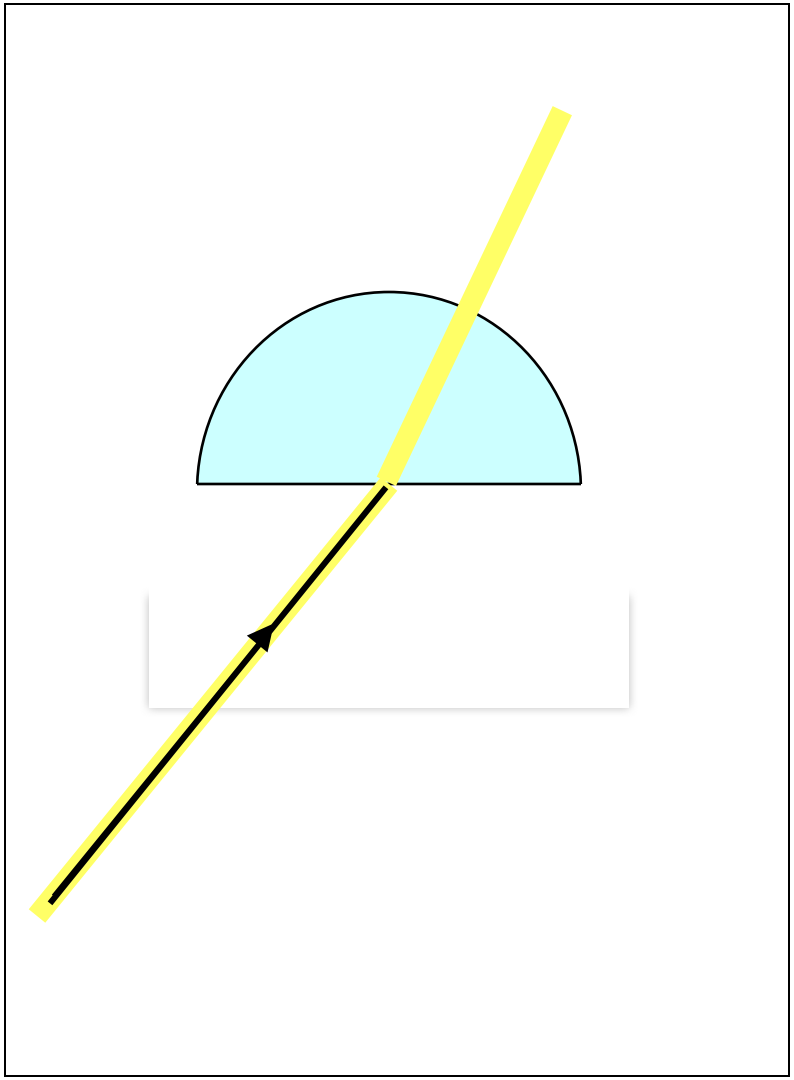
Refraction of Light

When light passes from one material to another it changes speed. This change in speed can cause it to change direction. We call this refraction.

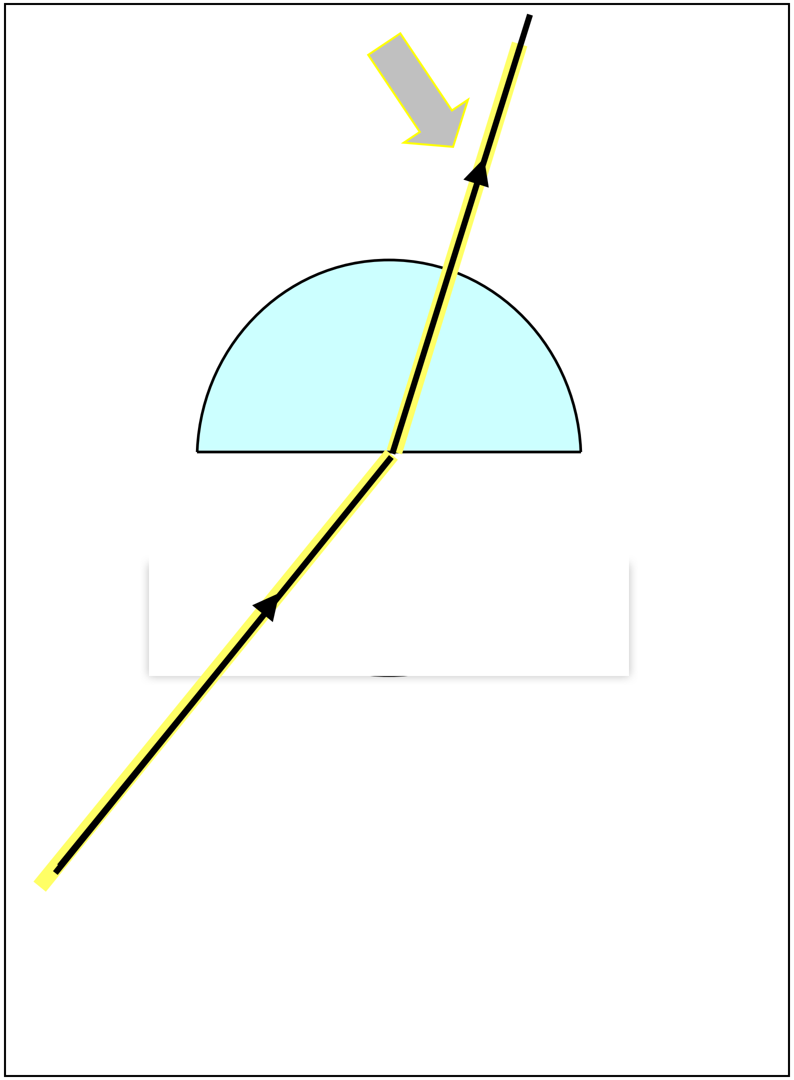
Place the block on the outline provided



Shine the light ray along the line

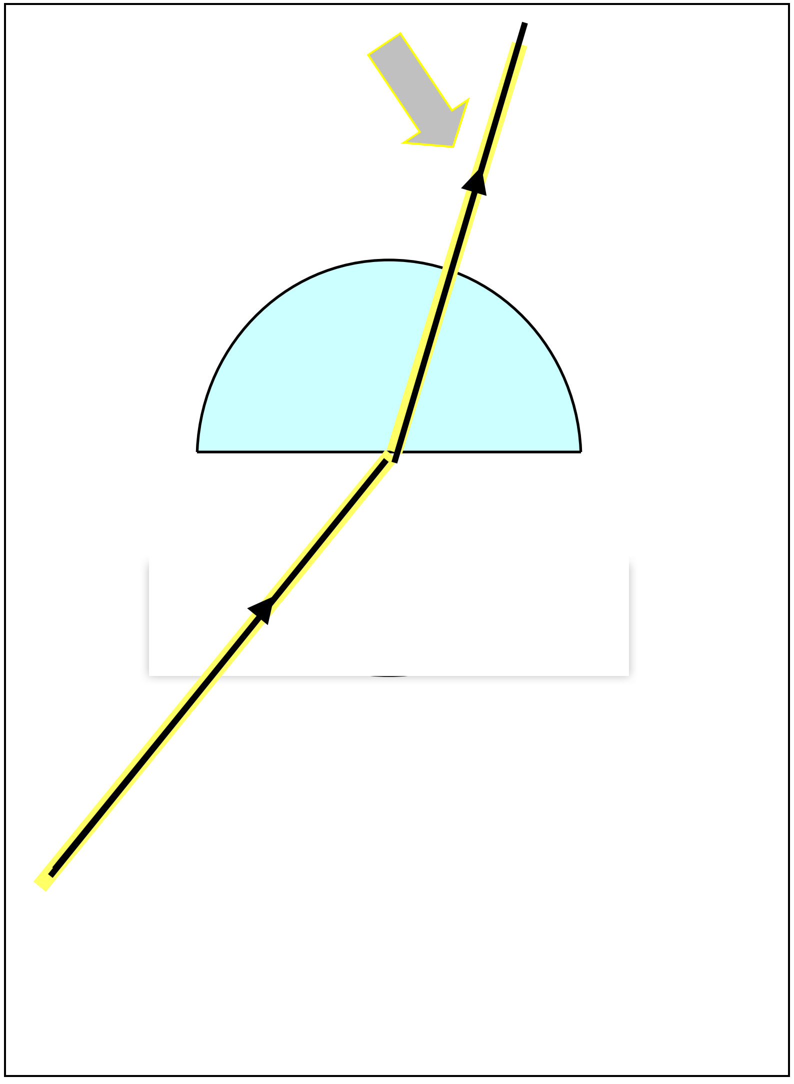


Accurately mark the path of the refracted ray

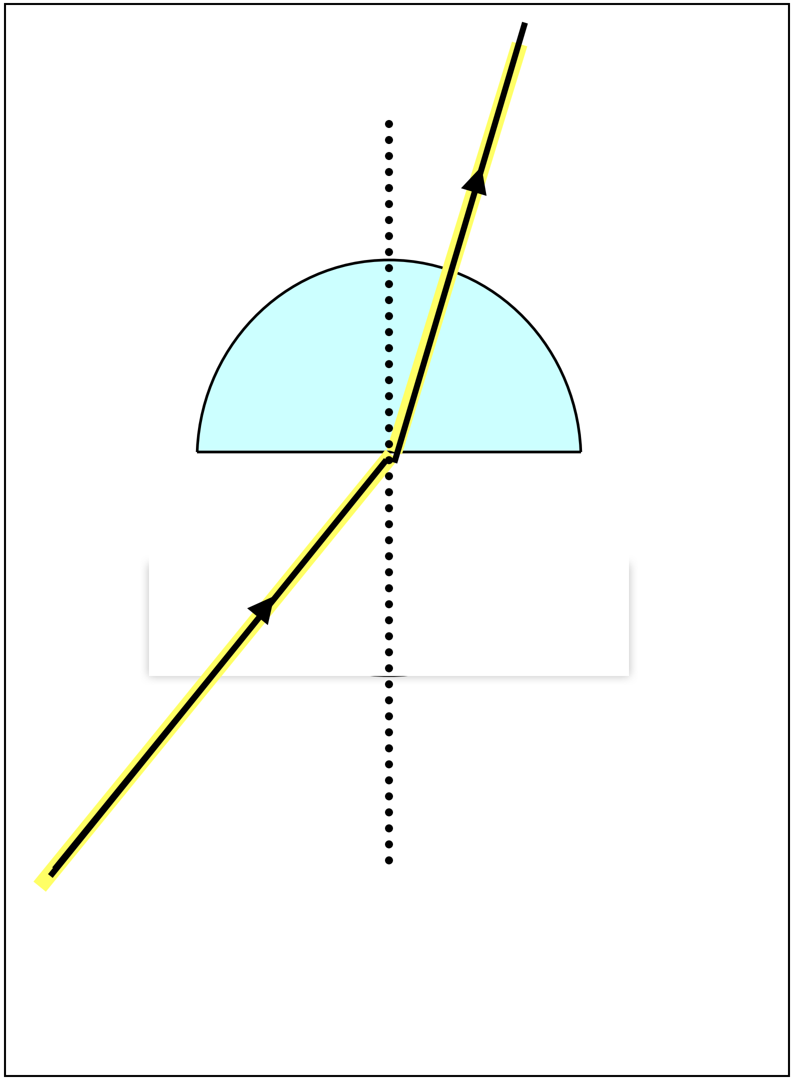


Then switch off the light source and remove the block

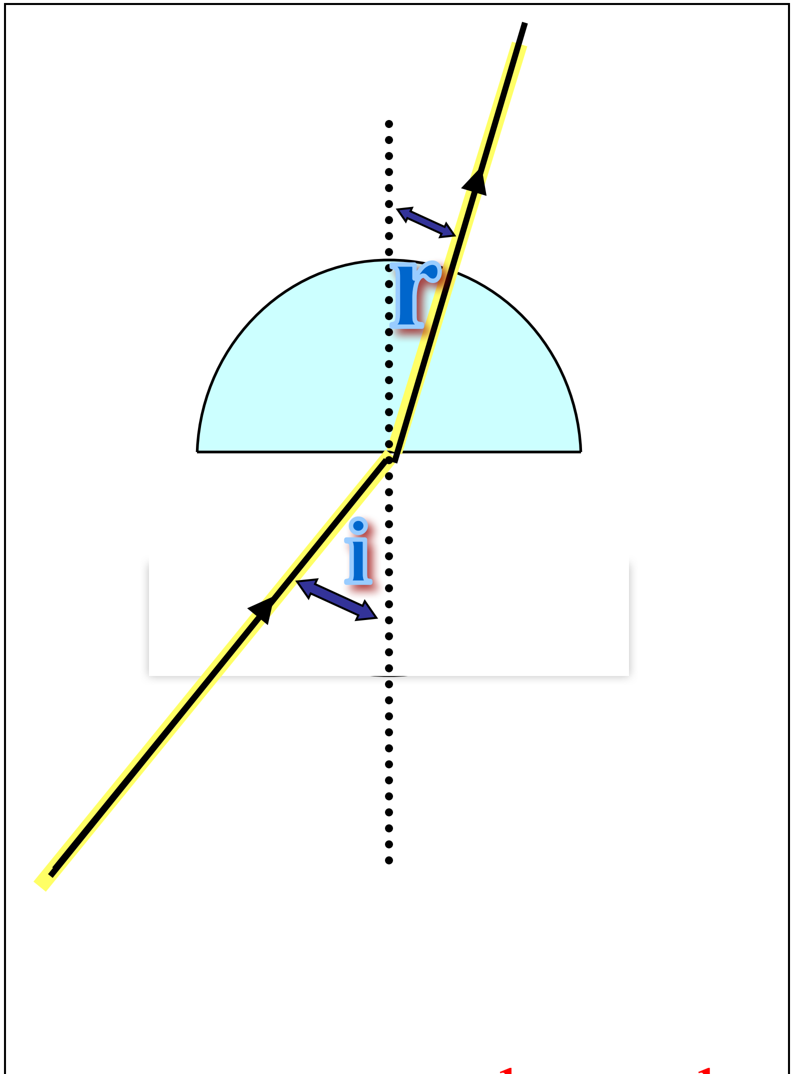
Remove the block and draw in the refracted ray



Carefully draw in the normal

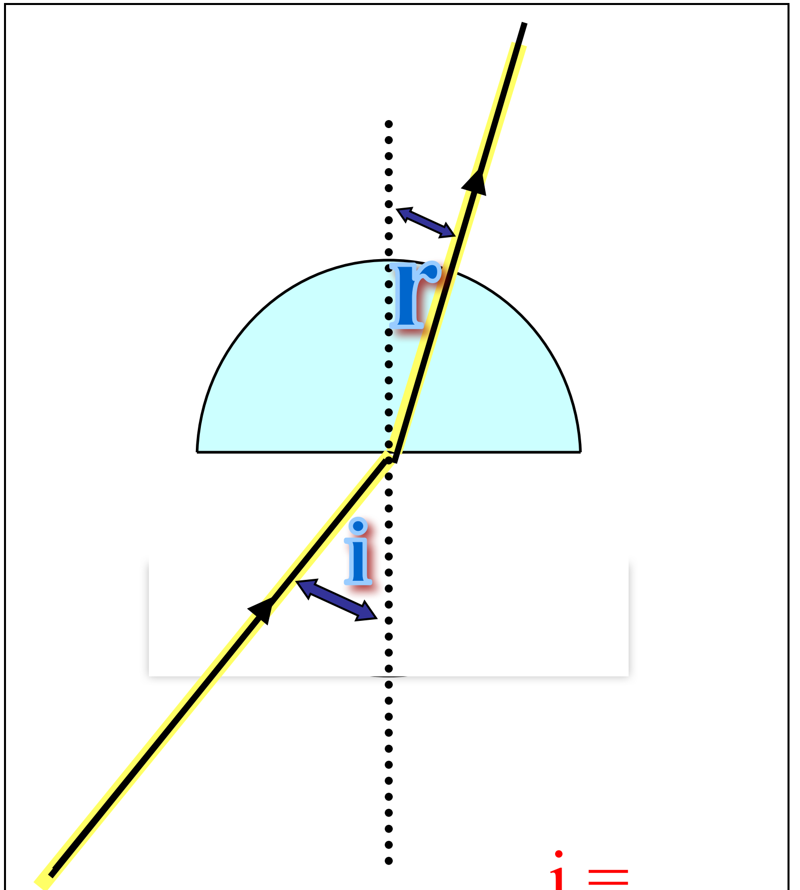


Mark the angles of incidence (i) and refraction (r)



Use a protractor to measure the angles of incidence (i) and refraction (r)

Record your results in the space provided



i = ______

r = ______

Use a protractor to measure the angles of incidence (i) and refraction (r)

Think!

