WAVES AND OPTICS

The knowledge and understanding for this unit is given below:

Waves

1. State that a wave transfers energy.
2. Describe a method of measuring the speed of sound in air, using the relationship between distance, time and speed.
3. State that radio and television signals are transmitted through air at 300 million m/s and that light is also transmitted at this speed.
4. Carry out calculations involving the relationship between distance, time and speed in problems on water waves, sound waves, radio waves and light waves.
5. Use the following terms correctly in context: wave, frequency, wavelength, speed, amplitude, period.
6. State the difference between a transverse and longitudinal wave and give examples of each.
7. Carry out calculations involving the relationship between speed, wavelength and frequency for waves.
8. State in order of wavelength the members of the electromagnetic spectrum: gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV and radio.

Reflection

1. State that light can be reflected.
2. Use correctly in context the terms: angle of incidence, angle of reflection and normal when a ray of light is reflected from a plane mirror.
3. State the principle of reversibility of a ray path.
4. Explain the action of curved reflectors on certain received signals.
5. Explain the action of curved reflectors on certain transmitted signals.
6. Describe an application of curved reflectors used in telecommunications.
7. Explain, with the aid of a diagram, what is meant by total internal reflection.
8. Explain, with the aid of a diagram, what is meant by ‘the critical angle’.
9. Describe the principle of operation of an optical fibre transmission system.

Refraction

1. State what is meant by the refraction of light.
2. Draw diagrams to show the change in direction as light passes from air to glass and glass to air.
3. Use correctly in context the terms angle of incidence, angle of refraction and normal.
4. Describe the shapes of converging and diverging lenses.
5. Describe the effect of a converging and diverging lens on parallel rays of light.
6. Draw a ray diagram to show how a converging lens forms the image of an object placed at a distance of:
   a) more than two focal lengths
   b) between one and two focal lengths
   c) less than one focal length in front of the lens.
7. Carry out calculations involving the relationship between power and focal length of a lens.
8. State the meaning of long and short sight.
9. Explain the use of lenses to correct long and short sight.

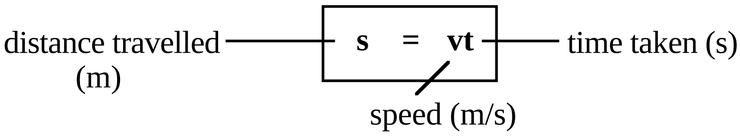
Units, prefixes and scientific notation

1. Use SI units of all quantities appearing in the above Content Statements.
2. Give answers to calculations to an appropriate number of significant figures.
3. Check answers to calculations.
4. Use prefixes (m,k,M,G).
5. Use scientific notation.

WAVES

Waves can transfer **energy**, e.g. water waves can transfer energy across the water.
Radio and television signals are waves that travel through the air at 300 million m/s. (3×10^8 m/s). This is the same speed as the speed of light.
The light from a thunder storm is seen before the sound of the thunder since the speed of light is much greater than the speed of sound.

The **distance** travelled by a wave travelling at a **constant speed** can be calculated using:



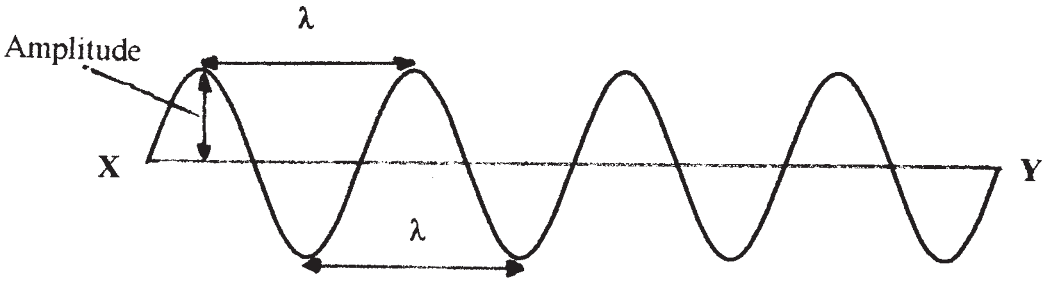
Note: these notes will have metres per second written as m/s. However you can use the negative index, e.g. m s^{-1}, if you prefer.

The **frequency, f,** of a wave is the number of waves that pass a point in 1 s.
Frequency is measured in hertz (Hz).

The **wavelength, λ,** of a wave is the horizontal distance between two adjacent troughs or crests or any two corresponding points on the wave.
Wavelength is measured in metres (m).

The **amplitude** of a wave is half the vertical distance between a trough and a crest.
Amplitude is measured in metres (m).

The **period, T,** of a wave is the time it takes one wave to pass a point.
Period is measured in seconds (s).

