Waves
ANSWERS

Wave Properties

What Does Wave even Mean?
STOP AND CHECK (PAGE 6)

- A wave is something that vibrates.
- The medium of a wave is the material that is vibrated as the wave moves through.
- When a wave travels through a medium, the particles in that medium move up and down (or side to side).

Types of Waves
STOP AND CHECK (PAGE 10)

- The frequency of a wave is how many full waves pass a single point every second. The period of a wave is how long it takes for a full-wave to pass a single point. Period and frequency are the inverse of each other.
- The wavelength of a wave is the distance between two neighbouring crests (or two neighbouring troughs, or any other corresponding points).
- The crest of a wave is its highest point; the trough of a wave is its lowest point.

Ways to Draw Waves
STOP AND CHECK (PAGE 11)

- The lines of a wave diagram represent either crests or troughs of the wave.

- Light waves are drawn as single straight arrows, indicating the direction they are travelling in, as they are thought of as rays. Wavelength is indicated by the distance between each wave from peak to peak.

Wave Properties

QUICK QUESTIONS (PAGE 11)

- All waves involve the transfer of energy, by creating a disturbance that moves the medium up and down or side to side. They all have alternating crests and troughs, points of maximum energy transfer in opposite directions.
- Sound waves are mechanical because they require a material to travel through. (The most obvious material they travel through is air, but sound can travel through liquids and solids too). Sound waves are longitudinal because they vibrate in the same direction as the wave is travelling.
- Light waves are electromagnetic because they don't need a material to travel through. Light waves are transverse because they vibrate at a right angle to the direction the wave is travelling.
- Bonus question: The water in ocean waves moves in the same direction as the overall wave, as well as up and down.
- A wave diagram must feature the wave as evenly spaced lines (to represent the wavelength), and show the direction the wave is travelling in by arrows. Sound waves are usually shown as circular lines, water waves as straight lines, and light as rays (without an indicated wavelength).

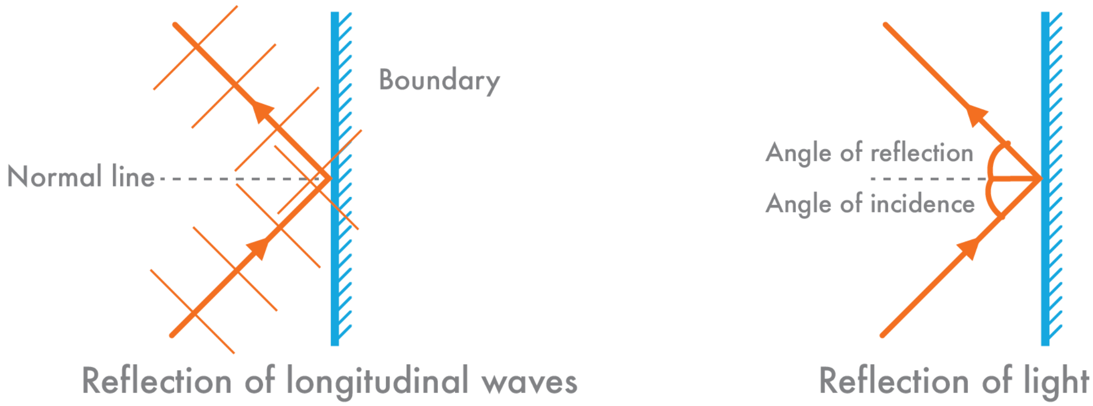
Wave Behaviour

Reflection and Refraction

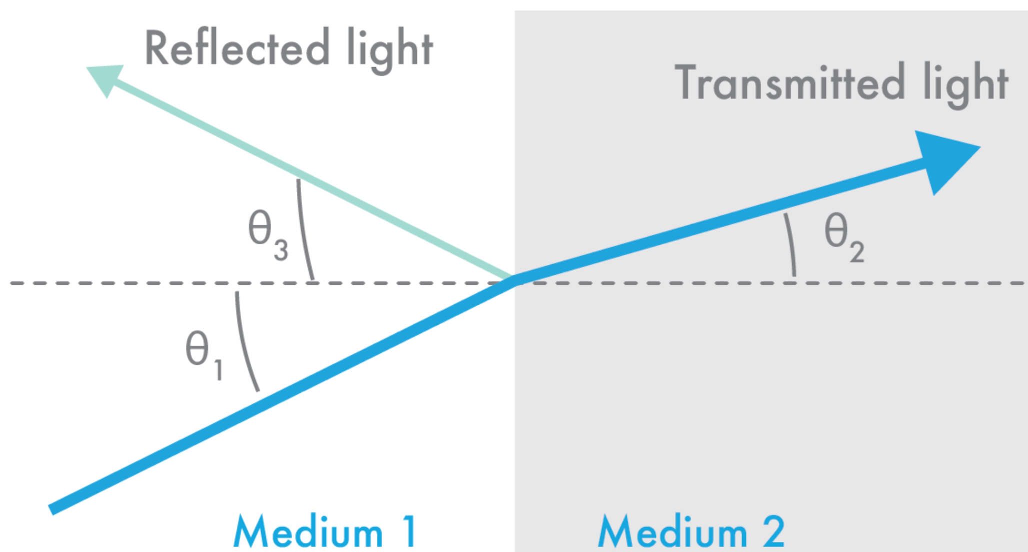
STOP AND CHECK (PAGE 6)