What happens when the ray of light shines into the block along the normal? Is refraction taking place?

What is meant by the angle of incidence?

Think!

What is meant by the angle of refraction?

What happens when the angle of incidence is greater than 0^o?

Refraction: Air to Glass

What happens when the ray of light enters the block along the normal?

There is no change in direction of the light i.e. it goes straight through. The light is refracted – it changes speed.

What do we mean by angle of incidence?

The angle of incidence is the angle between the incoming ray and the normal.

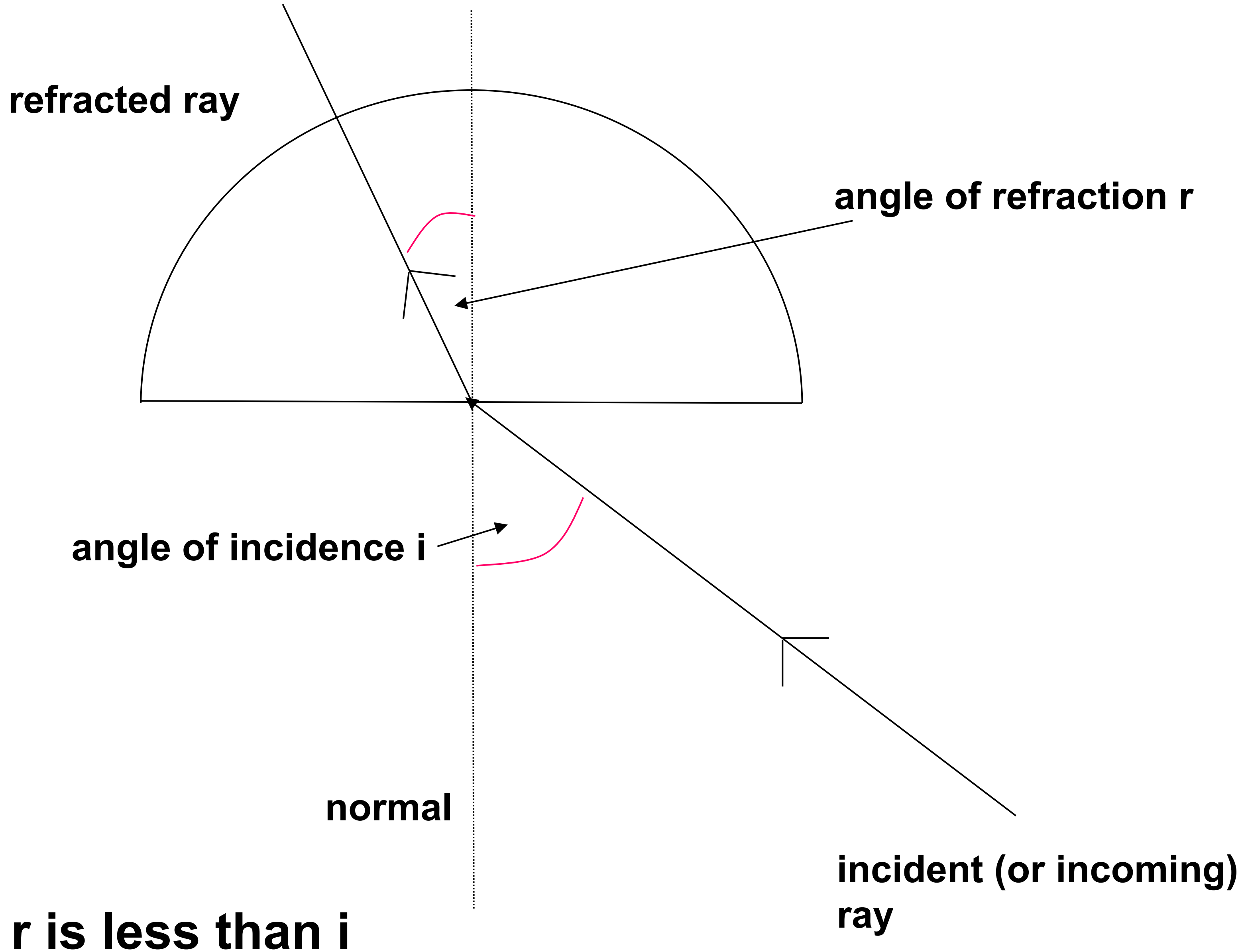
Refraction: Air to Glass

What do we mean by the angle of refraction?

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

What happens when the angle of incidence is greater than 0^o?

When the angle of incidence is greater than 0^o the light changes direction due to refraction.



r is less than i

Refraction

Light travels in a straight line.

When light travels from one material (e.g. air) to another (e.g. glass) it changes speed. This is called **refraction.**

This change in speed sometimes causes it to change direction.

Refraction is the **change in speed of light as it passes from one medium to another.**

Refraction of Light - Glass to Air

Watch the demonstration with the laser optics kit.

What is meant by the normal?

What is meant by the angle of incidence?

What is meant by the angle of refraction?

What do you notice about the angles of incidence and refraction? How do they compare?

Virtual Int 2 Physics -> Waves & Optics -> Refraction through blocks and prisms

Activity - Glass to Air

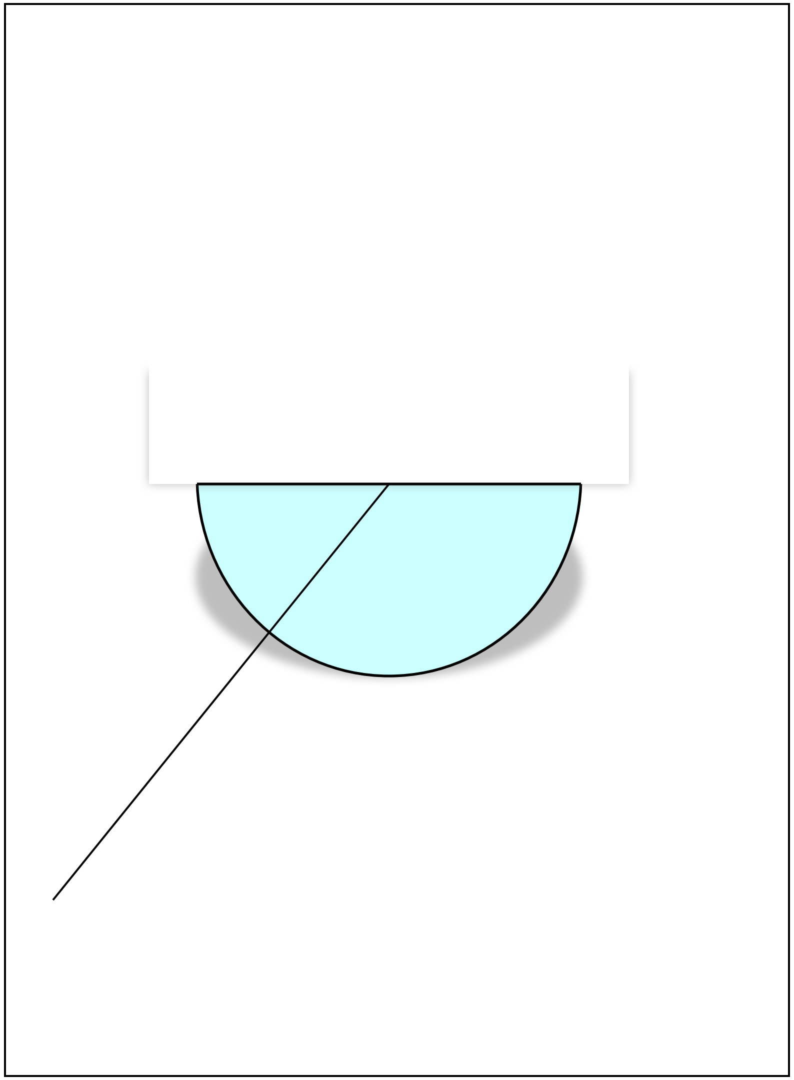
By the end of this practical session you will know:

how to draw a normal

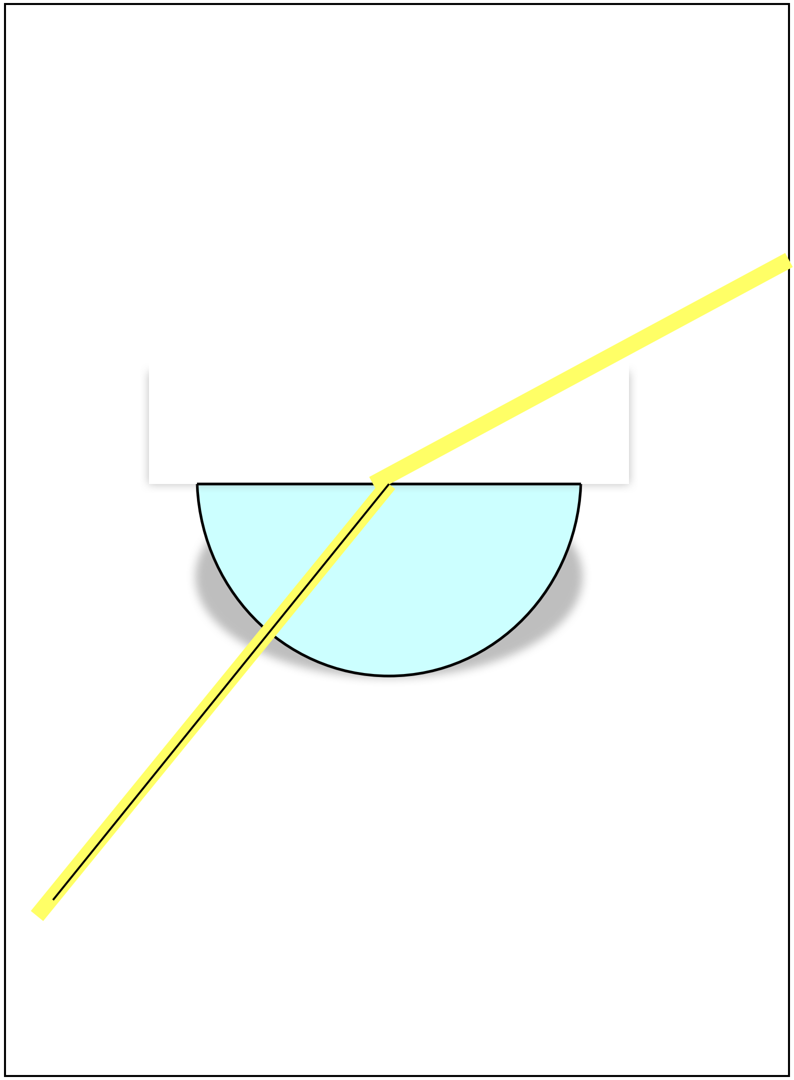
how to **identify**, and measure, angles of incidence and refraction as light passes from air to glass.

what is meant by refraction.