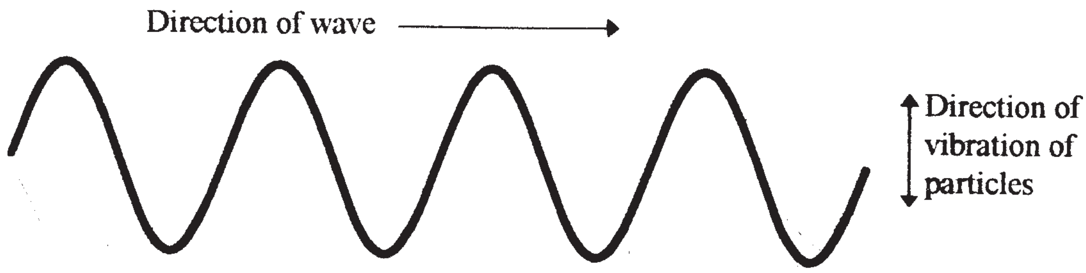


Example
In the diagram above the distance between X and Y is 10 m. If 20 waves pass B in 5 s, find a) the wavelength b) the frequency and c) the period of the wave.

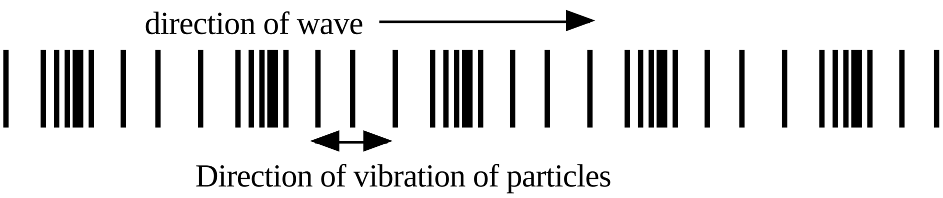
a) *XY = 4 complete wavelengths = 10 m.* $\lambda = {}^{10}/_{4} = 2.5$m
b) *In 5 s the number of waves that pass Y = 20*
In 1 s the number of waves that pass Y = ${}^{20}/_{5} = 4$ *Frequency, f = 4 Hz*

c) *20 waves pass B in 5 s*
Time for 1 wave = ${}^{5}/_{20} = 0.25$ *s* *Period of wave = 0.25 s*

Transverse and longitudinal waves
A transverse wave is one in which the particles making up the wave vibrate at 90° to the direction of the wave.
Examples of transverse waves are water waves, light, gamma rays, X-rays and all members of the electromagnetic spectrum.



A longitudinal wave's particles vibrate along the same line as the direction of the wave. Sound travels as a longitudinal wave.



Speed, frequency and wavelength.
The relationship between these is

$$\mathbf{v = f\lambda}$$

This is known as the wave equation.

The Electromagnetic Spectrum
Listed below are the members of the electromagnetic spectrum.

Gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV and radio.

Low λ → **increasing λ** → Long λ
High f ← **increasing f** ← Low f

Each member travels at the speed of light = 3×10^8 m/s

Example
Microwaves have a frequency of 9.4 GHz. Calculate their wavelength.

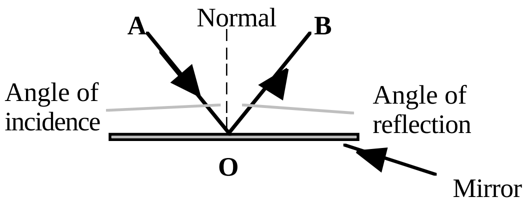
$$v = f\lambda$$

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{9.4 \times 10^9} = 3.2 \times 10^{-2} \quad (= 3.2\text{ cm})$$

REFLECTION

Light

The diagram below shows the path of a ray of light when reflected off a mirror.
The normal is a line drawn at 90^0 to the mirror.

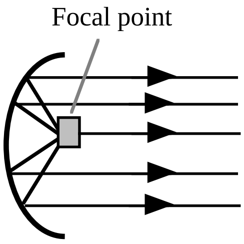


Angle of incidence = Angle of relection

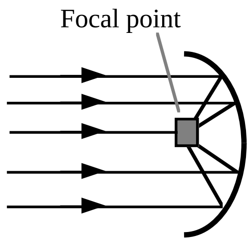
The **principle of reversibility of light** states that a ray of light which travels along any particular path from some point A to another point B travels by the same path when going from B to A, e.g. in the above diagram the ray travels from A to O to B. If the direction was reversed then the ray would follow B to O to A.

Curved Reflectors

These can be used in transmitters and receivers of waves, e.g. sound, infrared, microwaves, TV signals and satellite communication.



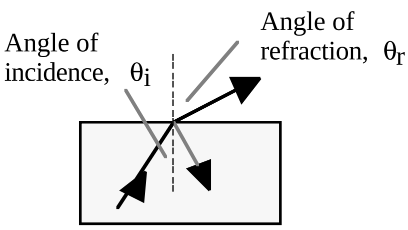
Transmitter placed at focal point.



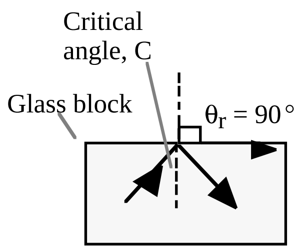
Receiver placed at focal point

Total Internal Reflection and Critical Angle

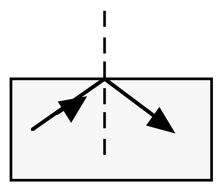
When light travels from glass to air, if the angle of incidence in glass gives an angle of refraction of 90° in air, then the angle in glass is known as the **critical angle, C.**
Beyond this angle there will be total internal reflection.



