

Exercise walk-through

7.1.1

Phase difference, the oscilloscope and intensity

A-Level Physics

Sheet 7.1.1 – what you need to know

You must be able to:

- find the **phase difference** of two points or two oscillations
- read the period, frequency and amplitude off an **oscilloscope** trace
- use $\text{intensity} = \frac{\text{power}}{\text{area}}$, including a point source
- use $\text{intensity} \propto \text{amplitude}^2$

What the exam asks

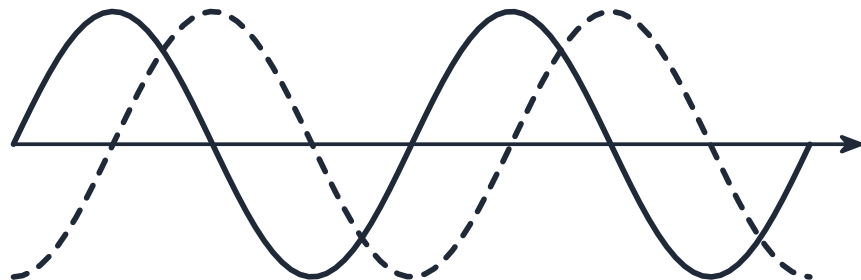
“State the phase difference between the oscillations of points R and T.” [1]

“Determine the time-base setting, in s cm^{-1} , of the CRO.” [2]

“Determine, in terms of I_0 , the final intensity of the wave.” [2]

Practise on exercise sheet 7.1.1, then try the real exam questions on past-paper sheet 7.1.1.

Phase, drawn



phase difference

Two points are **in phase** when they move together, and antiphase when one is exactly half a cycle behind.

Two points one wavelength apart are **in phase** (phase difference 0 or 2π); half a wavelength apart they are exactly **out of phase** (π).

Phase difference

$$\Delta\phi = \frac{x}{\lambda} \times 360^\circ$$

$$\Delta\phi = \frac{t}{T} \times 360^\circ$$

$360^\circ = 2\pi$ rad. Half a wavelength apart: **antiphase**, 180° .

A wave with $\lambda = 0.80$ m and $T = 0.40$ s

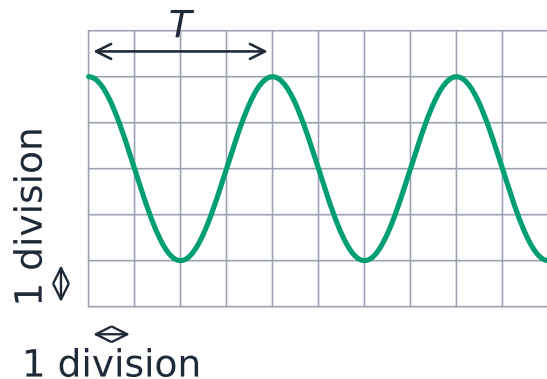
two points 0.30 m apart:

$$\Delta\phi = \frac{x}{\lambda} \times 360^\circ = \frac{0.30 \text{ m}}{0.80 \text{ m}} \times 360^\circ = 135^\circ, \text{ or } \frac{3}{4}\pi \text{ rad}$$

crests 0.10 s apart:

$$\Delta\phi = \frac{t}{T} \times 360^\circ = \frac{0.10 \text{ s}}{0.40 \text{ s}} \times 360^\circ = 90^\circ$$

Reading a CRO trace



period = $n \times$ timebase · peak voltage = $n \times$ Y-gain

- a **cathode-ray oscilloscope** (CRO)
plots voltage against time
- **time-base** : seconds per division across → read T
- **y-gain** : volts per division up → read amplitude