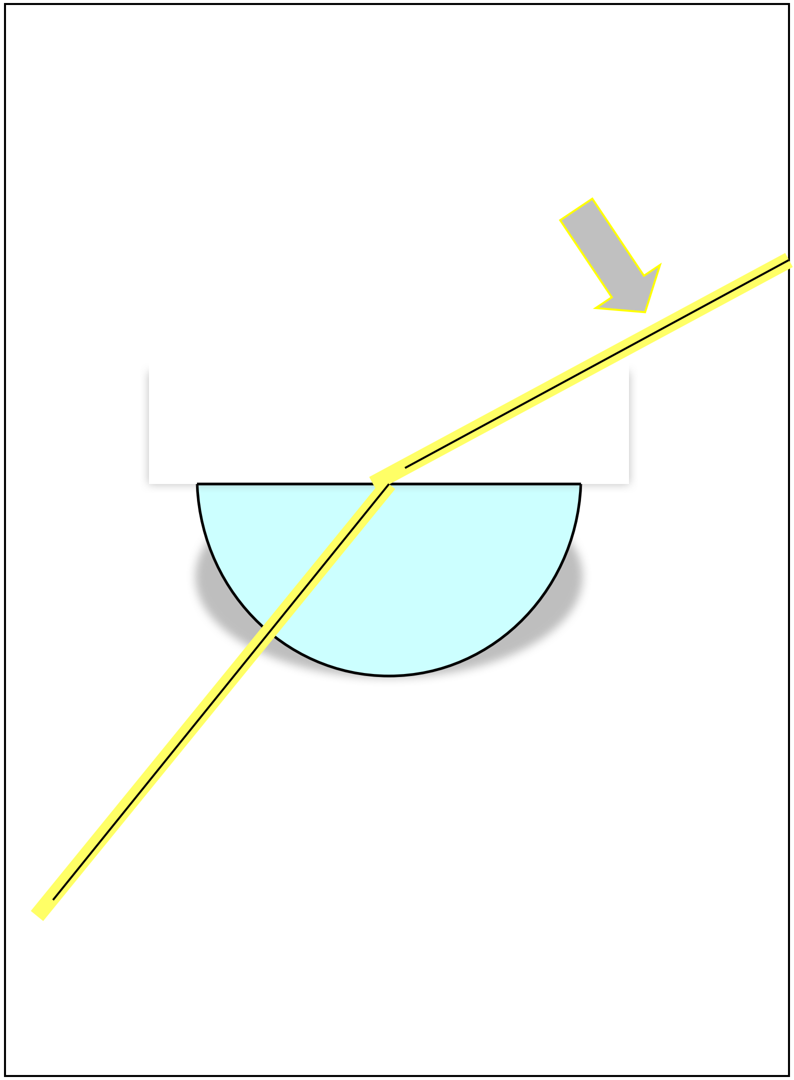
Place the block on the outline provided



Shine the light ray along the line

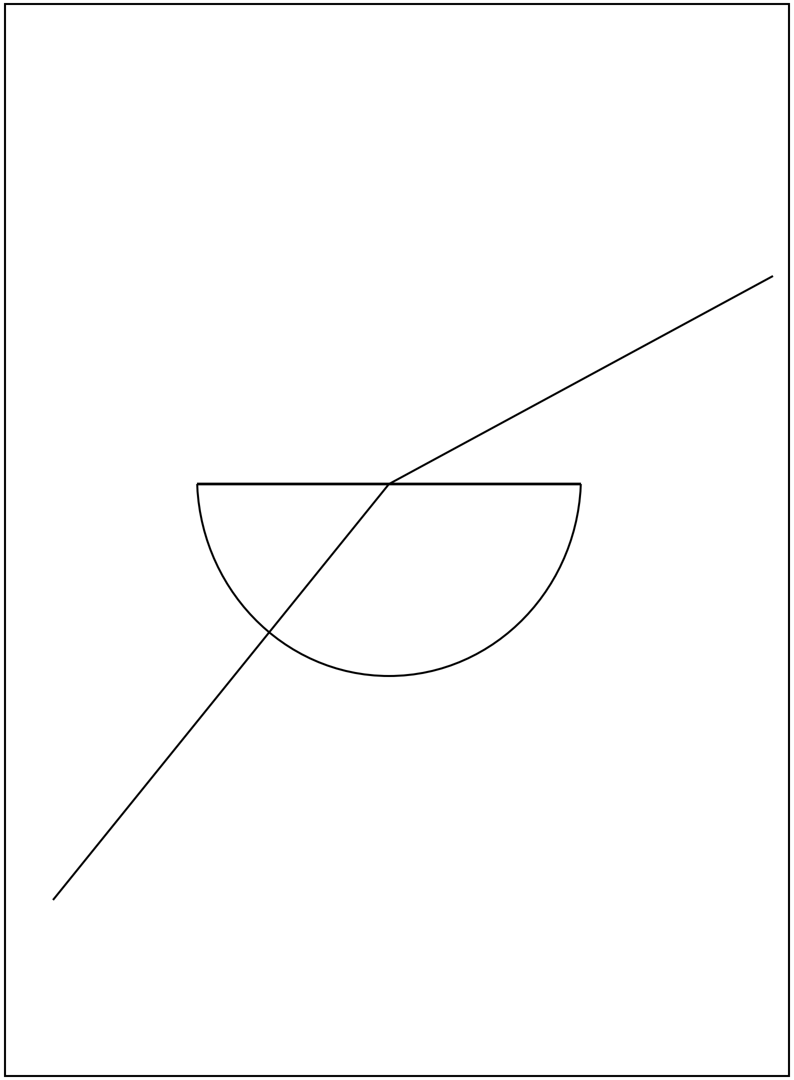


Accurately draw in the path of the refracted ray



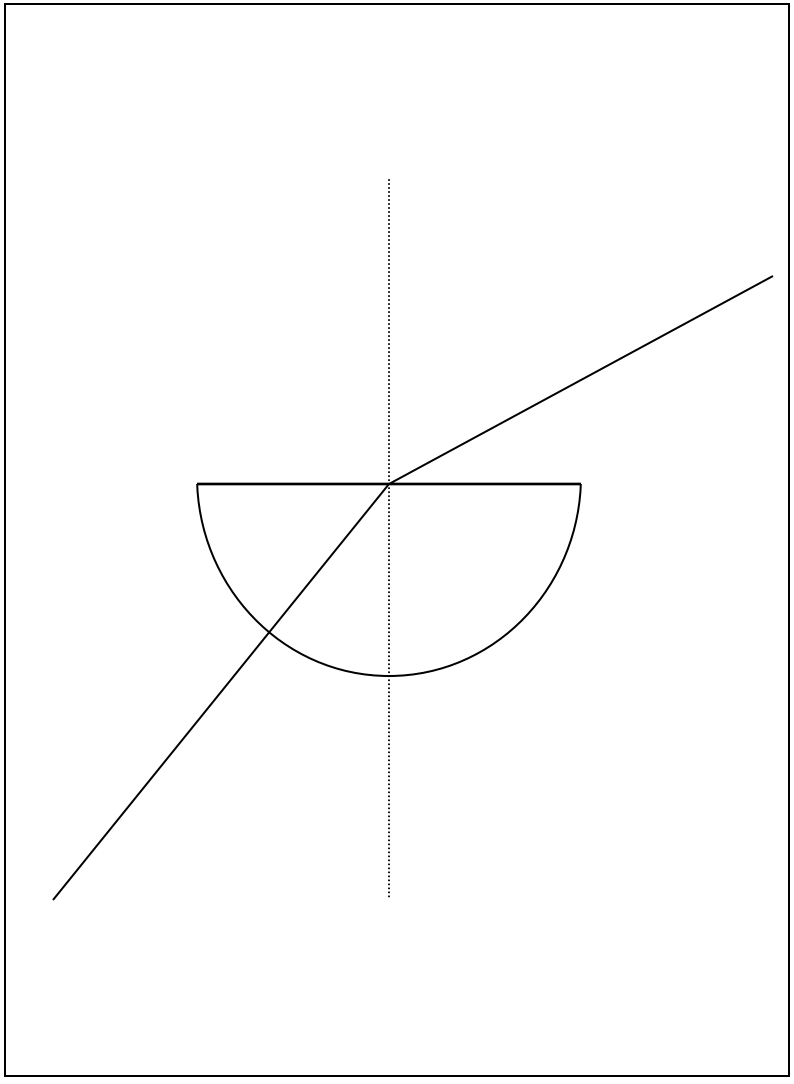
Then switch off the light source and remove the block

Accurately draw in the path of the refracted ray

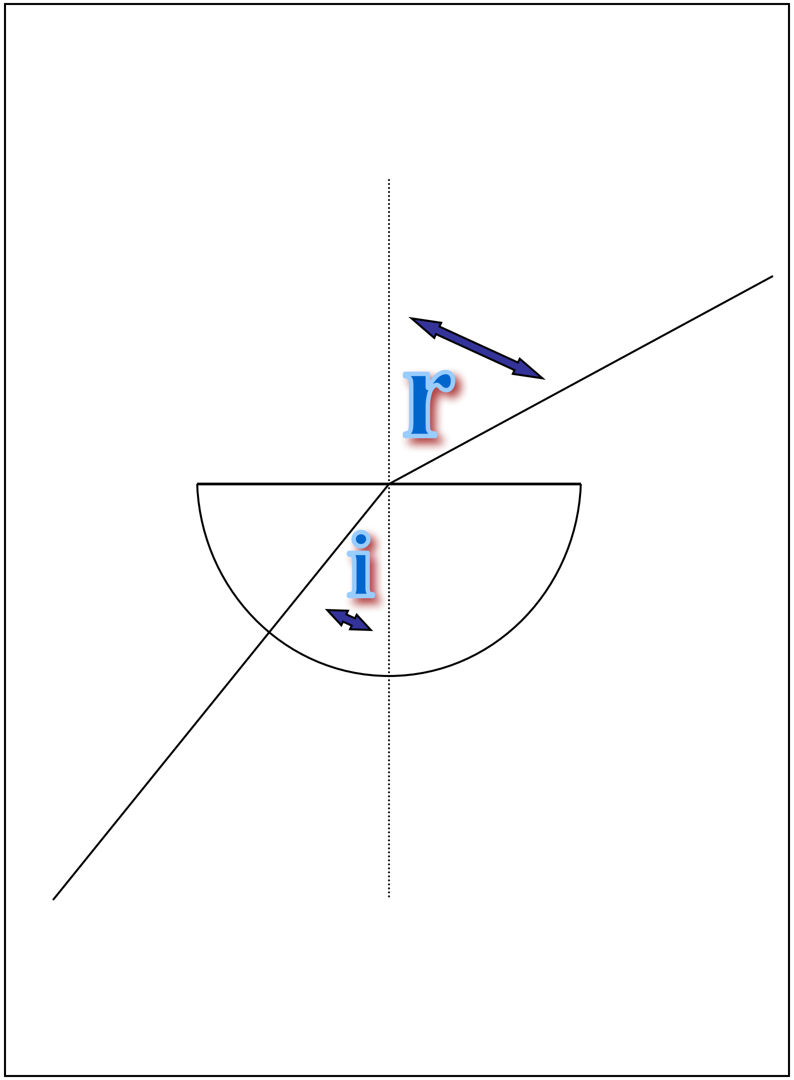


Then switch off the light source and remove the block

Carefully draw in the normal

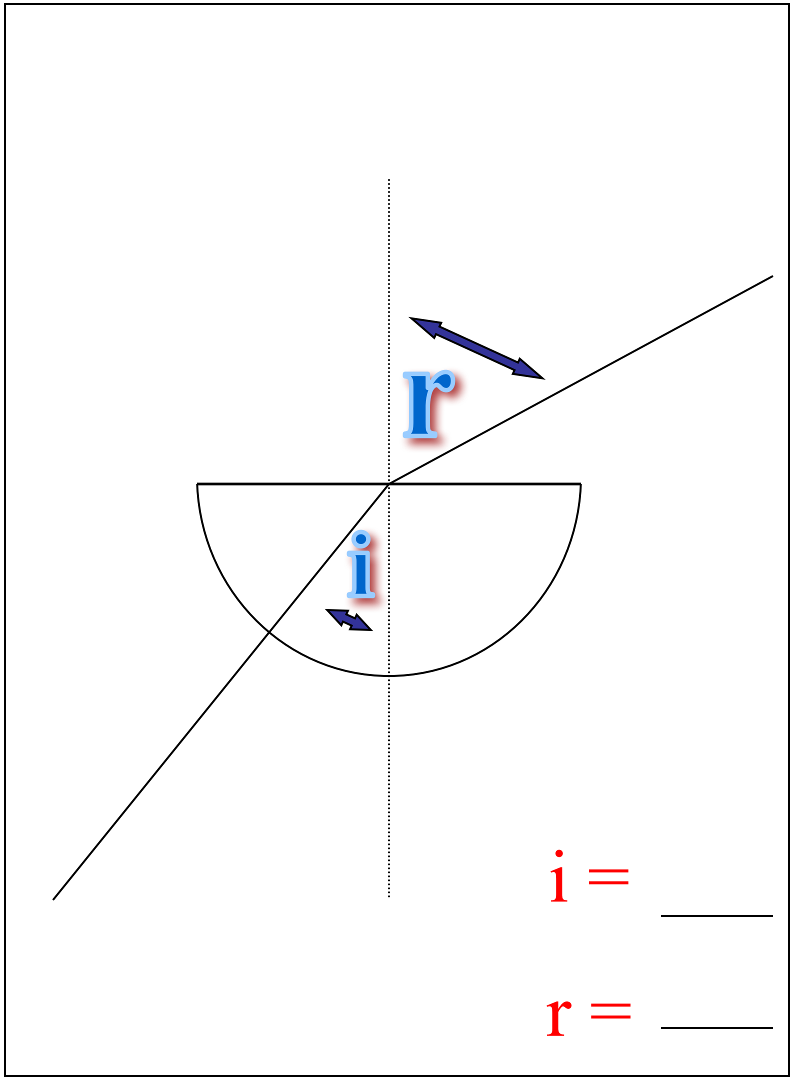


Measure the ANGLE OF INCIDENCE, i

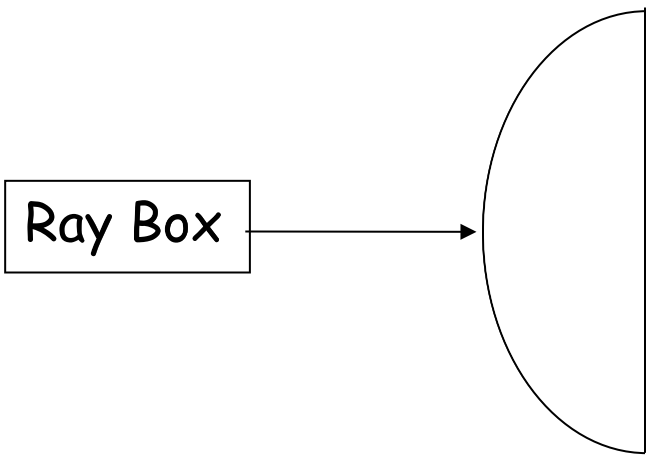


Measure the ANGLE OF REFRACTION, r

Record your results in the space provided



Refraction – Glass to Air



Angle of Incidence (i)	Angle of Refraction (r)
0° (along the normal)	
15°	
35°	
42°	
75°	

Think!

What happens when the ray of light shines into the block along the normal? Is refraction taking place?

What is meant by the angle of incidence?

Think!

What is meant by the angle of refraction?

What happens when the angle of incidence is greater than 0^o? What do you notice as you increase the angle of incidence?

Refraction - Glass to Air

What happens when the ray of light enters the block along the normal?

There is no change in direction of the light i.e. it goes straight through.

What do you notice as you increase the angle of incidence?

The angle of refraction increases. Some reflection can also be seen.

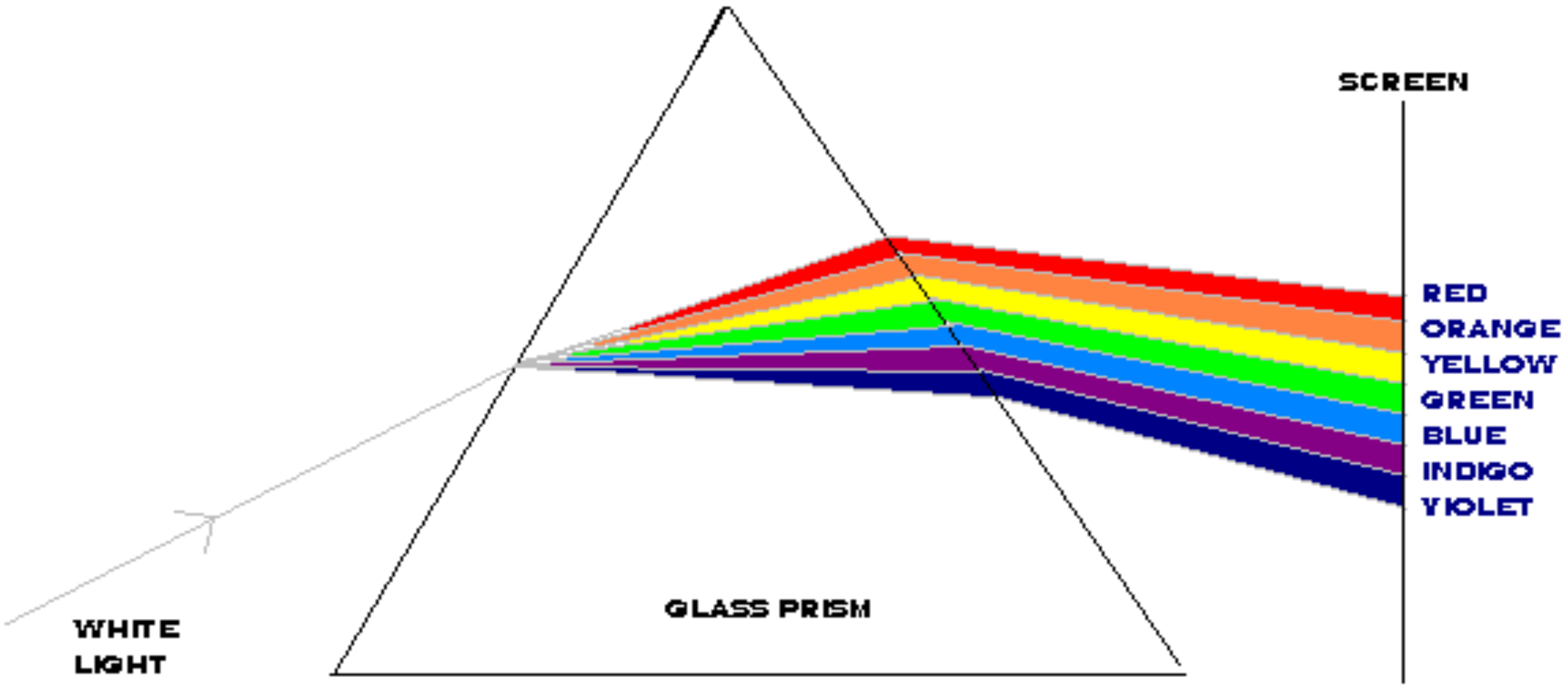
Refraction – Glass to Air

What is the relationship between the angle of incidence and the angle of refraction?

The angle of refraction is always larger than the angle of incidence.

What happens when the angle of incidence is 42° or above?

Total internal reflection occurs and no light escapes.



DISPERSION OF WHITE LIGHT BY A PRISM

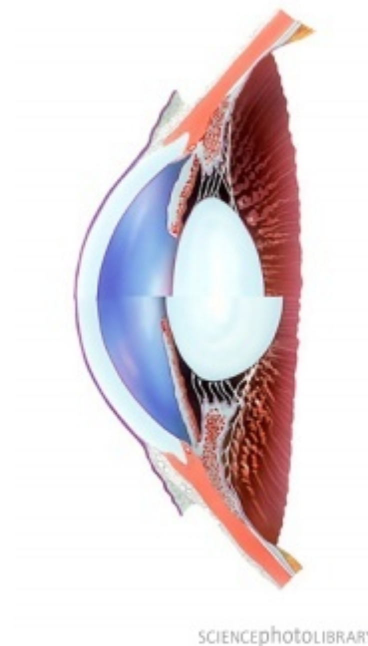
Blue light refracts more than red light

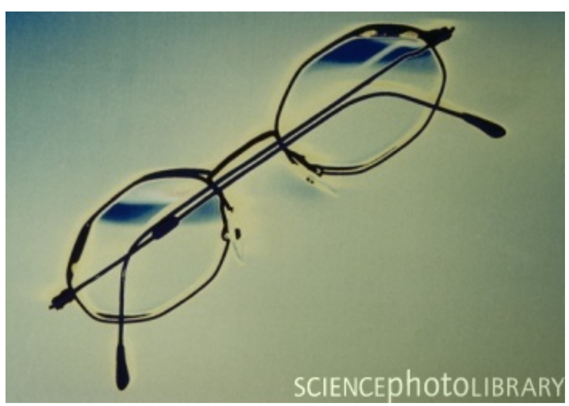
Why do we need to know about refraction?

Refraction explains:

how the eye focuses light;

sight defects such as long and short sight and how to correct them using contact lenses or glasses.





All lenses refract light. Lenses are used in cameras, telescopes and binoculars.

Total Internal Reflection and the Amazing Disappearing Coin

Key words: total internal reflection, critical angle, optical fibres

By the end of this lesson you will be able to:

Explain, with the aid of a diagram, what is meant by total internal reflection.

Explain, with the aid of a diagram, what is meant by the “critical angle”.

Describe the principle of an optical fibre transmission system.