Angle of incidence less than critical angle
($\theta_i < C$)



Angle of incidence = critical angle
Angle of refraction = 90 °
($\theta_i = C$)



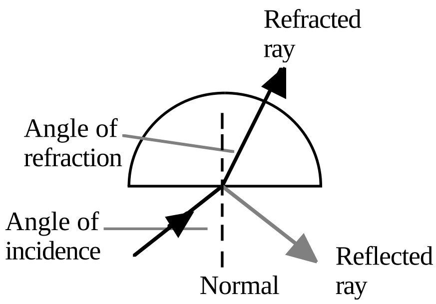
Angle of incidence greater than critical angle. Ray undergoes total internal reflection
($\theta_i > C$)

Optical Fibres

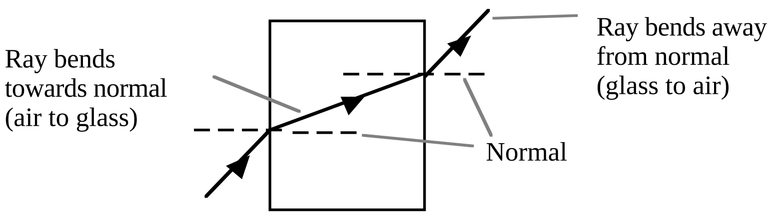
Light can travel through these by being totally internally reflected.

REFRACTION

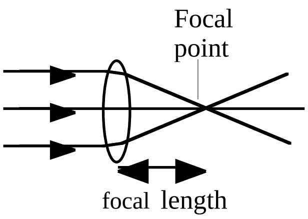
When light passes from one medium to another, e.g. air to glass, part is reflected back into air and the rest passes through the medium with a change in direction.



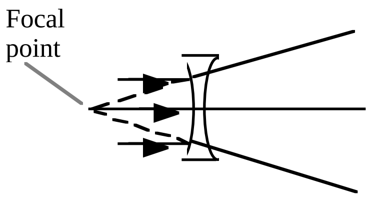
The light is said to be bent or **refracted** as it passes through the glass. This is due to the speed of light being less in glass than air. The ray will bend **towards** the normal.
The speed of a light ray increases as it leaves the medium. When a ray of light's speed increases then it will bend **away** from the normal.



Lenses
The ray diagrams below show the effect of converging and diverging lenses on parallel rays of light.



Converging lens



Diverging lens

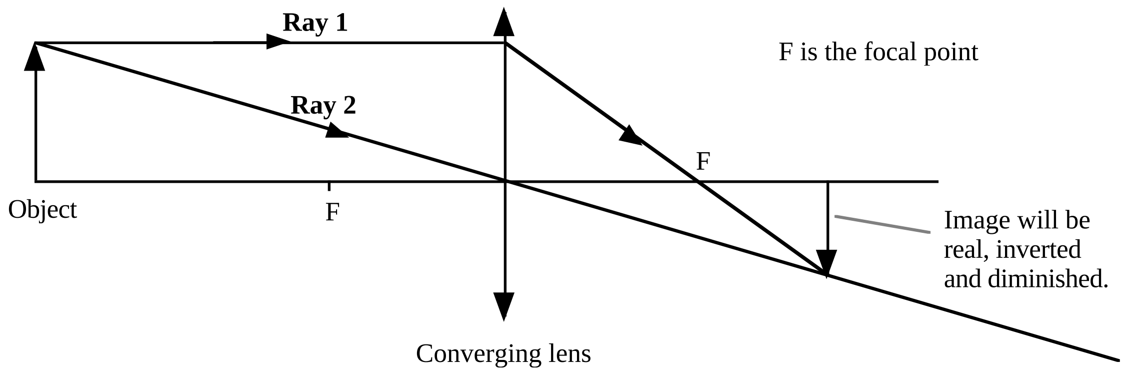
Image formation by a converging lens
Images can be described as:

- **real or virtual**
- **inverted or upright**
- **magnified, same size or diminished.**