5 ms/div, one cycle = 4 div

$$T = (4 \text{ div})(5 \text{ ms div}^{-1}) = 20 \text{ ms}$$

$$f = \frac{1}{T} = \frac{1}{0.020 \text{ s}} = 50 \text{ Hz}$$

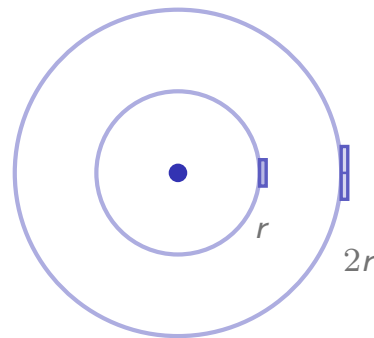
Intensity

Power through unit area:

$$I = \frac{P}{A}, \quad I \propto (\text{amplitude})^2.$$

A **point source** spreads over a sphere
 $4\pi r^2$:

$$I = \frac{P}{4\pi r^2}, \quad I \propto \frac{1}{r^2}.$$



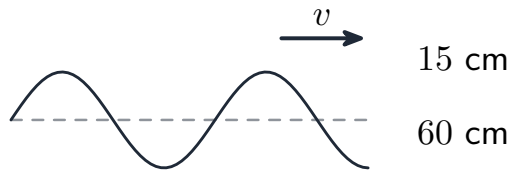
same power,
 $4 \times$ the area
 $\Rightarrow I/4$

60 W lamp, $r = 2.0$ m

$$I = \frac{P}{4\pi r^2} = \frac{60 \text{ W}}{4\pi (2.0 \text{ m})^2} \\ \approx 1.2 \text{ W m}^{-2}$$

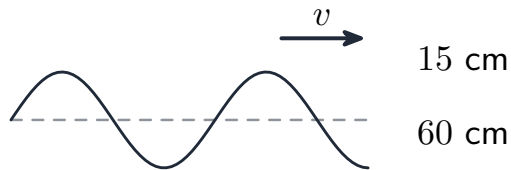
Exercise 2.1

2.1 Two points on a wave are 15 cm apart, and the wavelength is 60 cm. Calculate the phase difference between the oscillations of the two points. [2]



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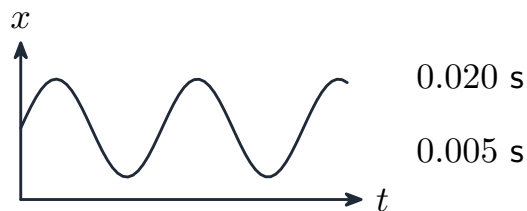


2.1

- $\Delta\phi = \frac{x}{\lambda} \times 360^\circ$
- $\Delta\phi = \frac{x}{\lambda} \times 360^\circ = \frac{15}{60} \times 360^\circ = \mathbf{90^\circ}$

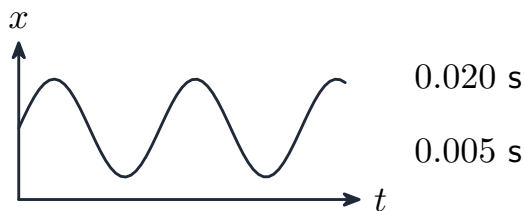
Exercise 2.2

2.2 Two oscillations have the same period, 0.020 s . One reaches its crest 0.005 s after the other. Calculate the phase difference, in radians. [2]



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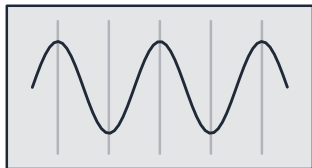
2.2

- phase difference from a time, $\Delta\phi = \frac{t}{T} \times 2\pi$

$$\Delta\phi = \frac{t}{T} \times 2\pi = \frac{0.005}{0.020} \times 2\pi = \frac{\pi}{2} \text{ rad}$$

Exercise 2.3

2.3 An oscilloscope shows exactly two cycles of a signal across 10 divisions. The time-base is set to 0.20 ms per division. Calculate the frequency of the signal. [2]

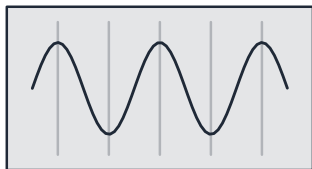


10

0.20 ms

Exercise 2.3

2.3 An oscilloscope shows exactly two cycles of a signal across 10 divisions. The time-base is set to 0.20 ms per division. Calculate the frequency of the signal. [2]



