

Waves that add: fringes and grating spectra

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Every answer shows the formula, the substitution and the final value with its unit in bold. Check the powers of ten carefully, because most mistakes in this topic come from converting millimetres and nanometres to metres.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB C.3

Problem 1 Conditions for interference

1. Constructive: path difference = $n\lambda$ ($n = 0, 1, 2, \dots$). Destructive: path difference = $(n + \frac{1}{2})\lambda$.
2. Coherent sources emit waves of the same frequency with a constant phase difference.
3. The atoms in each bulb emit light in random bursts, so the phase difference between the two bulbs changes randomly and the pattern averages out to uniform brightness.

Problem 2 Two loudspeakers

1. $\lambda = v/f = 340 \div 680 = \mathbf{0.5 \text{ m}}$.
2. Path difference = $6.15 - 5.40 = \mathbf{0.75 \text{ m}}$.
3. $0.75 \div 0.5 = 1.5$ wavelengths, an odd number of half wavelengths, so the waves are in antiphase and the sound is **quiet**.

Problem 3 Adding two pulses

1. $3.0 + 2.0 = \mathbf{5.0 \text{ cm}}$.
2. $3.0 + (-2.0) = \mathbf{1.0 \text{ cm}}$.
3. The **principle of superposition**: the resultant is the sum of the displacements.

Problem 4 Fringe spacing

1. $w = \lambda D/s$.
2. $w = 633 \times 10^{-9} \times 1.50 \div 0.25 \times 10^{-3} = \mathbf{3.8 \text{ mm}}$.
3. $3 \times 3.798 = \mathbf{11.4 \text{ mm}}$.

Problem 5 Lines per millimetre

1. 300 lines/mm: $d = 1 \div 300 \text{ mm} = 3.33 \mu\text{m}$. 800 lines/mm: $d = 1 \div 800 \text{ mm} = \mathbf{3.33 \mu\text{m}}$ and $\mathbf{1.25 \mu\text{m}}$.
2. The 800 lines/mm grating: smaller d gives a larger $\sin \theta = n\lambda/d$.
3. $800 \times 5.0 = \mathbf{4000 \text{ lines}}$.

Problem 6 Reading a fringe pattern

1. Neighbouring bright fringes are **2.0 mm** apart.
2. The second bright fringe is at **4.0 mm** from the centre.
3. $s = \lambda D/w = 600 \times 10^{-9} \times 1.50 \div 2.0 \times 10^{-3} = \mathbf{0.45 \text{ mm}}$.

Problem 7 Waves through gaps

1. 20 cm: little spreading, a straight beam with slightly curved edges. 2.0 cm: clear spreading with nearly circular wavefronts. 0.5 cm: strong spreading, almost circular waves.
2. The **0.5 cm gap**, since it is much narrower than the wavelength.
3. Sound has wavelengths of about 0.3 m to 3 m, similar to doorways, so it diffracts strongly. Light has a wavelength of about 500 nm, much smaller than any gap, so it hardly diffracts at all.

Problem 8 Wavelength from fringes

1. $w = 12.0 \text{ mm} \div 10 = \mathbf{1.20 \text{ mm}}$.
2. $\lambda = ws/D$.
3. $\lambda = 1.20 \times 10^{-3} \times 0.50 \times 10^{-3} \div 1.20 = 0.000 \text{ m} = \mathbf{500 \text{ nm}}$.

Problem 9 Red light to blue light

1. $w = \lambda D/s$, so w is directly proportional to λ .
2. $w = 2.4 \times 450 \div 650 = \mathbf{1.66 \text{ mm}}$.
3. Doubling s halves w : $1.662 \div 2 = \mathbf{0.831 \text{ mm}}$.

Problem 10 Angles from a grating

1. $d = 1 \div 400\,000 = \mathbf{2.50 \times 10^{-6} \text{ m}}$.
2. $\sin \theta = \lambda/d = 0.208$, $\theta = \mathbf{12^\circ}$.
3. $\sin \theta = 2 \times 0.208 = 0.416$, $\theta = \mathbf{24.6^\circ}$.

Problem 11 How many spots?

1. $d = 1 \div 600\,000 = \mathbf{1.67 \text{ }\mu\text{m}}$.
2. n_{max} is below $d/\lambda = 2.56$, so the highest order is **2**.
3. $\sin \theta = 2 \times 650 \times 10^{-9} \div 0.0000 = 0.78$, $\theta = \mathbf{51.3^\circ}$. Orders -2 to $+2$ give **5 bright spots**.