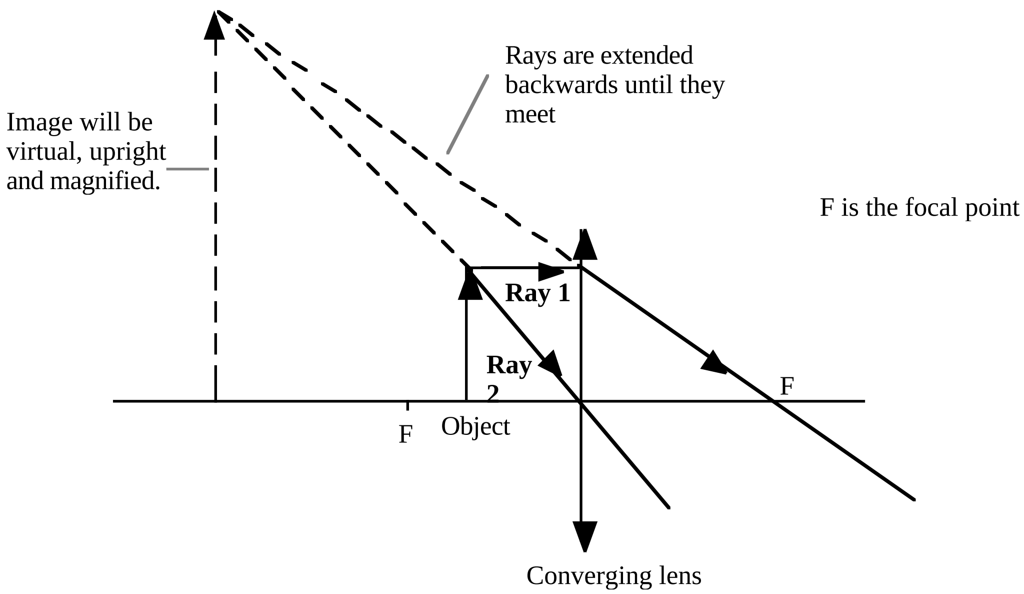
Ray Diagrams

- Choose an appropriate scale (better done on graph paper).
- Draw ray 1 from the tip of the object parallel to the axis, passing through the focal point of the lens.
- Draw ray 2 from the tip of the object, passing through the centre of the lens.
- Where the two rays meet will be the image of the tip of the object.

Object distance greater than twice the focal length



Object distance less than the focal length



The type of image formed is dependent on the object distance from the lens.

OBJECT POSITION FROM LENS	TYPE OF IMAGE
More than two focal lengths	Real, inverted and diminished
Between one and two focal lengths	Real, inverted and magnified
Less than one focal length	Virtual, upright and magnified

Power of a Lens

This is given by

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

focal length measured in metres

The power is measured in **dioptres (D)**.
A converging lens has a positive power.
A diverging lens has a negative power.

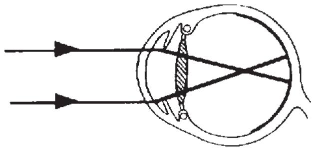
Example

Calculate the power of a converging lens with a focal length of 20 cm.

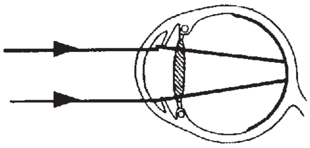
$f = 0.2\ m \qquad P = \frac{1}{f} = \frac{1}{0.2} = 5D$

Short and Long Sight

People who are short sighted have difficulty seeing distant objects. The image is formed short of the retina of the eye.

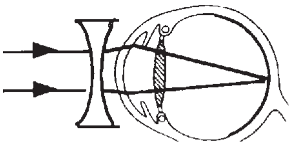


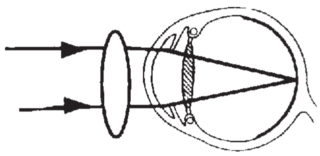
Long sighted people can see distant objects but have difficulty seeing near objects. The image would be formed behind the retina of the eye.



To rectify these:

- a diverging lens is used for short sight.
- a converging lens is used for long sight.



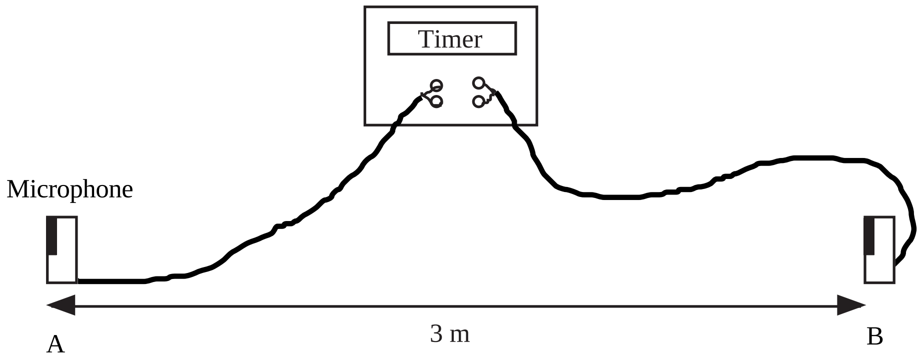


ACTIVITY 1

Title: **Speed of sound**

Aim: To measure the speed of sound in air.

Apparatus: Timer, two microphones and a metre stick.