10

0.20 ms

2.3

- two cycles span 10 divisions, so one cycle spans 5.0: $T = (\text{divisions}) \times (\text{time-base}) = 5.0 \times 0.20 \text{ ms} = 1.0 \text{ ms}$
- $f = 1/T = \mathbf{1.0 \times 10^3 \text{ Hz}}$

Exercise 2.4

2.4 A laser beam of power 2.0 mW has a cross-sectional area of 1.5 mm^2 . Calculate the intensity of the beam. [2]



Exercise 2.4

2.4 A laser beam of power 2.0 mW has a cross-sectional area of 1.5 mm². Calculate the intensity of the beam. [2]



2.4

- $I = P/A$ with $A = 1.5 \times 10^{-6} \text{ m}^2$

$$I = \frac{P}{A} = \frac{2.0 \times 10^{-3}}{1.5 \times 10^{-6}} = \mathbf{1.3 \times 10^3 \text{ W m}^{-2}}$$

Exercise 3.1

3.1 Two points on a progressive wave are 0.12 m apart. The phase difference between their oscillations is 60° . What is the wavelength? [1]

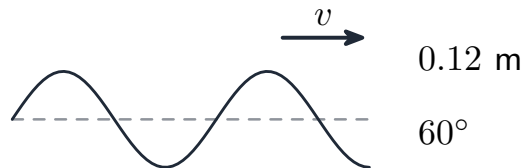


A 0.020 m

B 0.36 m

C 0.72 m

D 7.2 m



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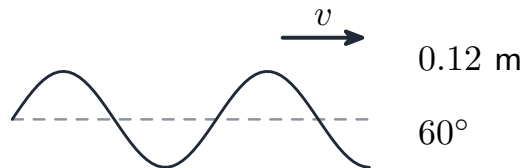


A 0.020 m

B 0.36 m

C 0.72 m

D 7.2 m



3.1 C

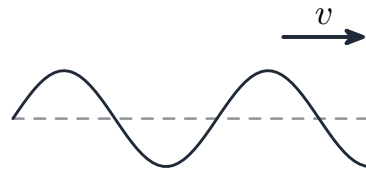
- $\lambda = \frac{360^\circ}{\Delta\phi} \times x = 6 \times 0.12 = 0.72 \text{ m}$
- **A** turns the ratio upside down

Exercise 3.2

3.2 The amplitude of a progressive wave falls to one third of its value, and the frequency does not change. What fraction of the original intensity remains? [1]

☐

- A** $\frac{1}{3}$
B $\frac{1}{6}$
C $\frac{1}{9}$
D $\frac{1}{27}$

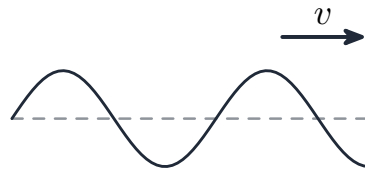


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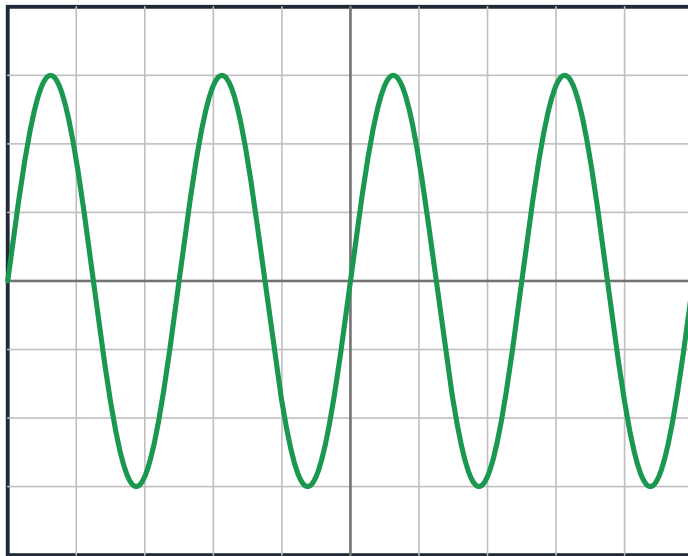


3.2 C

- intensity $\propto$ (amplitude)², so the intensity falls to $(\frac{1}{3})^2 = \frac{1}{9}$
- **A** treats the intensity as proportional to the amplitude

Setup for exercise 3.3

3.3 A signal generator drives a loudspeaker and is also connected to a cathode-ray oscilloscope. The trace is shown, and each square is one division. The time-base is set to 0.20 ms per division and the y-gain to 10 mV per division.