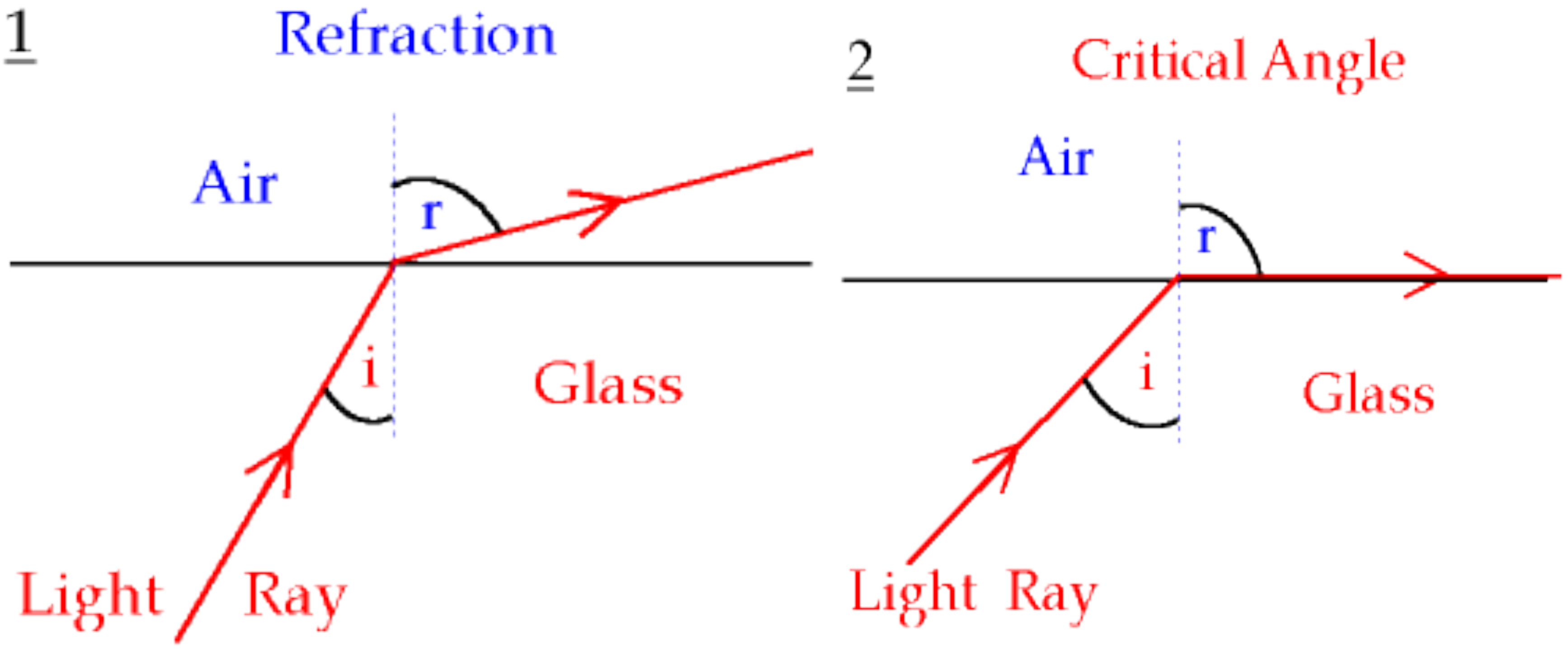
Critical Angle

We've seen that as light passes from glass to air, it changes direction away from the normal.

When light passes from glass to air there is an angle beyond which light cannot escape from the glass.

This is called the **critical angle.**

What happens at the critical angle?



What happens at the critical angle?

At the critical angle, the angle of refraction is 90°. Beyond the critical angle, Total Internal Reflection (TIR) occurs.

When TIR occurs the angle of incidence = angle of reflection.

Total internal reflection is used in fibre optics which are used in:

- medicine ;
- cable television ;
- internet ;
- telephone access.

Optical Fibres

Optical fibres are about the thickness of a human hair.

Each fibre is a thin piece of glass, coated with a thin layer (or cladding) of another glass.

Using Optical Fibres in Communication Systems

Optical fibre – sound transmitter and receiver.

What are the steps needed to use optical fibres in a communication system?

For example in a telephone system?

Transmission

The sound signal must be changed into an electrical signal. The signal is a series of electrical pulses.

What input device is used to convert sound to an electrical signal?

The electrical signal is converted into pulses of light which are transmitted through the optical fibre via total internal reflection.

Receiving

The light signal is changed back into an electrical signal using a photodiode.

The electrical signal is converted into sound. What output device is used to convert an electrical signal to sound?

What are the advantages of using optical fibres in communications?

The signal that passes along the fibre is not electrical so less likely to suffer from interference.

Cheaper to make than copper.

Can carry far more information than copper wires. (One optical fibre cable could take all the telephone calls being made in the world at any time!)

There is less loss of signal – so not as many amplifiers required.

Disadvantage – can be more difficult to join fibres than copper wires.

Key words: curved reflectors, received signals, transmitted signals

By the end of this lesson you will be able to:

Explain the action of curved reflectors on certain received signals.

Explain the action of curved reflectors on certain transmitted signals.

Describe an application of curved reflectors used in telecommunication.

Curved Reflectors

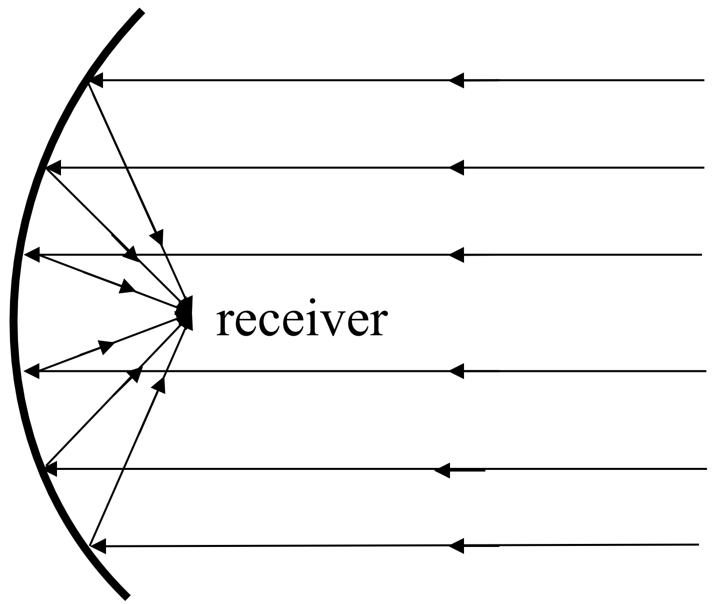
Watch the demonstration.

What do you notice about the light when a curved reflector is used? Where do we make use of curved reflectors?

Dish Aerials

A dish aerial can be used either to receive or to transmit a radio (or microwave) signal.

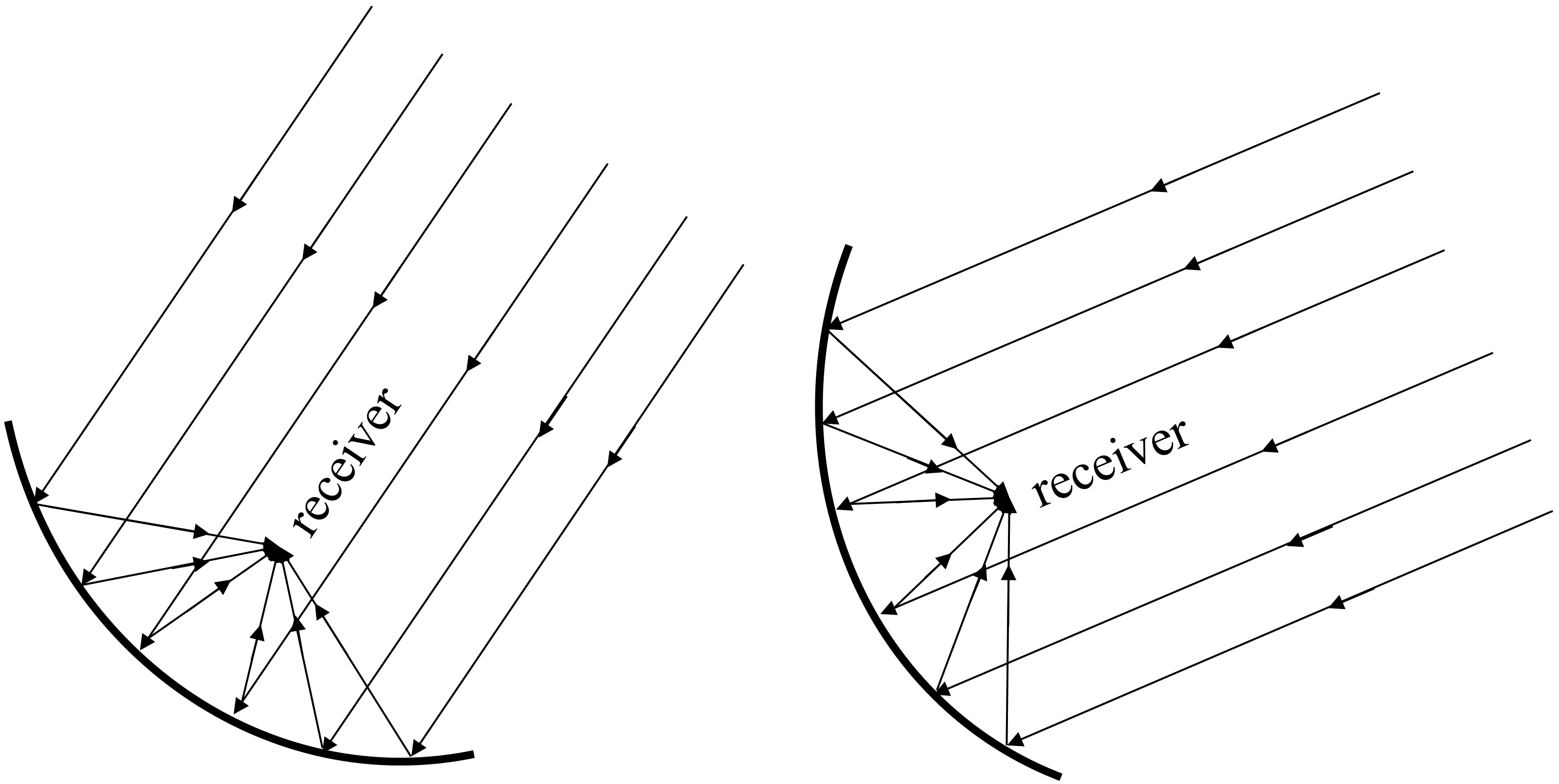
Virtual Int 1 Physics -> Telecommunications -> Satellites -> Curved reflectors



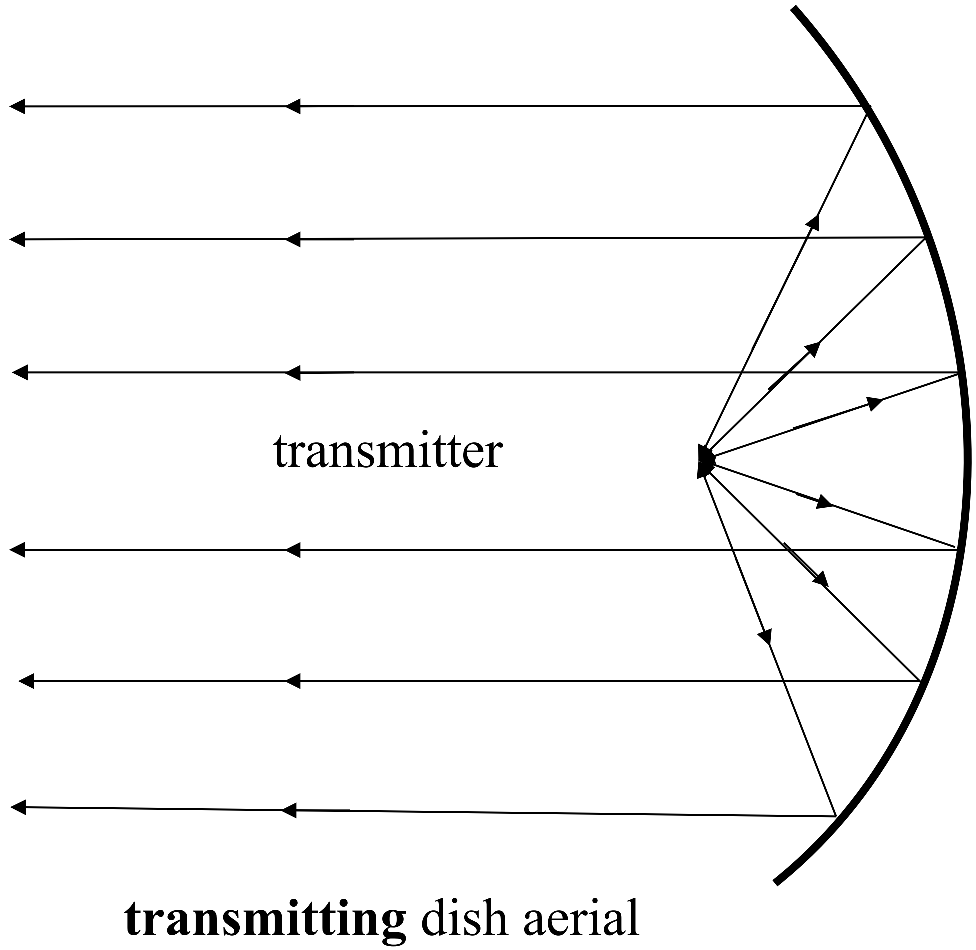
receiving dish aerial

The receiving dish aerial gathers in parallel rays from a distant object and reflects the rays to one point called the focus. The receiving aerial is placed at the focus to receive the strongest signal.

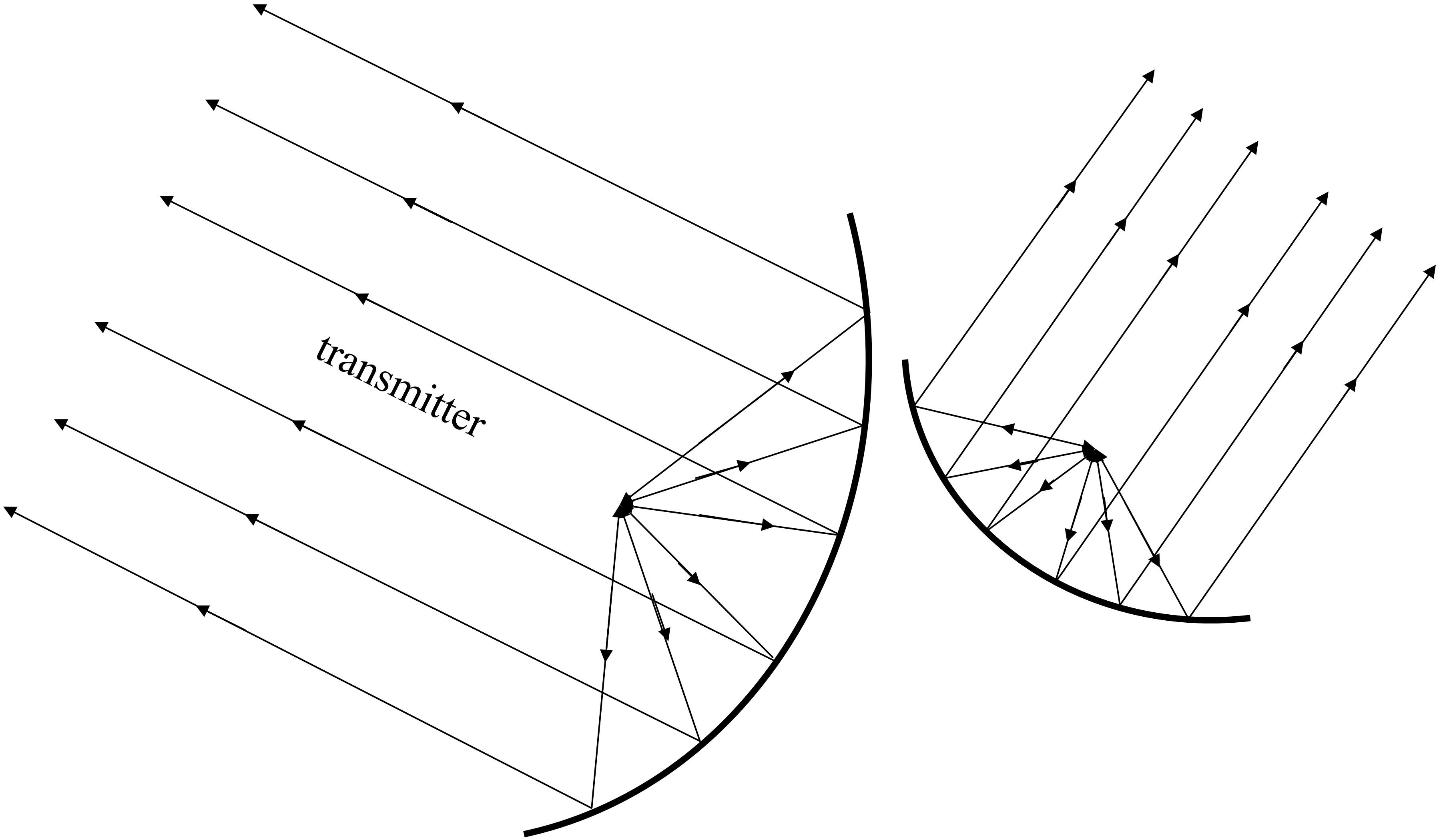
If we tilt the dish…



receiving dish aerial



The transmitting aerial allows a strong (concentrated) signal to be sent in a particular direction from the transmitting dish aerial.



transmitting dish aerial

Dish Aerials

What is the advantage of using a dish with a larger area?