- Reflection occurs when a wave hits a boundary at some angle to the normal line and bounces back at the same angle. Refraction occurs when a wave passes from one medium to another, causing the angle to the normal to change. A wave that is reflected retains the same angle to the normal, but with a changed direction, while a wave that is refracted has a change in angle to the normal.

- Reflection:



- Refraction:



- Refraction involves the angle to the normal changing.

Reflection in a bit More Detail

STOP AND CHECK (PAGE 19)

- During refraction, the speed of the wave increases if the wavelength increases, and decreases if the wavelength decreases, while the frequency of the wave does not change.

- The refractive index of air is about 1. (1.0003 exactly)
- The higher the value of a medium's refractive index, the more it bends light towards the normal line.
- n refers to refractive index, where:
  - n_1 is the refractive index of the first medium.
  - n_2 is the refractive index of the second medium.
- The angle of a wave to the normal:
  - θ_1 is the angle of incidence: The angle to the normal of the light in the first medium.
  - θ_2 is the angle of refraction: The angle to the normal of the light in the second medium.

Total Internal Reflection

STOP AND CHECK (PAGE 22)

- Total internal reflection only occurs when the light ray travels from a medium with a higher refractive index to one with a lower refractive index ($n_1 > n_2$). For total internal reflection to occur the angle of incidence must also be greater than the critical angle.
- When the angle of incidence is larger than the critical angle, total internal reflection occurs.
- When the angle of incidence is equal to the critical angle, the wave is refracted along the barrier, the angle of refraction is 90°.
- When the angle of incidence is less than the critical angle, the wave is refracted into the second medium as usual.

$$n_1 \sin(\theta_c) = n_2 \sin(90°)$$

or

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Diffraction

STOP AND CHECK (PAGE 23)

- When a wave goes through a gap, it is diffracted; in other words, it bends and spreads out.
- The size of the gap does matter. The closer the size of the gap is to the wavelength of the wave, the more the wave will spread out after going through the gap.

When Waves Interfere

STOP AND CHECK (PAGE 27)

- When the crests and the troughs of two waves are in the same place (the waves are in phase), their amplitudes are added together to form a larger wave. When the crests of each wave overlap the troughs of the other (the waves are out of phase), their amplitudes cancel each other out, and a smaller wave (or no wave) results. When the waves are neither in phase nor perfectly out of phase, we focus on the points on the resultant wave where there is no total wave (the nodes) and points where there is maximum total wave (the antinodes). The process of two waves overlapping and adding together is called interference.
- A node is a point of a wave with no amplitude, while an antinode is a point of a wave with maximum amplitude.
- Two waves are "in phase" when they overlap perfectly, as their crests and troughs are in the same place. Two waves are (perfectly) "out of phase" when the crests of each wave overlap exactly with the troughs of the other.
- The interference pattern formed by two source interference means that all the nodes form in a line and all antinodes form in a separate line. Nodal lines are formed due to zero-waves being found along the in-line nodes (the waves are perfectly out of phase). Antinodal lines are formed due to the maximum wave size being formed along the in-line antinodes (the waves are perfectly in phase).
- The bright bands of the double-slit experiment come from antinodal lines, where the two diffracted light waves constructively interfere.

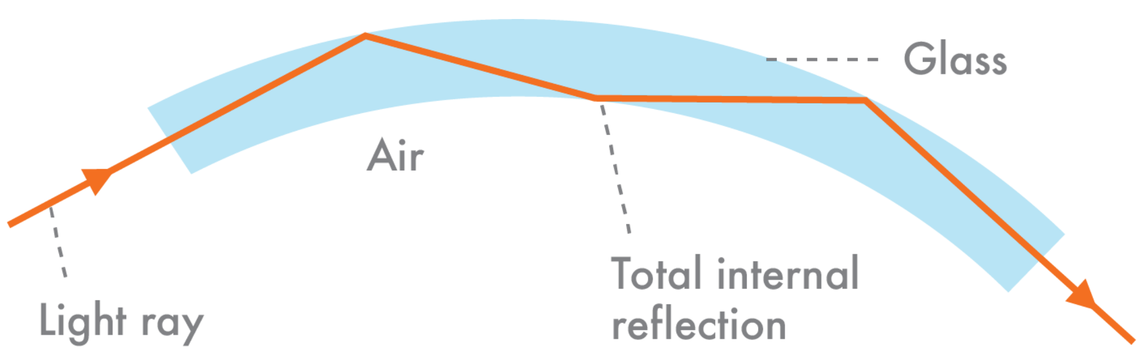
Wave Behaviour

QUICK QUESTIONS (PAGE 28)