Instructions

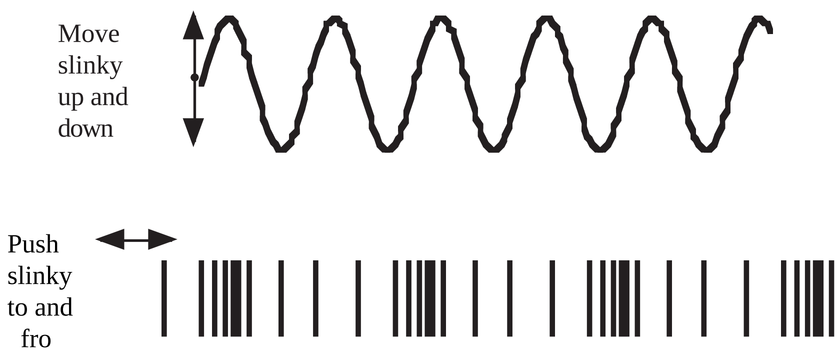
- Set up the apparatus as shown above.
- Bang two pieces of wood together to the left of microphone A.
- Make a note of the time it takes the sound to travel between the microphones.
- Repeat the experiment 5 times and calculate the average time.
- Calculate the average speed of sound.

ACTIVITY 2 (Teacher Demonstration)

Title: **Transverse and longitudinal waves**

Aim: To demonstrate the different properties of transverse and longitudinal waves using a slinky.

Apparatus: Slinky.



Instructions

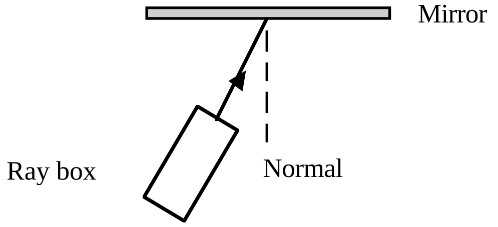
- After watching the demonstration, state the differences between a transverse and longitudinal wave.

ACTIVITY 3

Title: **Reflection**

Aim: To find the relationship between the angle of incidence and angle of reflection.

Apparatus: One plane mirror, a protractor, a single slit, a ray box and power supply.



Instructions

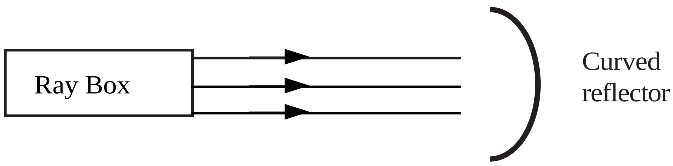
- Set up the apparatus as shown above.
- Construct a ray diagram and measure the angles of incidence and reflection.
- Do this for 5 different angles of incidence.
- Present your results in a table.
- State your conclusion.

ACTIVITY 4

Title: **Curved reflectors**

Aim: To trace the path of rays on being reflected from a curved mirror.

Apparatus: A curved reflector, a triple slit, a ray box and power supply.



Instructions

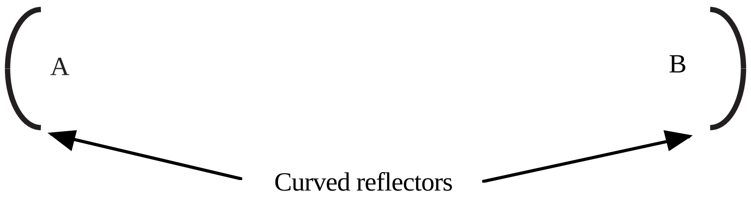
- Set up the apparatus as shown above.
- Mark the position of the curved reflector
- Trace the path of the rays before and after reflection.

ACTIVITY 5 (Teacher Demonstration)

Title: **Curved reflectors**

Aim: To demonstrate the use of curved reflectors in the transmission and reception of waves.

Apparatus: Two curved reflectors, a microwave transmitter and receiver, a microphone and oscilloscope.



Instructions

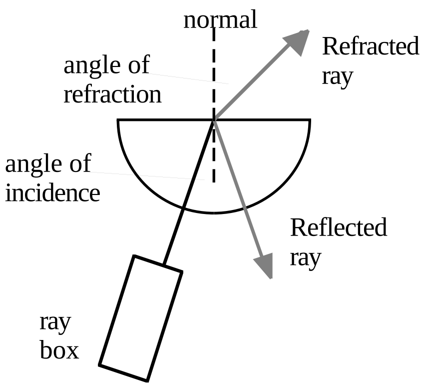
- Place a microwave transmitter at position A.
- Move the receiver at position B until a maximum reading is obtained.
- Draw the path of the rays in each case.
- Repeat the above using a loudspeaker at position A and microphone attached to an oscilloscope at position B.

ACTIVITY 6

Title: **Total internal reflection**

Aim: To investigate total internal reflection and measure the critical angle for perspex.

Apparatus: Semicircular perspex block, a protractor, a ray box and power supply.



Instructions

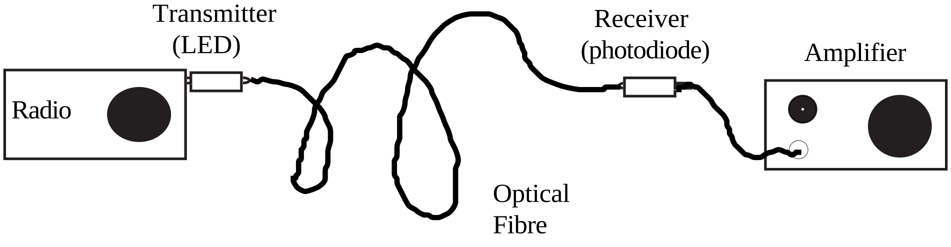
- State the aim of the experiment.
- Set up the apparatus as shown.
- Slowly increase the angle of incidence.
- Describe what happens.
- By drawing a ray diagram when the angle of refraction is 90^0, estimate the critical angle for the perspex block.

