Topic 3 Waves and the Particle Nature of Light
3B The behaviour of waves

3B.1 Wave phase and superposition

1 Rays show the direction of travel of the wave energy, whilst wavefronts show positions of identical phase position. Wavefronts and rays are always at right angles.

2 180° or π radians

3 (a) 0; or 360°; or 2π rad

(b) 180° or π rad

(c) 180°, π rad; or 900°, 5π rad

4 t = 1.0 s: same pulses now separated by 3.0 cm

t = 2.0 s: pulses now overlap by 1.0 cm in the middle, and the overlap portion is at displacement = −1.0 cm

t = 3.0 s: same pulses but now on opposite sides of each other and separated by 1.0 cm

3B.2 Stationary waves

1 λ = 0.75 m; f = 560 Hz

2 (a) 433 m s^{-1}

(b) 293 Hz

3 A graph of f on y-axis against $\frac{1}{L}$ on x-axis. Gradient is approximately 115, making mass per unit length approximately 4.4×10^{-4} kg m^{-1}.

4 Students' own answers, using $v = f\lambda = \sqrt{\frac{T}{\mu}}$

so $\mu = \frac{T}{v^2} = \frac{T}{f^2\lambda^2}$:

e.g. estimated frequency is 256 Hz (middle C); estimated wavelength for fundamental is twice size of piano = 2 m; from school Young modulus experiments, wire snaps after about 2 kg loading, but piano wire is very thick, so estimate tension as 100 N:

$\mu = \frac{T}{f^2\lambda^2} = \frac{100}{(256^2 \times 2^2)} = 3.8 \times 10^{-4}$ kg m^{-1}

3B.3 Diffraction

1 The wave energy could be diffracted around the tanker and still hit the small boat behind.

2 (a) The degree of diffraction depends on the relative size of the diffracting object and the wavelength. The radio wavelength is the same in both cases, and so it is more diffracted in the first instance, where the radio dish is closer to the same size as the wavelength.

(b) General broadcast transmissions would be preferred in the first instance, as the waves spread over a wide area. In the second instance, a directed beam would be preferred for situations in which the intended recipients location is known and fixed, such as communicating with an orbiting satellite.

3 Grating spacing $d = 1 \times 10^{-6}$ m. Therefore, $\lambda_1 = 4.48 \times 10^{-7}$ m; $\lambda_2 = 5.02 \times 10^{-7}$ m; $\lambda_3 = 5.88 \times 10^{-7}$ m

4 For λ_1, $n_{max} = 2$; λ_2, $n_{max} = 1$; λ_3, $n_{max} = 1$

3B.4 Wave interference

1 Coherent waves have the same frequency and a constant phase difference.

2 (a) 0°; they are in phase

(b) $\frac{\lambda}{2}$; they are 180° out of phase

(c) λ; 0°; they are in phase

(d) The fringes would be further apart.

3B Exam practice

1 C

2 B

3 B

4 C

5 D

6 QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence, including:

Identifies two rays of light

Two rays have same frequency / come from same source / are coherent

Path difference (between the two reflected rays)

They superpose (when they meet) / constructive and destructive interference occur

If they meet in phase / nλ / λ path difference, constructive interference / bright fringe

If they meet in antiphase / (n + ½) / λ / ½λ path difference, destructive interference / dark fringe

7 (a) $d = 2 \times 10^{-6}$ m

(b) λ = □□□□Θ/□

λ = 5.18×10^{-7} m

(c) □ = □□□□Θ/λ

sin 90° = 1 so $n = \frac{d}{\lambda}$

□ = 4

8 (a) Unit of LHS = m s^{-1}

Unit of T = kg m s^{-2}

Unit of μ = kg m^{-1}

(b) (i) Waves travel in both directions along wire

Waves superpose / interference effect / superposition occurs

Producing nodes and antinodes

OR node is produced where waves are 180º out of phase / antiphase

OR antinode is produced where waves are in phase

OR node produced at a point of destructive interference

OR antinode produced at a point of constructive interference

OR produces points / positions of constructive interference and points / positions of destructive interference

(ii) λ = 4 m

(iii) $v = \sqrt{\frac{150\ \text{N}}{0.005\ \text{kg m}^{-1}}}$

v = 173 m s^{-1}

(iv) Any three from:

At most frequencies there is no standing wave / as frequency changes from a standing wave the wave no longer occurs / standing waves only occur at some frequencies

At higher frequencies there are more nodes / antinodes / loops (not 'more waves')

There is always a node at either end OR number of nodes = number of antinodes plus one

Amplitude is less if there is a greater number of nodes

Length = nλ/ 2 / after first standing wave, they occur when frequency ×2, ×3, ×4, etc. / for frequency nf_0

9 (a) Diffraction is the spreading out of a wave (not bending, not bending round, not just change in direction) as it passes (through) a gap / slit / aperture OR passes (around) an obstacle

(b) Indication that two or more (waves) meet / overlap / coincide and the (total) displacement at a point is the sum of the individual displacements

(c) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, including:

Identifies that the rock(s) or gap(s) in the rocks cause diffraction

OR cause wave(front)s to become curved / waves to spread out

Waves / wavefronts (from each gap) overlap / meet

(At some places) waves are in phase (accept path difference equal to whole number of wavelengths)

OR (at some places) waves are in antiphase (accept path difference equal to whole number of wavelengths plus half a wavelength)

Constructive superposition / interference occurs

OR destructive superposition / interference occurs (must correspond to phase differences if referred to elsewhere)

Maximum / large amplitude erodes beach / disturbs sand the most

OR minimum / zero amplitude does not disturb sand (as much)

OR reduced amplitude disturbs sand less

10 (a) Half wave vibration, with wire at a maximum in the centre and S and T still at the fixed points

Some indication that the whole wire moves up and down with a node in the centre and S and T always fixed – perhaps shown as a dashed curve opposite a solid curve

(b) Ends fixed at S and T with 1.5 wavelengths shown in between

Alternate positions for nodes also shown (perhaps as a dashed line)

(c) Plucking the wire sends waves along it.

These reflect from the fixed end points.

The waves and their reflections are coherent / have the same frequency and a constant phase relationship.

So they superpose/interfere (to produce a stationary wave).