- Light refracts when it passes from one medium to another. The angle of refraction (θ_2) is determined by the angle of incidence (θ_1), the refractive index of the first medium (n_1), and the refractive index of the second medium (n_2), as can be seen in Snell's Law:

  $$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$

  The higher the value of a medium's refractive index, the more it bends light towards the normal line; the lower the value of its refractive index, the more it bends light away from the normal line.
- Using Snell's Law:
  - $\theta_1 = 35°$
  - $n_1 = 1.33$
  - $n_2 = 1.0$
  - $1.33\times\sin(35°) = 1.0\times\sin(\theta_2)$
  - $\sin(\theta_2) = 0.76286$
  - $\theta_2 = \sin^{-1}(0.76286) = 49.7°$ (1 d.p.)
- A fibre optic cable has an inner core of a high refractive index and an outer coating with a lower refractive index. Light is shone through the cable at an angle greater than the critical angle for these two refractive indexes. This causes it to reflect back inside the cable, towards the other side. It approaches this side of the cable at the same angle, still greater than the critical angle, keeping the light inside. This repeats, even as the cable bends through the body, until the light reaches the end of the cable and lights up the inside of the body.



- When light passes through the two slits, two sources of overlapping diffracted light result. Where these two light waves meet in phase, along antinodal lines, they constructively interfere and result in bright bands on the screen. Where these two light waves meet perfectly out of phase, along nodal lines, they destructively interfere and result in bands of no light at all.

Light

How to Draw Ray Diagrams

STOP AND CHECK (PAGE 30)

- d_o is the distance between the object and the lens/mirror. d_i is the distance between the image and the lens/mirror.
- Mirrors reflect, and lenses refract.
- The object is the real item we are placing in front of the mirror. The image is a perceived duplication of the object formed when reflected or refracted rays converge

Important Definitions

STOP AND CHECK (PAGE 31)

- The principal axis is a straight line, parallel to the ground, that cuts through the middle of the mirror or lens.
- The focal point of a curved mirror is the point where all rays parallel to the principal axis are reflected through. The focal point of a lens is the point where all rays parallel to the principal axis are refracted through.
- Magnification is calculated using the equation $m = \frac{h_i}{h_o}$.
- Focal length: f
- Object height: h_o
- Image height: h_i

What are Images?

STOP AND CHECK (PAGE 33)

- A real image is created when light rays are reflected back to a single point and can be projected onto a screen.
- When light waves all meet up at the same point, they are converging.
- A virtual image is created when light appears to converge but isn't, and it cannot be projected onto a screen.

Curved Mirrors can Make Real and Virtual Images

STOP AND CHECK (PAGE 36)

- A concave mirror has a positive focal length.
- A convex mirror has a negative focal length.
- Incoming rays that are parallel to the principal axis are reflected through the focal point. Incoming rays that go through the focal point are reflected parallel to the principal axis.
- The image formed by a concave mirror is both real and inverted when the object is behind the focal point.

Lenses

STOP AND CHECK (PAGE 38)

- A positive focal length is in front of the lens, on the same side as the object. Convex lenses have positive focal lengths.
- A negative focal length is behind the lens, on the other side of the object. Concave lenses have negative focal lengths.
- If a ray passes through the centre of a lens, it continues to travel in a straight line.

Performing Calculations

STOP AND CHECK (PAGE 40)

- When the image is real, d_i is positive.

- When the image is virtual, d_i is negative.
- Concave mirrors and convex lenses have positive focal lengths, and convex mirrors and concave lenses have negative focal lengths.

Light

QUICK QUESTIONS (PAGE 40)

- Real images are formed when light rays converge at a point, while virtual images are formed when light rays only appear to converge at a point. Real images can be projected onto a screen, while virtual images cannot. Real images can only be formed by concave mirrors and convex lenses, while all concave and convex mirrors and lenses can produce virtual images.
- The image formed by the concave mirror here is enlarged, inverted, and real. The image formed by the convex mirror here is diminished, upright, and virtual.
- No image is formed.
- The image formed by the concave lens here is diminished, upright, and virtual.
- h_o = 2cm
  d_o = 4cm
  f = 2cm
  The image is the same size as the object.
  The object is behind the focal length of a concave mirror, so the image is real.