The dish collects more of the incoming beam and focuses it – resulting in a stronger signal. Satellite TV in Scotland requires a bigger dish than in England!

Dish Aerials

A dish aerial can be used either to receive or to transmit a radio (or microwave) signal.

Key words: converging, diverging, lenses, parallel light rays, power, focal length

By the end of this lesson you will be able to:

Describe the shape of converging and diverging lenses.

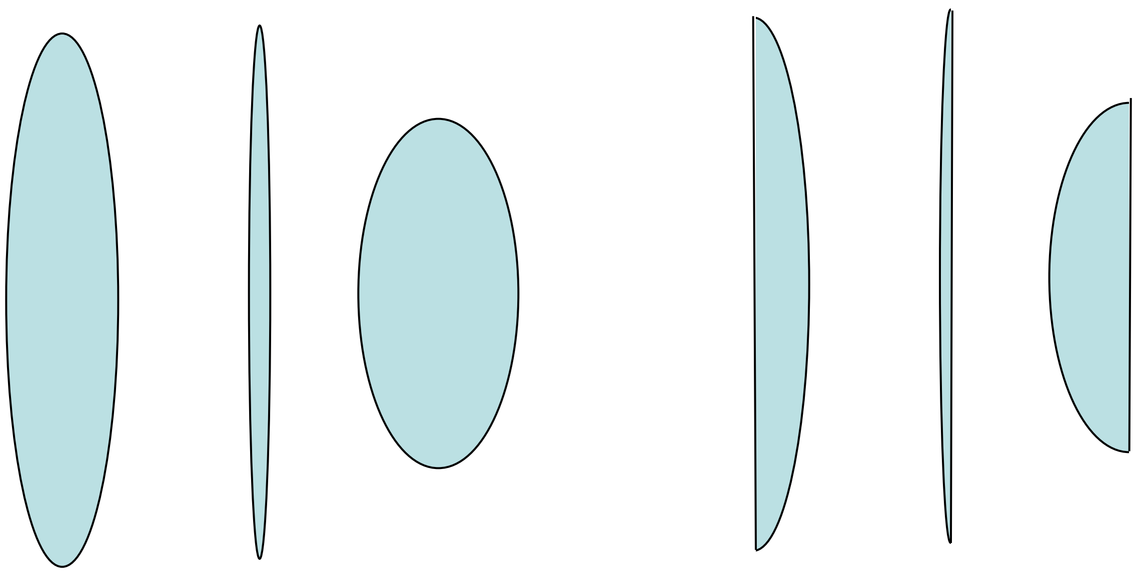
Describe the effect of converging and diverging lenses on parallel rays of light.

Carry out calculations involving the relationship between power and focal length of a lens.

Lenses

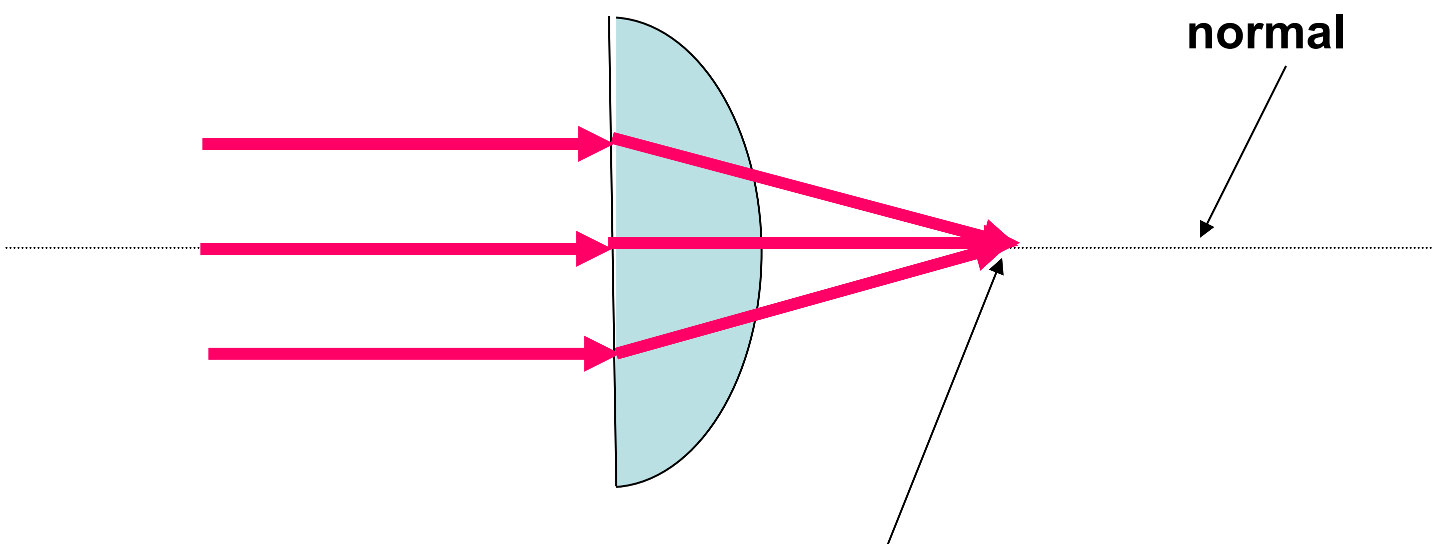
Lenses refract light.

A convex lens is one which is thicker in the middle than at its edge. It bulges out.



Lenses

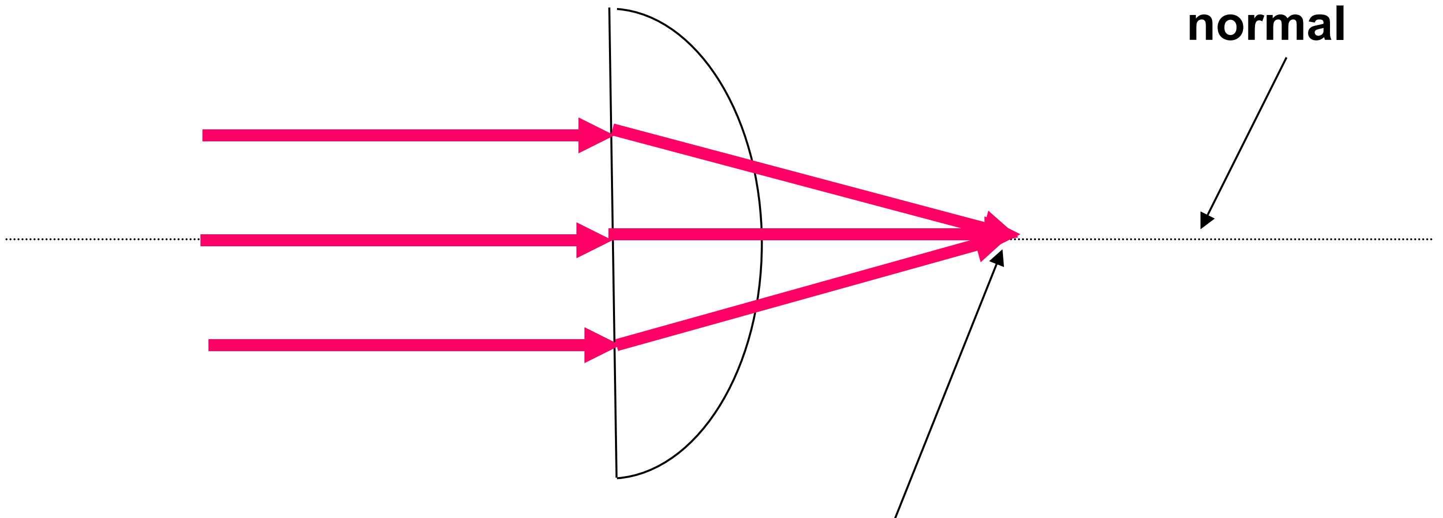
When we shine parallel rays through a convex lens…



Convex lenses bring parallel light rays to a focus. They are converging lenses.

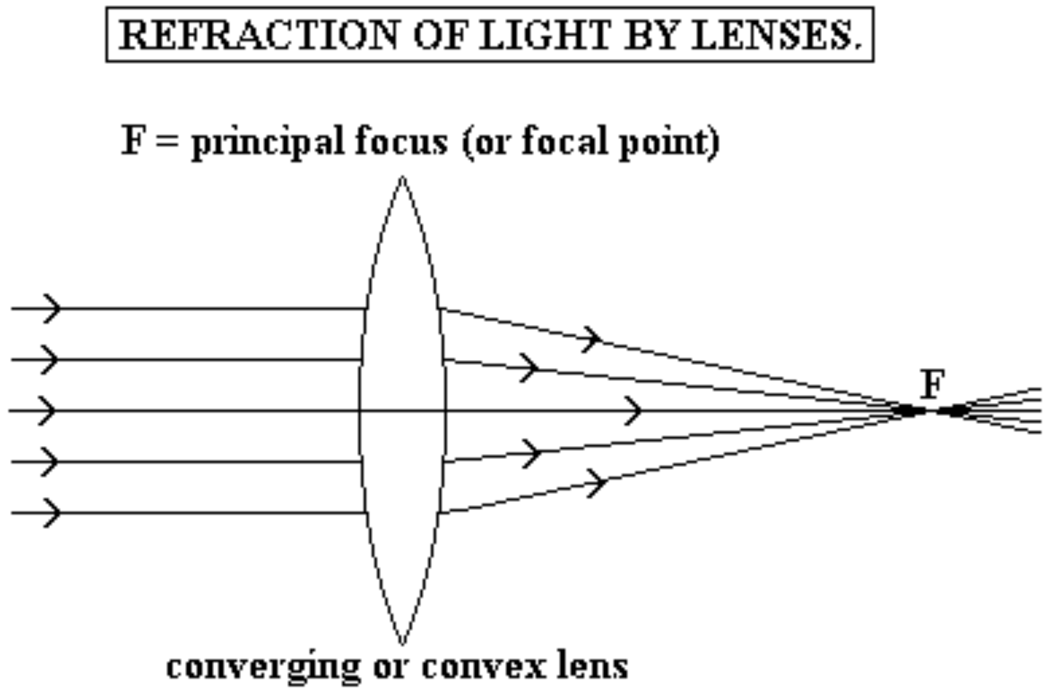
Lenses

The focal length of the lens is the distance between the centre of the lens and the focus.



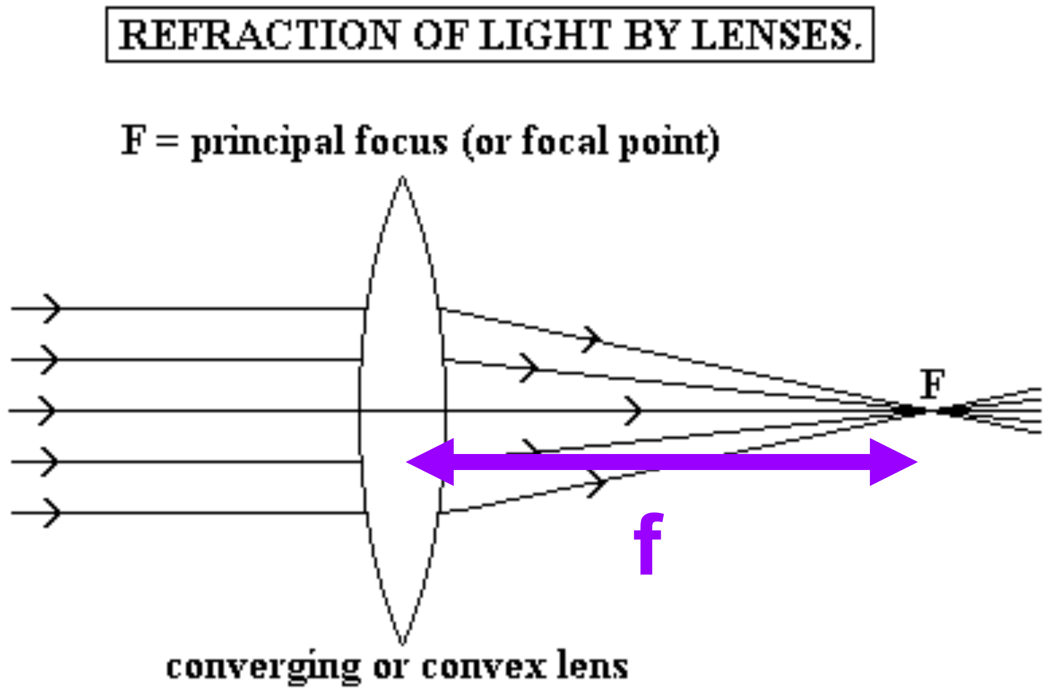
Convex lenses bring parallel light rays to a focus. They are converging lenses.

When parallel light rays enter a **CONVEX** lens they are **CONVERGED** (focused)



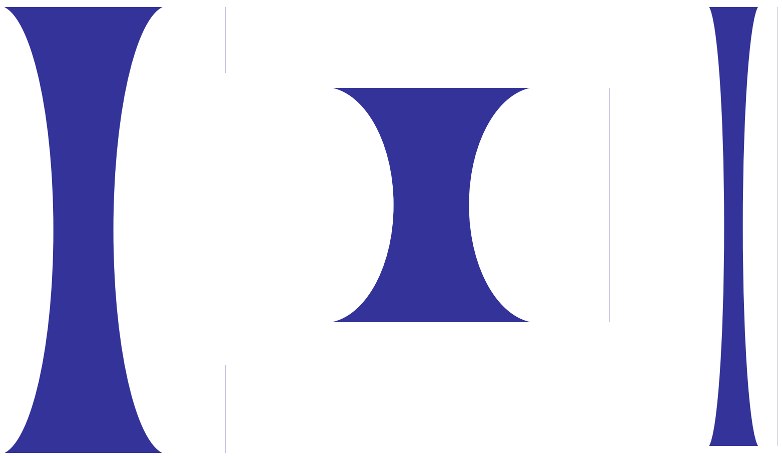
The rays meet at a point called the **PRINCIPAL FOCUS** ('F' in the diagram)

The distance from the centre of the lens to the principal focus is called the FOCAL LENGTH **(f)**



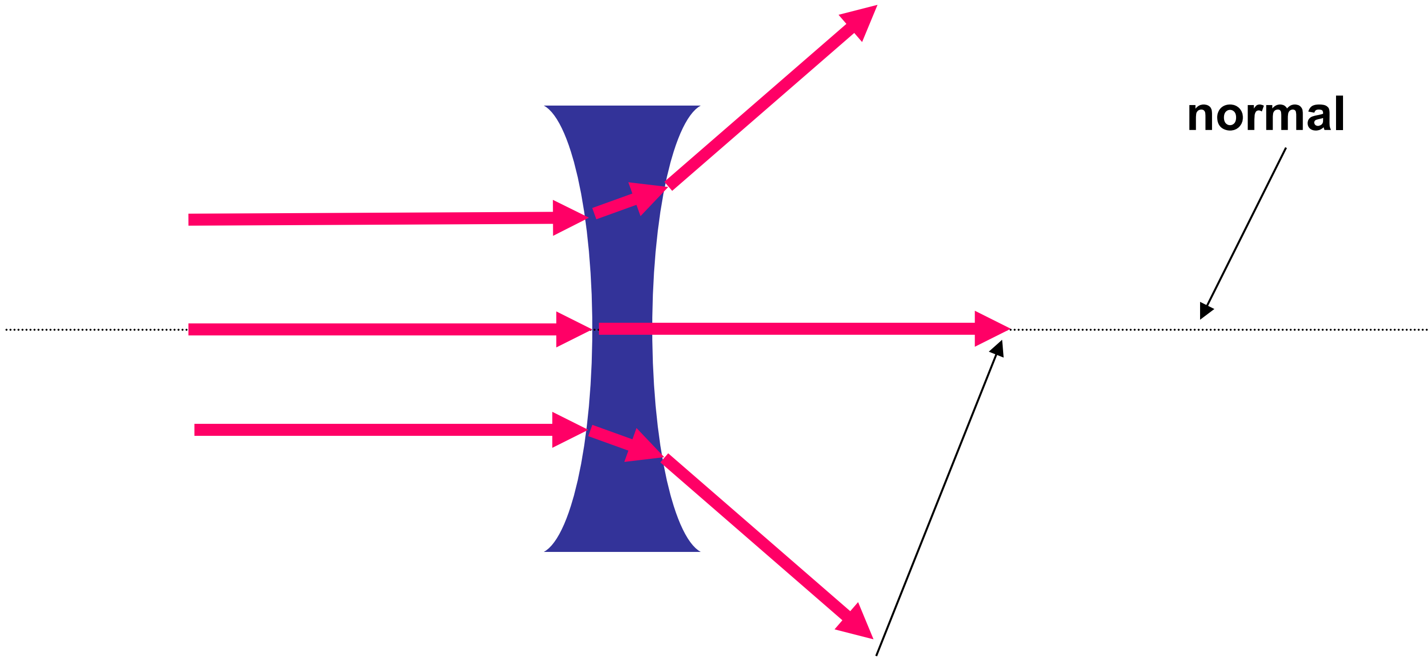
Lenses

A concave lens is one which is thinner in the middle than at its edge. It "caves" in.