ACTIVITY 7

Title: **Optical Fibres**

Aim: To demonstrate light transmission through an optical fibre.

Apparatus: A radio, an LED transmitter, a photodiode receiver, an amplifier, optical fibre and a 12 V light bulb with power supply.



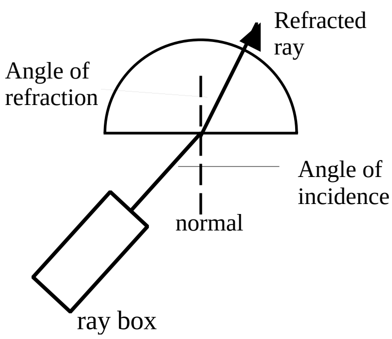
Instructions

- Hold one end of the optical fibre near a light bulb and view the other end.
- Set up the apparatus as shown above.
- Explain, using a diagram, how the light signal is carried through the fibre.

ACTIVITY 8

Title: **Variation of angle of refraction with angle of incidence** (Outcome 3)**.**

Apparatus: A semicircular perspex block, a protractor, a ray box and power supply.



Instructions

- Set up the apparatus as shown in the diagram.
- Draw the ray diagrams for different angles of incidence and measure the corresponding angle of refraction.
- Measure at least 5 different sets of readings.
- Use an appropriate format to display the variation of the angle of refraction with the angle of incidence.

ACTIVITY 9

Title: **Lenses**

Aim: To see the effect that a converging and diverging lens have on parallel rays of light.

Apparatus: A ray box, power supply, a triple slit, converging and diverging lenses.

Instructions

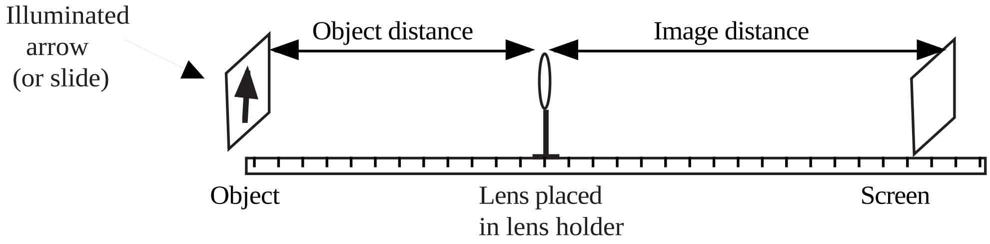
- Set up the apparatus as shown above.
- Copy and complete the ray diagrams.
- Calculate the power of each lens.
- Repeat for lenses of different thickness.

ACTIVITY 10

Title: **Image formation**

Aim: To see how the position, nature and size of an image depends on the object distance from a converging lens.

Apparatus: Converging lens of known focal length, lens holder, illuminated object, metre stick and a white screen.



Instructions

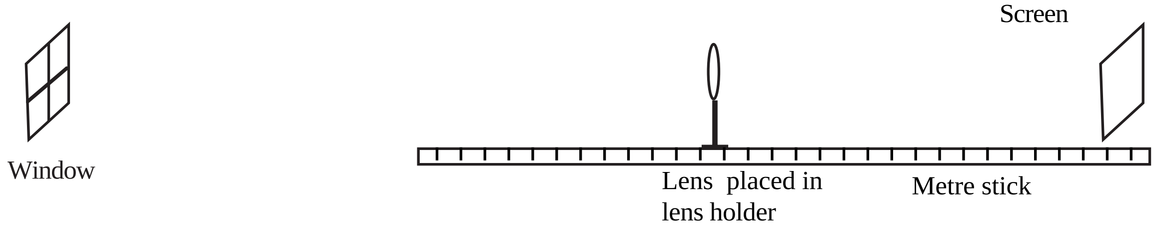
- Set up the apparatus as shown above.
- Position the object distance at greater than twice the focal length of the lens.
- Move the screen until a clear image is formed on it.
- Note the type of image formed and the image distance from the lens.
- Repeat the procedure for object distances:
  a) between one and two focal lengths
  b) less than one focal length.
- Check your answers by constructing ray diagrams for each case.

ACTIVITY 11

Title: **Spherical lenses**

Aim: To find the focal length of a spherical convex lens.

Apparatus: Converging lenses, lens holder, metre stick and screen.