Problem 12 Wavelength from a measured angle

1. $d = 1 \div 500\,000 = \mathbf{2.00 \times 10^{-6} \text{ m}}$.
2. $\lambda = d \sin \theta \div n = 2.00 \times 10^{-6} \times \sin 20.0^\circ \div 1 = 2.00 \times 10^{-6} \times 0.342 = 0.000 \text{ m} = \mathbf{684 \text{ nm}}$.

3. About 684 nm is **red** light.

Problem 13 A white light spectrum

1. $d = 2.00 \mu\text{m}$. Violet: $\sin \theta = 0.200$, $\theta = \mathbf{11.5^\circ}$. Red: $\sin \theta = 0.350$, $\theta = \mathbf{20.5^\circ}$.
2. Red is deviated more because θ increases with wavelength ($\sin \theta = n\lambda/d$).
3. Second-order red: $\sin \theta = 0.700$, $\theta = 44.4^\circ$. Third-order violet: $\sin \theta = 0.600$, $\theta = 36.9^\circ$.
The third-order violet is at a smaller angle than the second-order red, so they **overlap**.

Problem 14 Single-slit spreading

1. $\sin \theta = \lambda/a = 600 \times 10^{-9} \div 0.10 \times 10^{-3} = \mathbf{0.006}$.
2. $\theta = \mathbf{0.344^\circ}$.
3. Half-width = $D \tan \theta = 2.0 \times 0.006 = 12 \text{ mm}$, so the full width is **24 mm**.

Problem 15 Phase difference

1. $1.25 \times 10^{-6} \div 500 \times 10^{-9} = \mathbf{2.5 \lambda}$.
2. Phase difference = $2\pi \times 2.5 = \mathbf{5\pi \text{ rad (15.7 rad)}}$.
3. 2.5 is an odd number of half wavelengths ($5 \times \lambda/2$), so the point is **dark**.

Problem 16 A film over one slit

1. Light through the film travels more optical path, so the position of zero overall path difference moves towards the slit with the film.
2. $(n - 1)t = N\lambda$, with $N = 8$.
3. $t = N\lambda \div (n - 1) = 8 \times 600 \times 10^{-9} \div 0.50 = 0.000 \text{ m} = \mathbf{9.6 \mu\text{m}}$.

Problem 17 Fringe spacing against distance

1. A straight line through the origin: w is directly proportional to D , as expected from $w = \lambda D/s$.
2. Gradient = $(3.25 - 0.65) \div (2.50 - 0.50) = \mathbf{1.3 \text{ mm/m}} = 0.0013$ (no unit, m per m).
3. gradient = λ/s , so $\lambda = 0.0013 \times 0.40 \times 10^{-3} = 0.000 \text{ m} = \mathbf{520 \text{ nm}}$.

Problem 18 Two colours together

1. $w = \lambda D/s$: 450 nm gives **1.8 mm**; 600 nm gives **2.4 mm**.
2. $4 \times 1.8 = 7.2 \text{ mm}$ and $3 \times 2.4 = 7.2 \text{ mm}$, which are equal (the ratio 450 : 600 = 3 : 4).
3. The distance is **7.2 mm**.

Problem 19 Spot the error

1. 0.0020 mm is $2.0 \times 10^{-6} \text{ m}$, not $2.0 \times 10^{-3} \text{ m}$: the conversion from mm to m was missed by a factor of 1000.

2. $\lambda = d \sin \theta \div n = 2.00 \times 10^{-6} \times 0.500 \div 2 = 5.00 \times 10^{-7} \text{ m} = \mathbf{500 \text{ nm}}$.
3. $5.0 \times 10^{-4} \text{ m}$ is half a millimetre, far larger than any visible wavelength (400 to 700 nm).

Problem 20 Close wavelengths

1. $d = 1.667 \text{ }\mu\text{m}$. 577 nm: $\sin \theta = 0.6924$, $\theta = \mathbf{43.82^\circ}$. 579 nm: $\sin \theta = 0.6948$, $\theta = \mathbf{44.01^\circ}$.
2. Separation = $44.01 - 43.82 = \mathbf{0.19^\circ}$.
3. With more lines illuminated the maxima become narrower, so two close angles can be seen as separate lines instead of one blurred spot.