Lenses

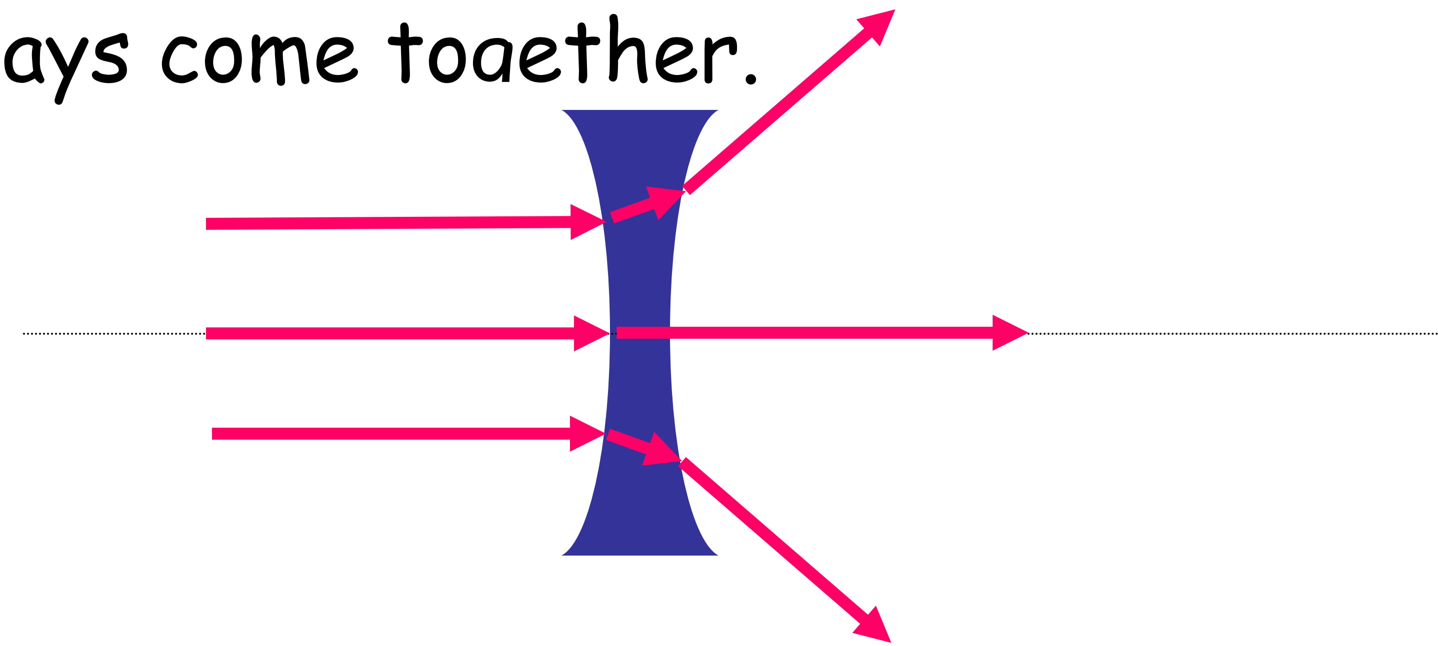
When we shine parallel rays through a concave lens…



Concave lenses cause parallel light rays to diverge.

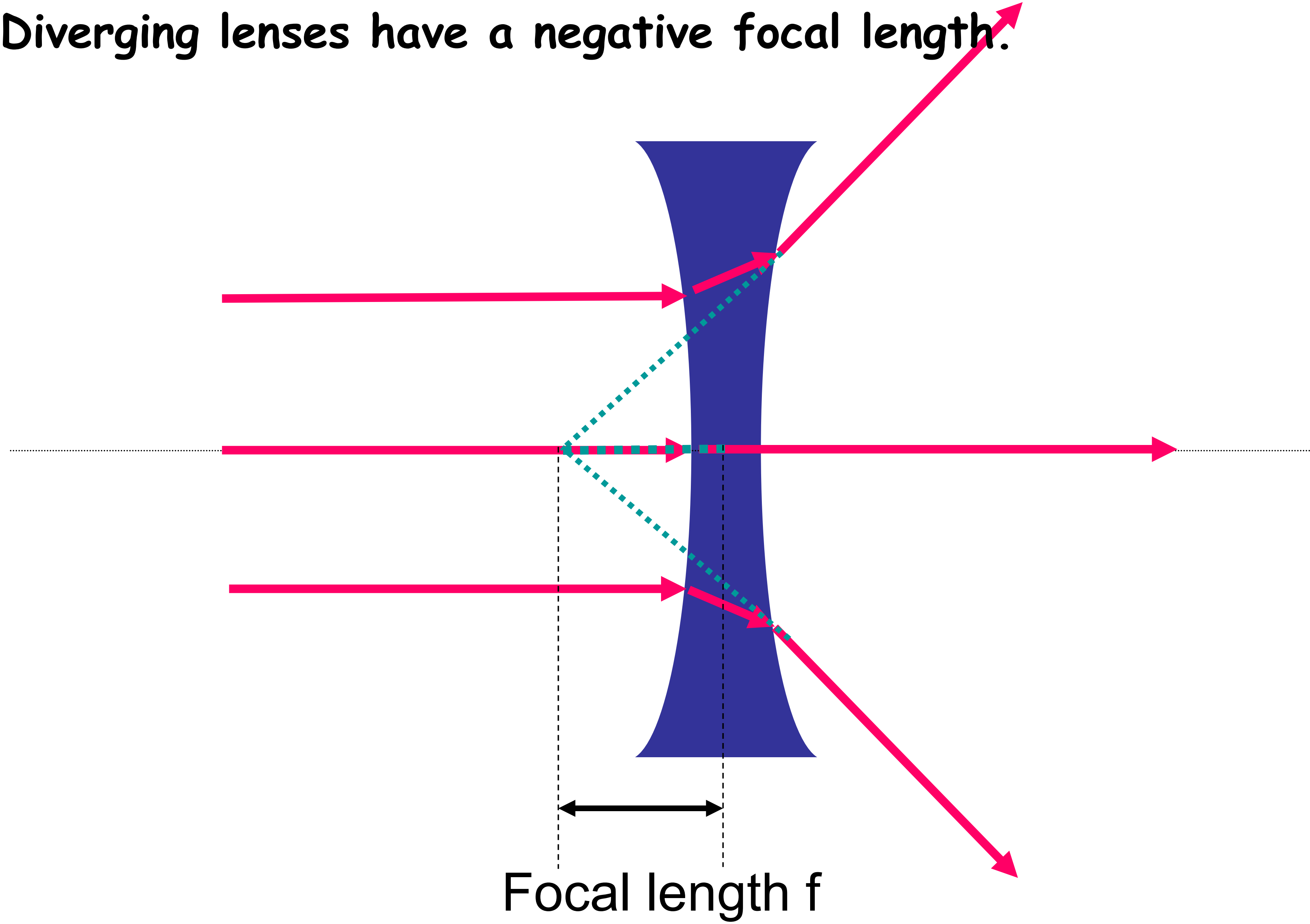
Measuring the Focal Length of a Concave Lens

The focal length of a lens is the distance from the centre of the lens to where the rays come together.

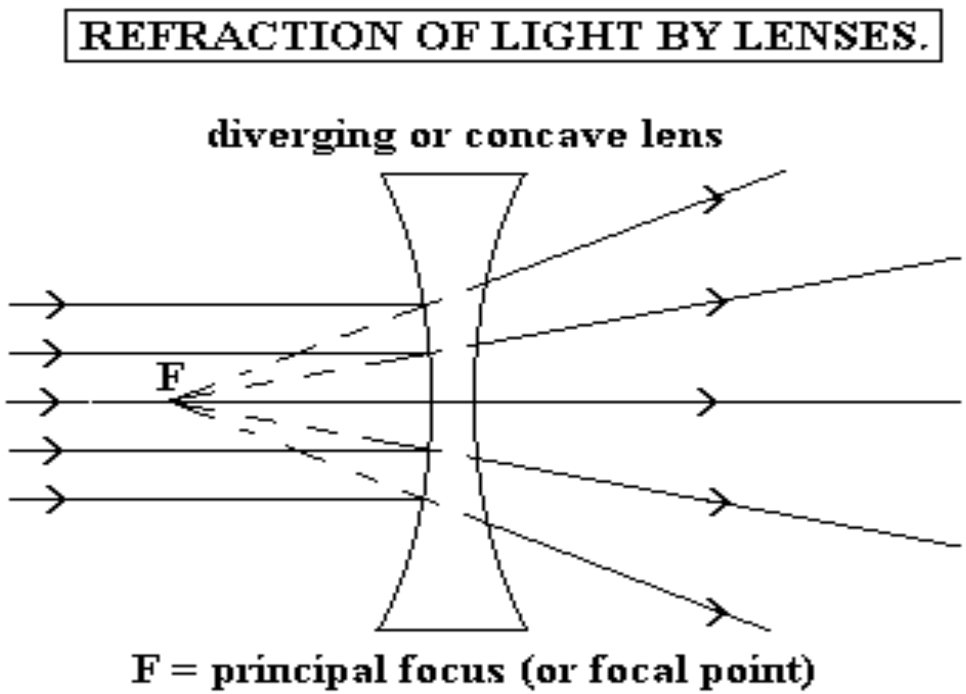


But a concave lens causes the rays to diverge!

Diverging lenses have a negative focal length.

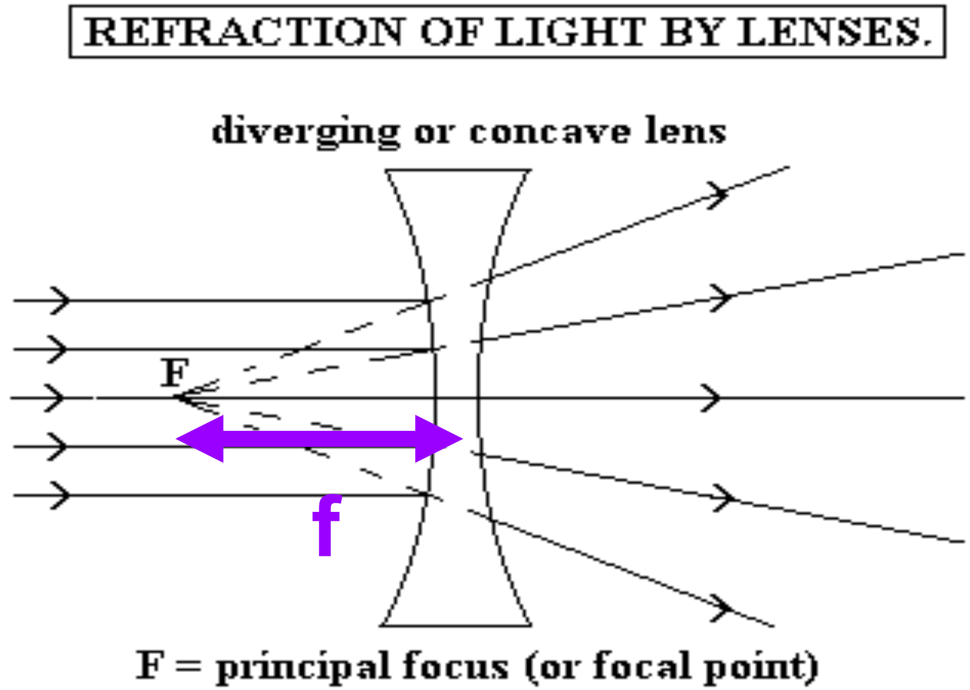


When light rays enter a **CONCAVE** lens they are **DIVERGED** (spread)



This time the principal focus is **BEHIND** the lens

As before, the distance to the principal focus is the **FOCAL LENGTH**



Because the focal length is in the opposite direction, we give it a **NEGATIVE** value

Summary (so far)

Type of lens	**What it does**	**Focal length**	
Convex	CONVERGES light (brings the rays together)	Positive	
Concave	DIVERGES light (spreads the rays)	Negative	

Thick and Thin Lenses

Observe the demonstration with the lenses.

Can you predict which lenses will be converging? And which will be diverging?

Is there a relationship between the thickness of the lens and the focal length?

Measuring the Focal Length of a Converging Lens

Step 1: Identify a distant light source. Hold the lens between the light source and screen (piece of paper).

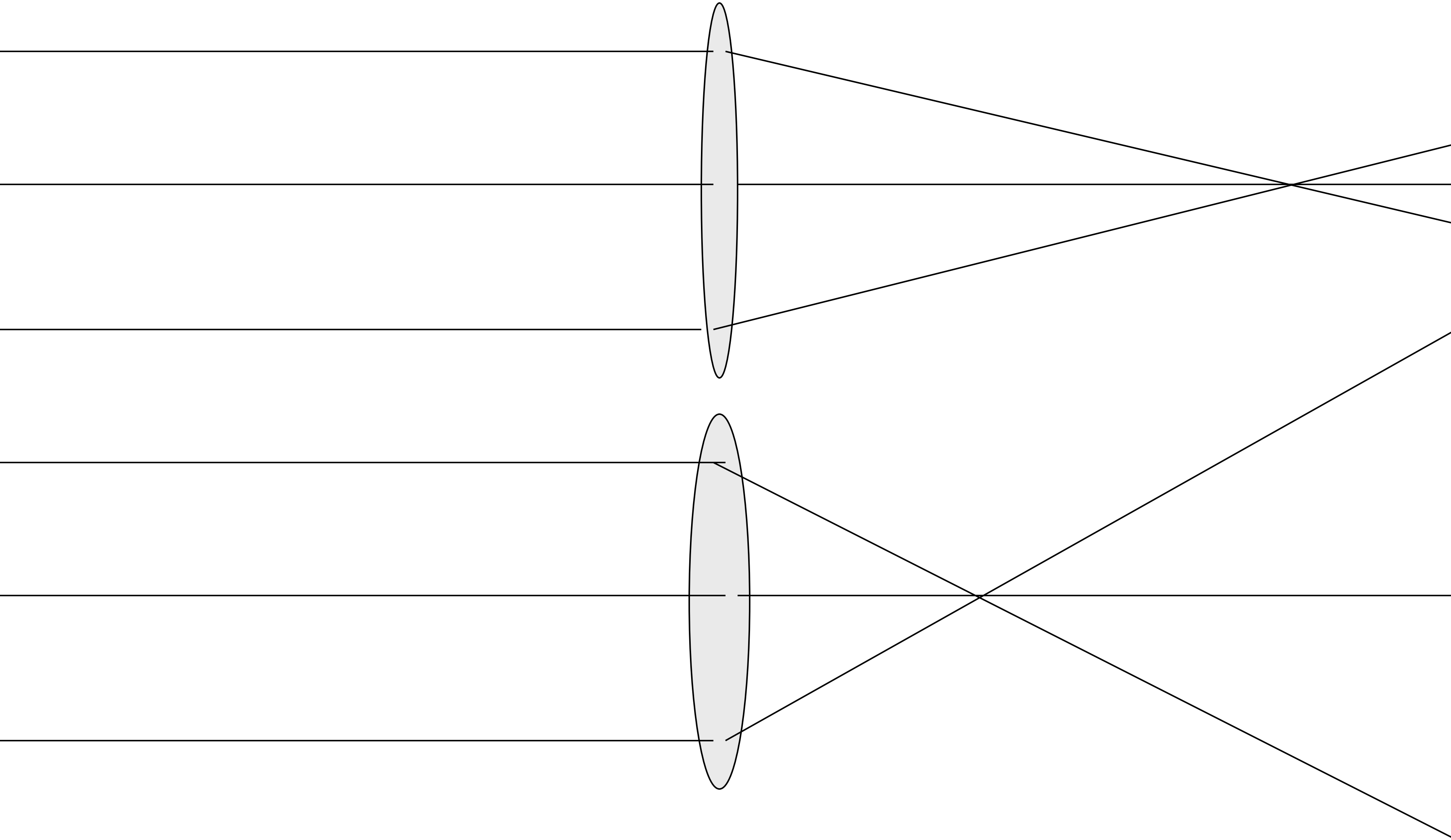
Step 2: Move the lens back and forward until a focused image appears on the screen.