Exercise 3.3 (a)

(a) Determine the period of the signal.

[2]

Exercise 3.3 (a)

(a) Determine the period of the signal.

[2]

(a) one cycle spans 2.5 divisions

- $T = (\text{divisions}) \times (\text{time-base}) = 2.5 \times 0.20 \text{ ms} = \mathbf{0.50 \text{ ms}}$

Exercise 3.3 (b)

(b) Calculate the frequency of the sound from the loudspeaker.

[1]

Exercise 3.3 (b)

(b) Calculate the frequency of the sound from the loudspeaker. [1]

$$(b) \ f = 1/T = 1/(0.50 \times 10^{-3}) = \mathbf{2.0 \times 10^3 \text{ Hz}}$$

Exercise 3.3 (c)

(c) Determine the amplitude of the signal.

[1]

Exercise 3.3 (c)

(c) Determine the amplitude of the signal.

[1]

(c) amplitude $A = n \times (\text{volts per division}) = 3.0 \text{ divisions} \times 10 \text{ mV} = \mathbf{30 \text{ mV}}$

Exercise 3.3 (d)

(d) The speed of sound is $340 \frac{\text{m}}{\text{s}}$. Calculate the wavelength of the sound.

[2]

Exercise 3.3 (d)

(d) The speed of sound is $340 \frac{\text{m}}{\text{s}}$. Calculate the wavelength of the sound. [2]

(d) $\lambda = v/f$

$$\lambda = \frac{v}{f} = \frac{340}{2000} = \mathbf{0.17 \text{ m}}$$

Exercise 3.3 (e)

(e) The output of the signal generator is turned down at the same frequency, and the amplitude of the trace falls to 2.0 divisions. The amplitude of the sound is proportional to the amplitude of the signal. Calculate $\frac{\text{new intensity}}{\text{original intensity}}$ for the sound. [2]

Exercise 3.3 (e)

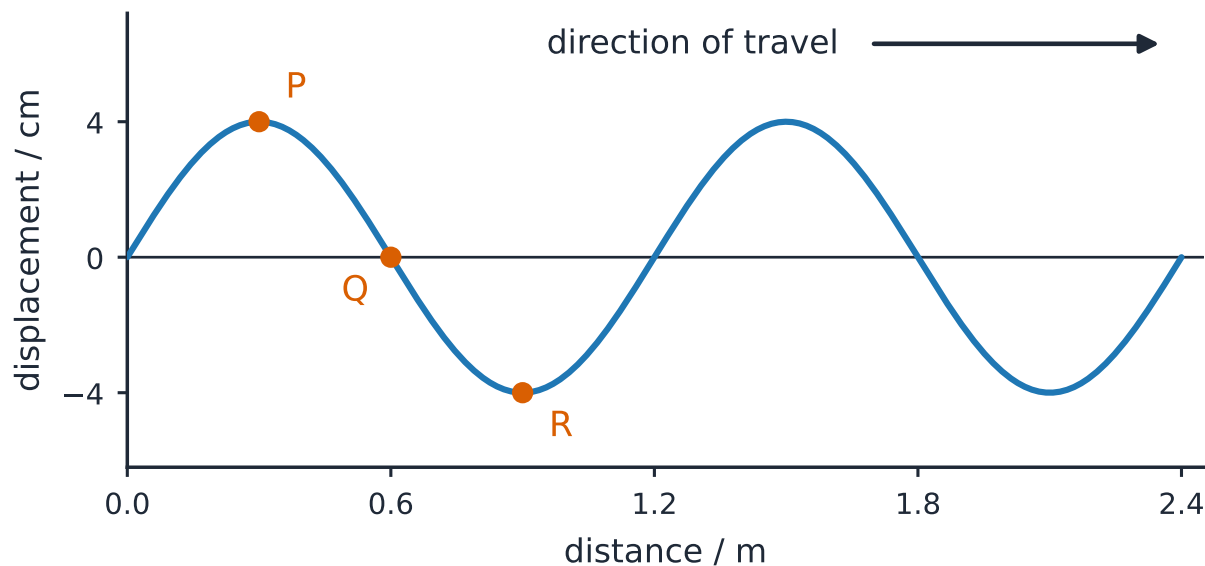
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(e) $\text{intensity} \propto (\text{amplitude})^2$

