Contents

Waves

In **Waves** you need to know about the terms and concepts used to describe progressive and stationary waves. You need to be able to describe the similarities and differences between transverse and longitudinal waves and the principle of superposition of waves. You also need to describe the principles behind interference, diffraction and refraction.

Progressive and stationary waves

Progressive waves

Progressive waves transfer energy from one place to another. In order to move, the waves must have something to move through — this is called a medium (e.g. water waves move through water and sound moves through air). As the waves propagate they cause the particles of the medium to oscillate.

A **progressive wave** carries energy from one place to another.

Describing waves

When describing progressive waves the following terms are used:

- Amplitude is a measure of the energy of the wave. It measures the difference between the maximum displacement of the wave and the undisturbed medium that the wave passes through.
- Wave speed, c, is the rate of motion relative to the medium, measured in metres per second, $m\,s^{-1}$.
- Frequency, f, is the number of waves per second propagating through the medium, measured in hertz, Hz. 1 Hz = 1 complete wave per second. Frequency is related to the time period T (measured in seconds) of a wave (the time taken for one wave to repeat itself) through $f = 1/T$.
- Wavelength, λ, is the distance that the wave takes to repeat itself once, measured in metres, m.

Knowledge check 31

Calculate the frequency of an ultrasound wave with a time period of 40 μs.

Knowledge check 32

Calculate the frequency of red laser light with $\lambda = 632.8\,\text{nm}$.

Wave speed, frequency and wavelength are related to each other by the wave equation:

$$c = f\lambda$$

Phase and phase difference

As waves repeat themselves with a regular period or cycle, the **phase** of a wave describes the fraction of the wave cycle that has elapsed since the origin of the wave. Phase is usually measured as an angle, either in degrees (where one complete cycle is 360°) or in radians (where one complete cycle is 2π radians) *or* by the fraction of the cycle. For example, a wave that is a quarter of the time through its cycle has a phase of 90°, $\frac{\pi}{2}$ radians or $\frac{T}{4}$ fraction.

Two points on a wave, or two different waves, can be compared by their **phase difference**, Φ. This is the difference in the phase angle or fraction of the cycle between the two points. Two points with the same phase are said to be *in-phase* and two points that are exactly half a cycle or 180° or π radians apart are said to be in *anti-phase*.

The **phase** of a wave describes the fraction of the wave cycle that has elapsed since the origin of the wave.

Phase difference describes the difference in phase angle between two points on a wave or two different waves.

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Worked example

Water waves are transverse waves that travel along the surface of a body of water such as a lake. Figure 23 shows the displacement of three buoys on the surface of the lake as one such water wave travels across the surface of the lake.

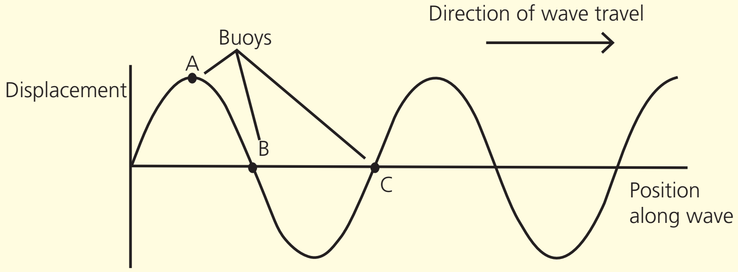

Figure 23 Water waves travelling across the surface of a lake

Buoys B and C are 12.0 m apart and one complete wave passes buoy C in 4.0 s.

a Calculate:
- **i** the frequency of the waves
- **ii** the speed of the waves

b State the phase difference between buoys:
- **i** A and B
- **ii** A and C

c Describe the motion of buoy B during the passage of the next complete wave cycle.

Answers

a i frequency $= \frac{1}{\text{time period}} = \frac{1}{4.0\text{ s}} = 0.25\text{ Hz}$

ii wave speed = frequency × wavelength = $0.25\text{ Hz} \times 12.0\text{ m} = 3.0\text{ m s}^{-1}$

b i A and B are one-quarter of a cycle out of phase, so their phase difference is $\frac{\pi}{2}$ radians or 90°.

ii A and C are three quarters of a cycle out of phase, corresponding to a phase difference of $\left(\frac{3\pi}{2}\right)$ radians or 270°.

c The motion of the buoy is at right angles to the direction of energy transfer of the wave. The buoy moves up to a position of maximum displacement, back to equilibrium, then to maximum negative displacement and finally back to the equilibrium position again.

Measuring the speed of sound

The speed of sound in air can be measured directly by using a pair of microphones and a datalogger. The microphones are placed a known distance d apart and a sound is generated close to one of the microphones. The time delay Δt between the two microphones picking up the sound is measured using the datalogger timing program, then the speed of sound is calculated via $c = d/\Delta t$.