Step 3: Measure the distance between the centre of the lens and the screen on which the focused image appears – this is the focal length.

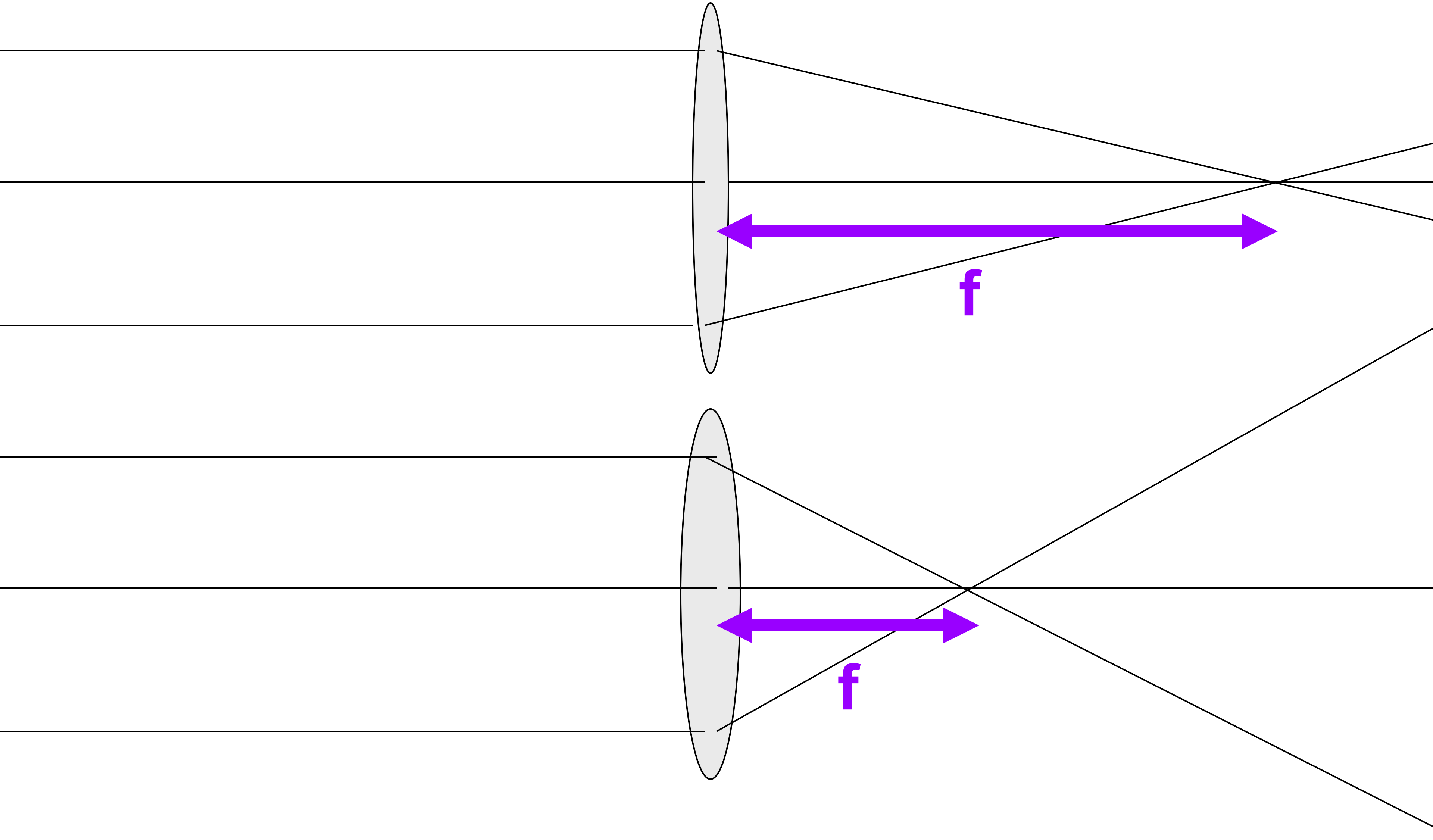
Measuring the Focal Length of a Converging Lens

Note your results.
Why must a distant light source be used?
Which lens had the shortest focal length?
Which lens had the longest focal length?
Which lens is the weakest?
Which lens is the strongest?
Could you predict this without making measurements?

Compare these 2 convex lenses:



The thicker lens has a shorter focal length



POWER OF A LENS

To calculate a lens' power, use this equation:

$$\textit{power} \quad \frac{1}{\textit{focal length}}$$

For short:

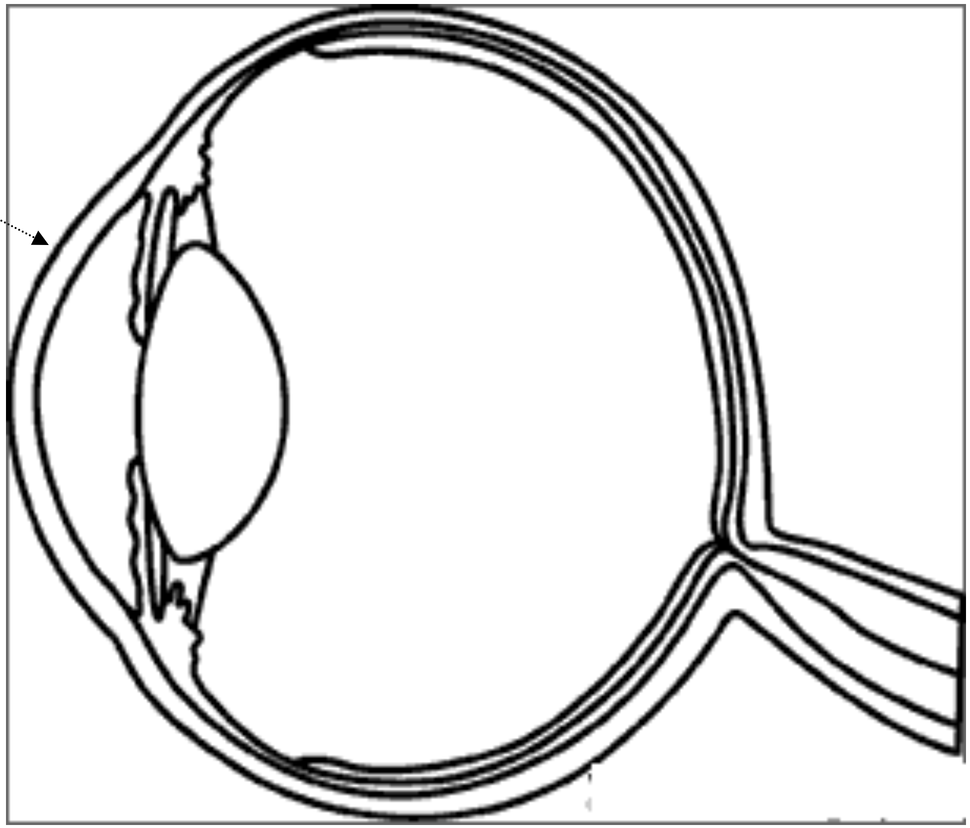
$$P \quad \frac{1}{f}$$

DIOPTRES
(D)

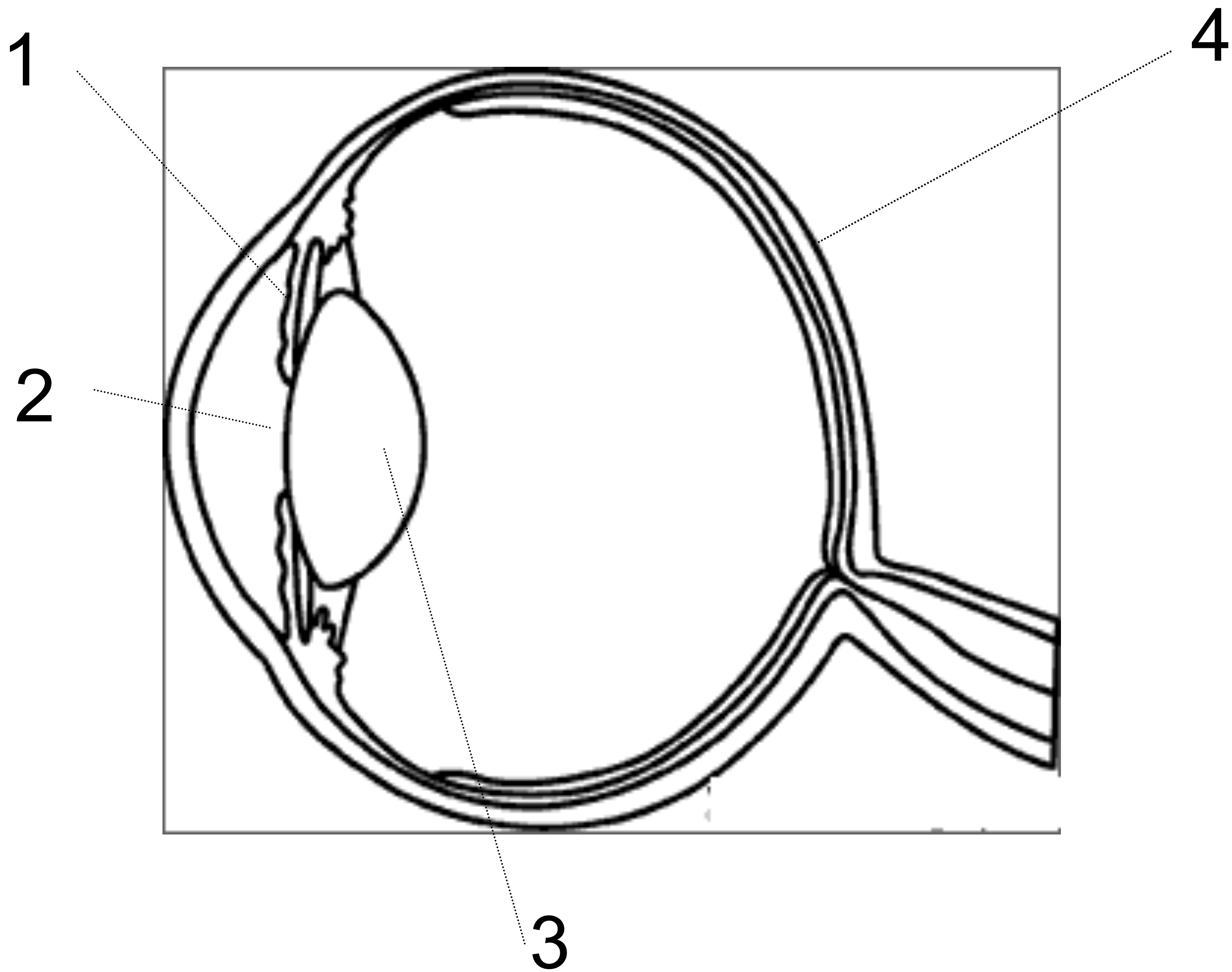
METRES
(m)

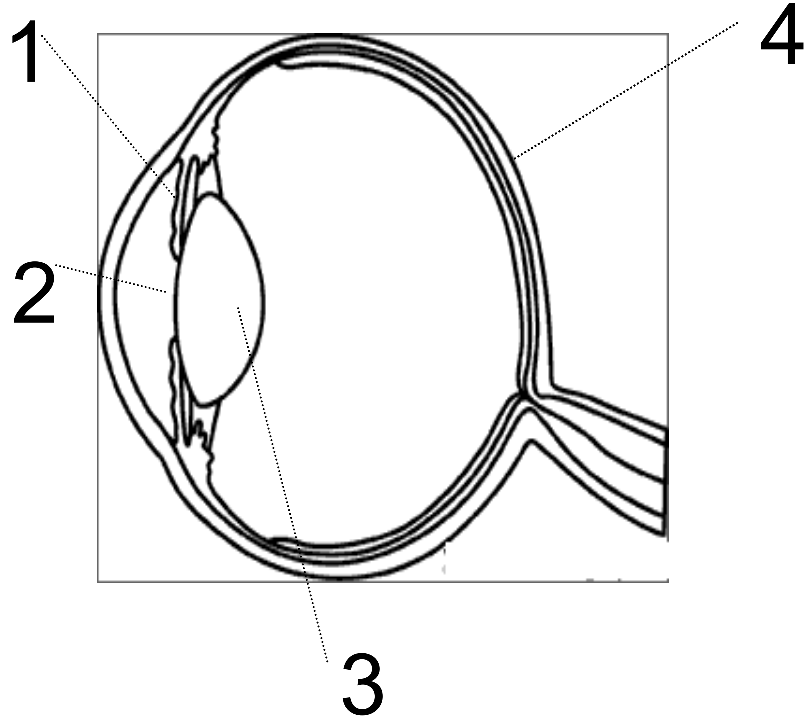
The Human Eye

Light enters the front of the eye at the cornea. It is transparent, and it is here that most of the refraction occurs.



The Human Eye

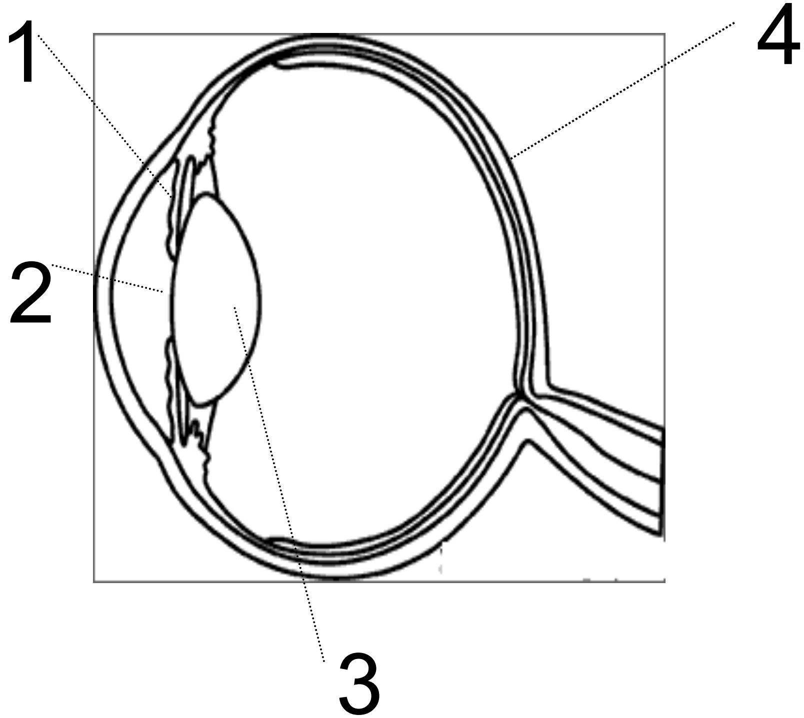




1 controls the amount of light which enters the eye

It is called

the iris

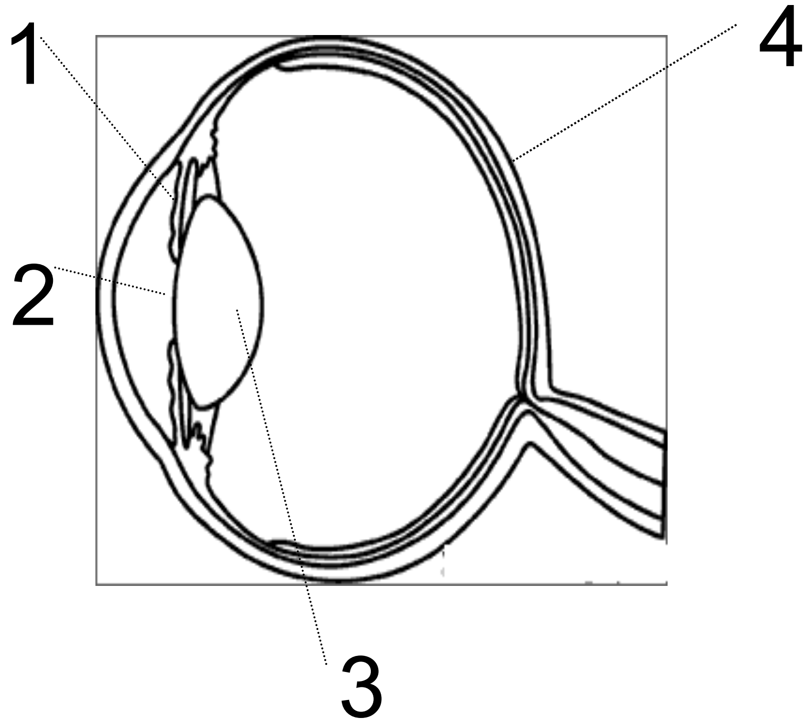


2 is the hole in the middle of the iris. It allows light to enter the eye.