Instructions

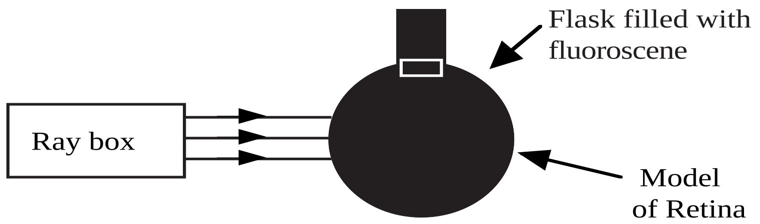
- Set up the apparatus as shown above.
- Move the lens until a clear image of the window is seen on the screen.
- Measure the distance from the screen to the lens.
- Repeat for different lenses.
- Calculate the power of each lens.

ACTIVITY 12 (Teacher Demonstration)

Title: **The model eye**

Aim: To demonstrate how short and long sightedness can be remedied using lenses.

Apparatus:



Instructions

- With the rays focusing short of the retina, place a lens in front of the flask until they focus on the retina.
- Repeat with the rays focusing behind the retina.
- Draw ray diagrams showing how the problems of long and short sight can be corrected using lenses.

WAVES AND OPTICS PROBLEMS

Speed of waves

1. Thunder is heard 20 seconds after a lightning flash. If the speed of sound is 340 m/s, how far away is the storm?

2. Explain why, during a thunder storm, you see the lightning before you hear the thunder.

3. On a day when the speed of sound in air is 330 m/s, how long would sound take to travel a distance of 1.6 km?

4. During a thunder storm it is noticed that the time interval between the flash of lightning and the clap of thunder gets less. What does this tell you about the storm?

5. Describe a method of measuring the speed of sound in air giving:
   a) the apparatus used
   b) the measurements taken
   c) any equations used in the calculation.

6. Ten pupils are standing on Calton Hill, looking at Edinburgh Castle. They measure the time difference between seeing the smoke from the one o'clock gun and hearing the bang. The measured times are 3.8 s, 4.2 s, 4.0 s, 3.8 s, 4.4 s, 3.8 s, 4.0 s, 4.2 s, 3.6 s, and 4.2 s.
   a) Calculate the average time for the group.
   b) Calculate the distance from the Castle to Calton Hill if the speed of sound is 330 m/s.

7. An explosion in Grangemouth could be heard in South Queensferry one minute later . Given they are 20 km apart, calculate the speed of sound in air.

8. On a day when the speed of sound is 330 m/s, how long would the sound take to travel a distance of 19.8 km?

9. In a race the runners are at different distances away from the starter. They will hear the starting horn at different times. Using the speed of sound as 340 m/s, calculate the time difference in hearing the horn for two runners who are 5 m and 15 m from the starter.

10. Calculate how long it would take light to travel from the sun to the earth, a distance of 1.49×10^8 km.

11. How long will it take a radio signal to travel from Britain to Australia, a distance of 1.8×10^4 km.

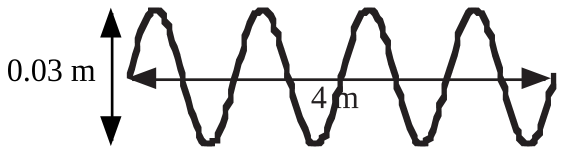
12. a) Explain, using a diagram, the difference between a transverse and longitudinal wave.
    b) What type of waves are the following:
       i) sound waves
       ii) water waves
       iii) light waves.

13. Explain, using the particle model, why sound travels quicker in metals than gases.

14. Explain why sound cannot travel through a vacuum.

Speed, frequency, wavelength and period

15. The diagram below represents a wave 0.2 s after it has started.



Calculate the following quantities for this wave:
a) wavelength
b) amplitude
c) frequency
d) speed.

16. A swimming pool is to have a wave-making machine installed. The time taken for a wave to travel the length of the 50 m pool has to be 20 s and the wavelength has to be 4 m.
a) Calculate the speed of the waves.
b) Calculate the required frequency of the waves.

17. Wave A has a wavelength of 6 cm and a frequency of 50 Hz. Wave B travels 250 m in 1 minute 40 s. Which wave travels faster - and by how much?

18. 40 waves are found to pass a point in 20 s. If the waves have a wavelength of 0.015 m, calculate their speed.

19. Calculate the wavelength of a wave of frequency 0.1 Hz and speed 5 m/s.

20. State what is meant by the period of a wave.

21. If the speed of a water wave is 0.6 m/s and the wavelength of each wave is 6 cm, calculate
a) the frequency
b) the period of the wave.

22. Waves of wavelength 5 cm travel 120 cm in one minute.
Find their
a) speed
b) frequency
c) period.

23. A sound generator produces 25 waves every 0.1 s. If the speed of sound is 330 m/s, find:
a) the wavelength of the sound
b) the period of the waves.

24. a) List the members of the electromagnetic spectrum in order with the largest wavelength first.
b) What do all the members have in common?

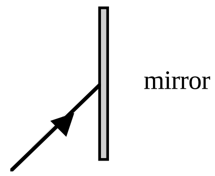
25. How far will radio waves travel in a) 2 m s b) 0.25 m s c) 1 m s.