Exam tip

Make sure that you know how to convert an angle in degrees to radians. 1° = (2π/360) radians. Common angles used are 90° = π/2 radians, 180° = π radians, 270° = 3π/2 radians and 360° = 2π radians.

Knowledge check 33

What is the phase difference in degrees and radians between a crest and neighbouring trough of a water wave?

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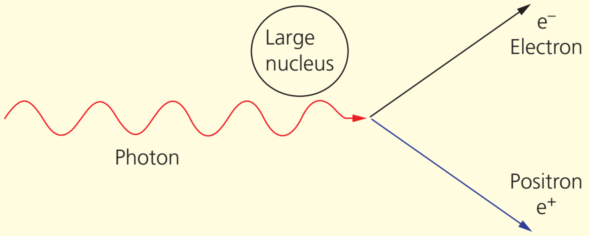


Figure 5

(a) State the name of this process. (1 mark)

(b) The electron has the following properties:

- rest-mass energy, m = 0.510999 MeV
- lepton number, L = +1
- baryon number, B = 0
- (relative) charge, $Q = -1.6 \times 10^{-19}$ C

State the corresponding values for the positron. (4 marks)

(c) Calculate the minimum energy of the photon in joules to undergo this process. State your answer to an appropriate number of significant figures. (3 marks)

(d) Describe what is likely to happen to the positron shortly after its creation. (2 marks)

e You need to know (learn) the mechanisms of both pair production and annihilation.

Student answer

(a) Pair production ✓.

(b) Positron values are:

- rest-mass energy, m = 0.510999 MeV ✓
- lepton number, L = –1 ✓
- baryon number, B = 0 ✓
- charge, $Q = +1.6 \times 10^{-19}$ C ✓

e Although this is a straightforward question, the rest-mass energy is stated rather than the more common 'mass'. You must remember that both mass and rest-mass energy are the same for particles and antiparticles.

(c) The energy, E, of the photon must be (rest-mass energy of electron + rest-mass energy of positron):

E (eV) = 2 × 0.510999 MeV = 1.021998 ✓ MeV

E (J) = 1.021998×10^{6} eV × 1.60×10^{-19} J eV^{-1} = 1.64×10^{-13} J ✓

(The answer must be to 3 significant figures as e is given to 3 sf ✓)

e A-grade students avoid the most common error in this question of failing to convert the energy in MeV into joules.

(d) The positron is likely to immediately meet another electron and undergo annihilation ✓, producing a pair of gamma photons ✓.

e C-grade students will not give the emission of a pair of gamma rays as part of their answer.

Question 14

During electron capture a quark changes its identity.

e 'Identity' in this case means what type of quark it is.

(a) Explain what is meant by electron capture. (4 marks)

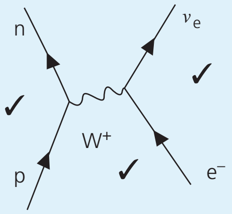
(b) Draw a Feynman diagram for electron capture. (3 marks)

Student answer

(a) An (atomic/orbital/shell) electron ✓ interacts with a proton ✓ in the nucleus (via the weak interaction) ✓ forming a neutron and an electron neutrino ✓.

e You could also describe this decay in terms of a change in quark identity (u to d). C-grade students may just state 'the capture of an electron by a proton' without giving the outcome of the process.

(b)



Question 15

A laser emits a ray of monochromatic, coherent blue light that travels through a single slit which is much narrower than the wavelength of the light. A diffraction pattern is produced on a distant screen, as shown in Figure 6.

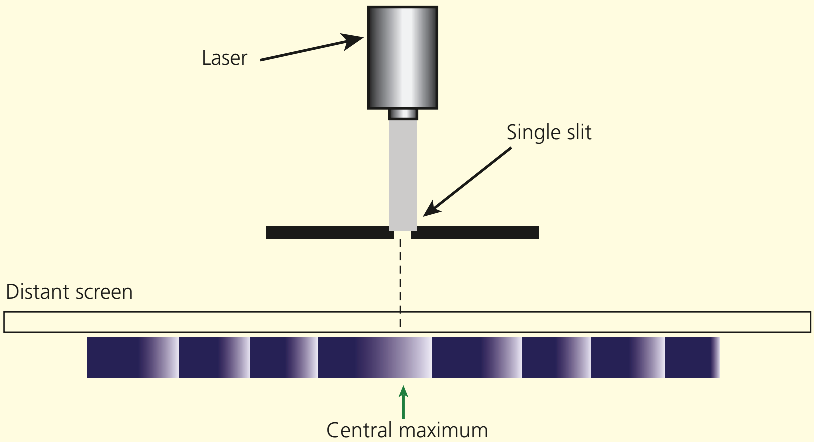


Figure 6