$$\frac{I_{\text{new}}}{I_{\text{original}}} = \left(\frac{2.0}{3.0} \right)^2 = \mathbf{0.44}$$

Setup for exercise 3.4

3.4 A transverse wave travels to the right along a rope at $3.0 \frac{\text{m}}{\text{s}}$. The graph shows the displacement of the rope against distance at one instant. P is at a crest, Q has zero displacement and R is at a trough.



Exercise 3.4 (a)

(a) Calculate the frequency of the wave.

[2]

Exercise 3.4 (a)

(a) Calculate the frequency of the wave.

[2]

(a) from the graph $\lambda = 1.2 \text{ m}$

$$f = \frac{v}{\lambda} = \frac{3.0}{1.2} = \mathbf{2.5 \text{ Hz}}$$

Exercise 3.4 (b)

(b) State the phase difference between the oscillations of P and R.

[1]

Exercise 3.4 (b)

(b) State the phase difference between the oscillations of P and R. [1]

(b) **180°**, or π rad: P and R are half a wavelength apart

Exercise 3.4 (c)

(c) State the direction in which Q is moving at this instant, and explain how you know.[2]

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(c) State the direction in which Q is moving at this instant, and explain how you know.[2]

(c) **upwards**

- the wave moves to the right, so the crest now at P moves towards Q; drawing the wave a moment later shows the rope at Q above the axis

Exercise 3.4 (d)

(d) State the displacement of P a quarter of a period later.

[1]

Exercise 3.4 (d)

(d) State the displacement of P a quarter of a period later. [1]

(d) **zero:** in a quarter of a period P moves from the crest back to its rest position

Exercise 3.4 (e)

(e) The amplitude of the wave is increased to 6.0 cm at the same frequency. Calculate $\frac{\text{new intensity}}{\text{original intensity}}$. [1]

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$$(e) \text{ intensity} \propto (\text{amplitude})^2: \frac{I_2}{I_1} = \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{6.0}{4.0}\right)^2 = \mathbf{2.25}$$

Exercise 3.5 (a)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W.

(a) Define intensity.

[1]

Exercise 3.5 (a)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W.

(a) Define intensity. [1]

(a) intensity is the power per unit area, where the area is at right angles to the direction of travel of the wave

Exercise 3.5 (b)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W .

(b) Show that the intensity of the sound 5.0 m from the loudspeaker is about $2.5 \times 10^{-3} \text{ W m}^{-2}$. [2]



0.80 W

5.0 m

Exercise 3.5 (b)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W.

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0.80 W

5.0 m

(b) the power spreads over a sphere of area $4\pi r^2$

$$I = \frac{P}{4\pi r^2} = \frac{0.80}{4\pi \times 5.0^2} = \mathbf{2.5 \times 10^{-3} \text{ W m}^{-2}}$$

Exercise 3.5 (c)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W.

(c) State the distance from the loudspeaker at which the intensity is one quarter of this value. [1]

Exercise 3.5 (c)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W.

(c) State the distance from the loudspeaker at which the intensity is one quarter of this value. [1]

(c) **10** m: twice the distance spreads the power over four times the area

Exercise 3.5 (d)

3.5 A small loudspeaker radiates sound evenly in all directions. The sound power is 0.80 W.

(d) The amplitude of the sound wave 5.0 m from the loudspeaker is a . Determine the amplitude 10 m from the loudspeaker, in terms of a . [2]

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(d) intensity $\propto$ (amplitude)², so one quarter of the intensity means half the amplitude

- amplitude = **$a/2$**