It is called

the pupil

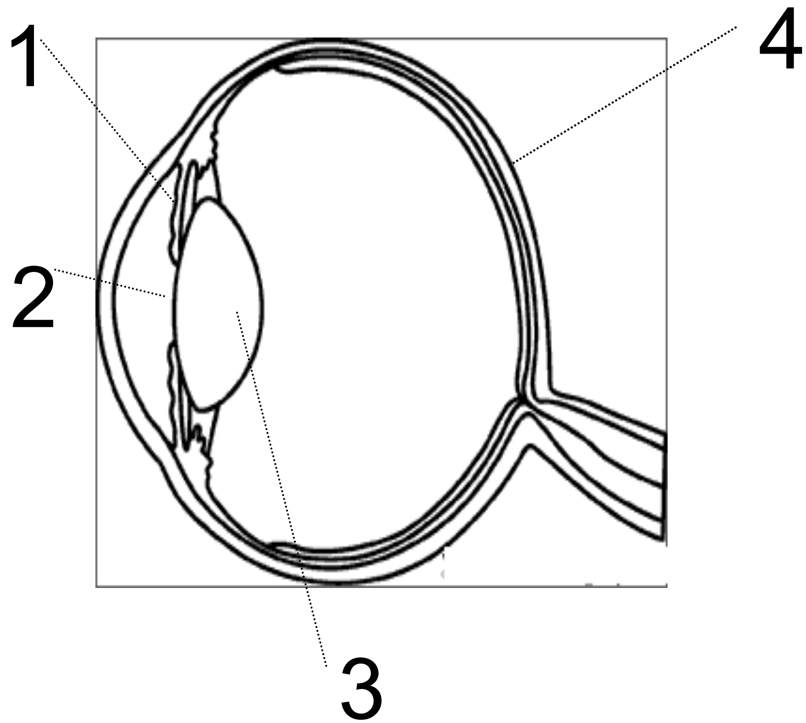
In bright light will the pupil be large or small?



Along with the cornea, 3 focuses the light. It is called

the jelly lens

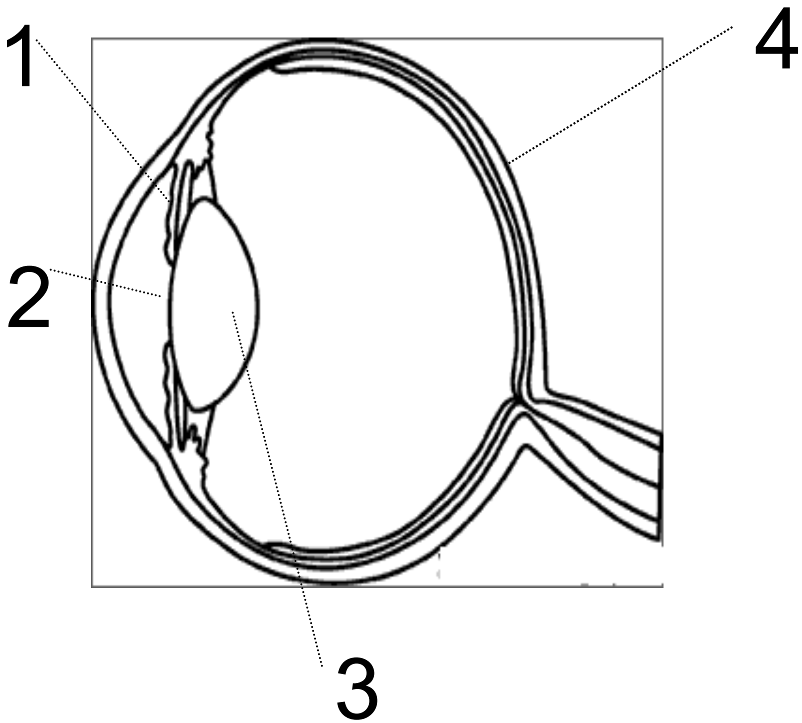
How does the eye lens focus on objects at different distances?



4 is where the "light picture" is built up. It is called

the retina

The retina contains nerve cells which are affected by light and send signals to the brain along the optic nerve.



4 is where the "light picture" is built up. It is called

the retina

To see objects clearly, light must be focused on the retina.

Remember!

Most of the refraction occurs in the cornea - not the lens!

Common Sight Defects

Long and short sight are caused by the failure of the eye's lens to bring the light rays to a focus on the retina.

Long and Short Sight

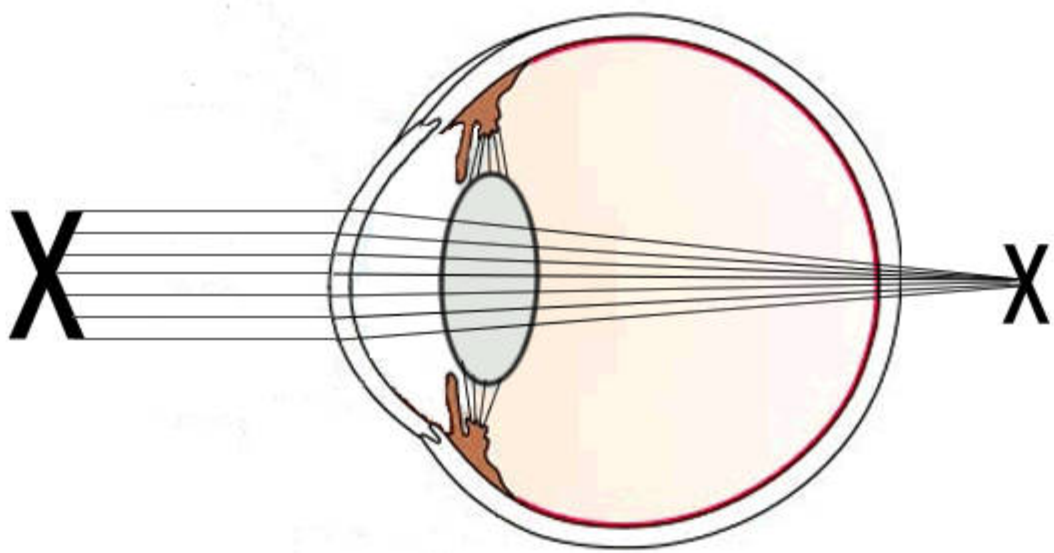
Observe the demonstration of long and short sight.

Where do the rays meet when a person is long sighted?
What type of lens can be used to correct this?
Where do the rays meet when a person is short sighted?
What type of lens can be used to correct this?

Long Sight

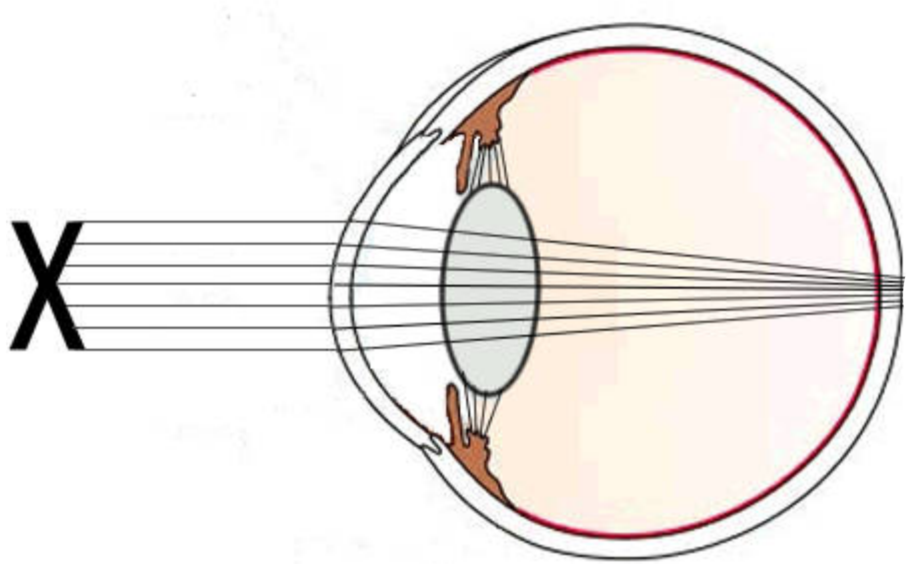
A person with long sight can see far away objects clearly. Objects close up appear blurred.

Long sight occurs when the light rays are focused "beyond" the retina.



Long Sight

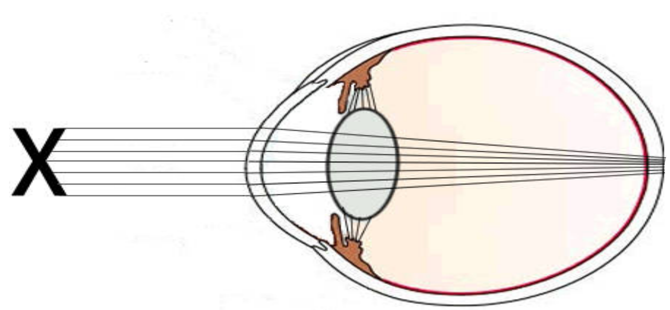
Remember that rays do not actually pass beyond the back of the eye!



Long sight can occur because the eyeball is shorter than normal from front to back. It can also be caused by the ciliary muscles not

Long Sight

Long sight can occur because the eyeball is shorter than normal from front to back. It can also be caused by the ciliary muscles not relaxing to make the lens fat enough. Remember the fatter the lens, the more powerful and the more quickly rays are brought to a focus.



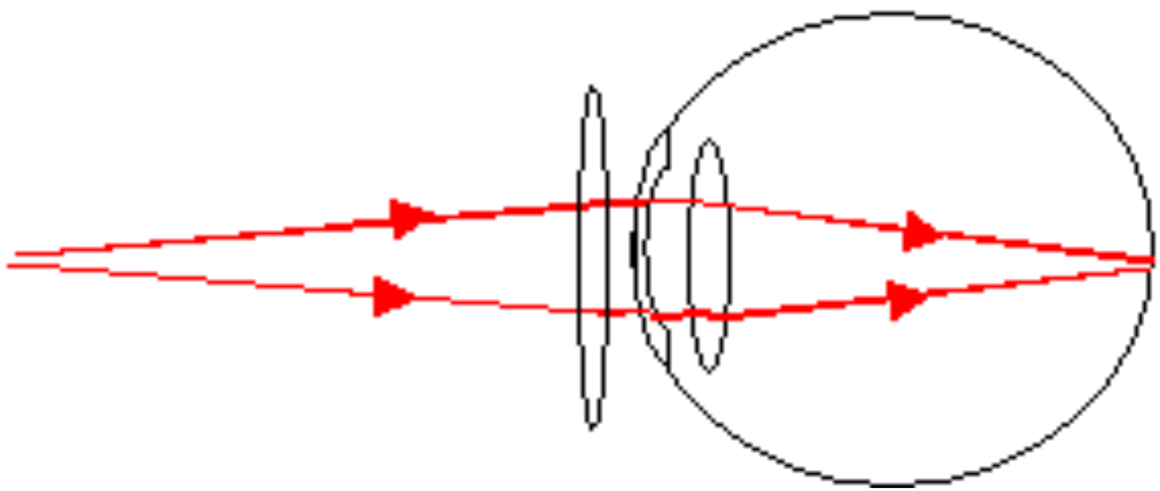
Long Sight

A person with long sight can see far away objects clearly. The rays are parallel and can be brought to a focus on the retina.

Objects close up appear blurred. The rays coming from a close up object are diverging and the eye does not bring them to a focus on the retina.

Long Sight

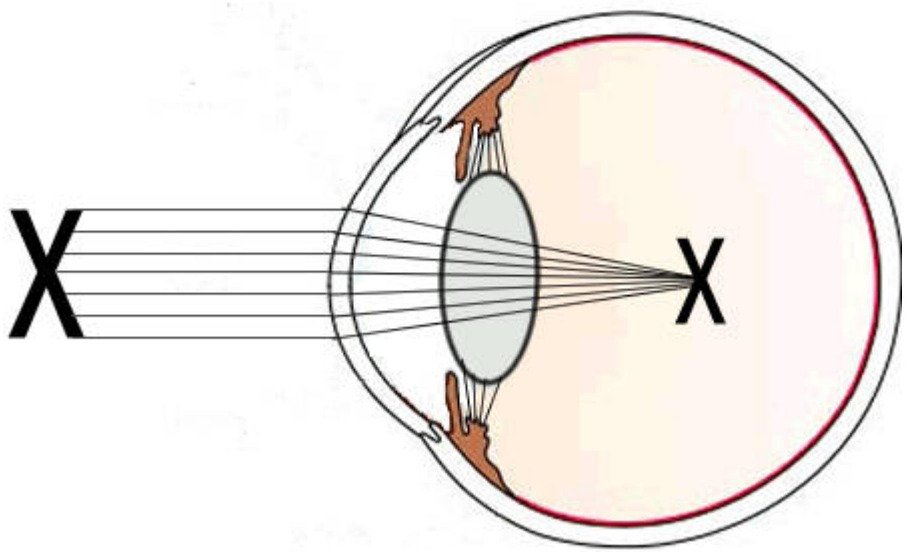
A convex lens converges the light rays before the cornea/lens and allows the eye to focus the light on the retina rather than behind the retina.



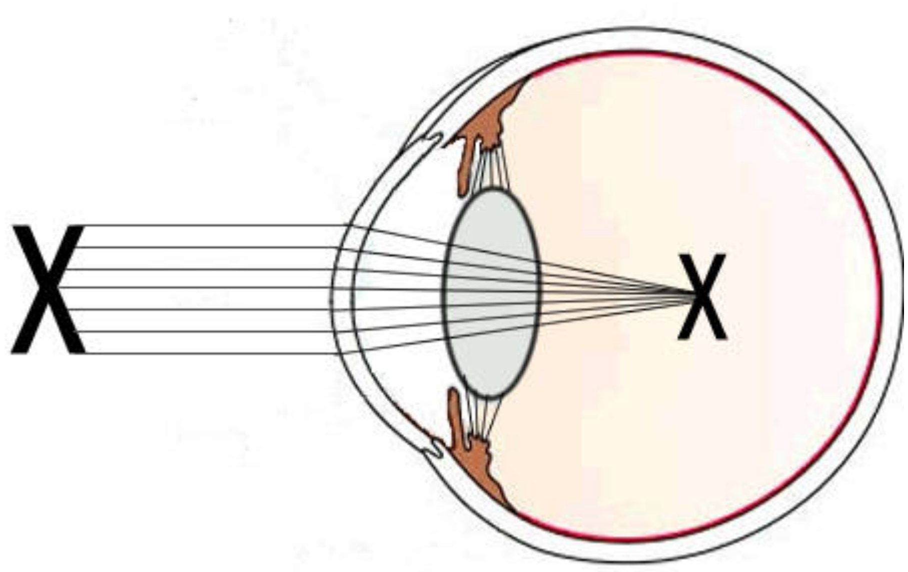
Short Sight

A person with short sight can see close objects clearly. Objects far away appear blurred.

Short sight occurs when the light rays are focused in front the retina.



Short Sight



Short sight can occur because the lens in the eye is very curved. It can also be caused by the ciliary muscles not making the lens thin enough.

Short Sight

A person with short sight can see close up objects clearly. The rays are diverging and can be focused on the retina.

Distant objects appear blurred. The rays coming from a distance object are parallel and the eye brings them to a focus too soon.

Short Sight

A concave lens diverges the light rays before the cornea/lens and allows the eye to focus the light on the retina rather than in front of the retina.