26. Calculate the wavelength of waves of frequency a) 5 GHz b) 4 MHz c) 200 GHz.

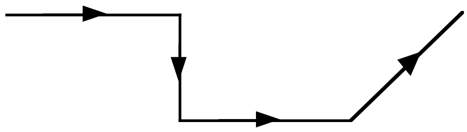
27. Calculate the transmission frequency of Radio Scotland broadcasting on 370 m on the Medium waveband. Give your answer in MHz.

Reflection

28. Copy and complete the diagram below labelling clearly
a) the angle of incidence
b) the angle of reflection
c) the normal.



29. The diagram shows the path of a ray of light . The ray was made to change direction using mirrors, but these have been left out.

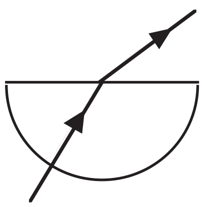


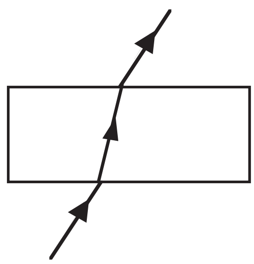
Copy the ray of light and complete the diagram by placing the mirrors in exactly the correct position.

30. If you were given a semicircular glass block, a ray box and single slit, describe how you would demonstrate total internal reflection. Include a diagram in your explanation.

31. Copy the following diagrams, showing the path of the rays when their direction is reversed.

a) b)





32. Explain, using a diagram, how a curved reflector is used in a torch to produce a beam of light.

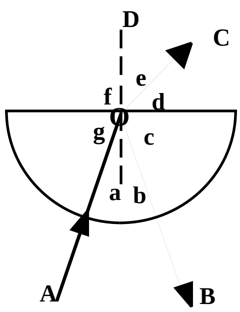
3. An outside broadcast unit at a football game beams television signals by means of a satellite dish to a receiver unit. Show by means of a diagram how
   a) the beam is sent
   b) the beam is received.

34. How can a curved reflector be used to ensure heat is directed more efficiently from an electric fire.

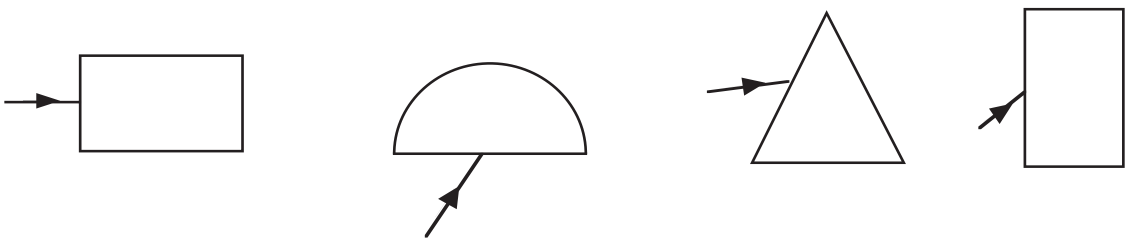
35. a) Optical fibre systems use repeater stations. What is the purpose of repeater stations?
   b) Light signals travel through glass at a speed of 2×10^8 m/s. How long would it take to travel between two repeater stations which were 100 km apart?

Refraction

36. Identify the following from the diagram shown below.
   i) the incident ray ii) the reflected ray iii) the refracted ray
   iv) the normal v) the angle of incidence vi) the angle of refraction
   vii) the angle of reflection.



37. Copy and complete the following diagrams.
   a) b) c) d)



38. By constructing accurate ray diagrams, describe the images produced using a converging lens of focal length 5 cm for the following object distances,
   a) 15 cm b) 8 cm c) 2 cm.

39. A projector can be used to produce a magnified image on a screen.
   a) Describe where the slide would have to be positioned, relative to the converging lens, to form this image.
   b) To ensure seeing the image the right way up what would have to be done to the slide?

40. A slide viewer produces a virtual, magnified image. Where would the object (the slide) have to be placed, relative to the lens, to produce this type of image?

41. Describe how the power of a lens could be found experimentally. This should include :
   a) a list of apparatus used
   b) a description of the procedure
   c) how the measurement(s) was used to find the power of the lens.

42. Find the power of the following lenses :
   a) f = 25 cm b) f = 10 cm c) f = 20 cm

43. Calculate the focal length of the following lenses :
   a) P = +2 D b) P = +2.5 D c) P = -8 D d) P = -5 D

44. a) Explain how being
      i) short sighted
      ii) long sighted would affect a person.
   b) Show how rays would pass through an eye resulting in
      i) short sight ii) long sight
   c) Explain which type of lens would be used to correct the above conditions.

NUMERICAL ANSWERS

1. 6800 m

3. 4.85 s

6. a) 4 s
   b) 1320 m

7. 333 m/s

8. 60 s

9. 0.029 s

10. 497 s

11. 0.06 s

15. a) 1 m
    b) 0.015 m
    c) 20 Hz
    d) 20 m/s

16. a) 2.5 m/s
    b) 0.625 Hz

17. A by 0.5 m/s

18. 0.03 m/s

19. 50 m