7.1.1 Phase difference, the oscilloscope and intensity

Name: _____ Class: _____ Date: _____ **Total: 31 marks**

KEY WORDS phase difference • oscilloscope • intensity • antiphase • amplitude

Objective

Answer exam questions on **phase difference**, the **oscilloscope** and **intensity**: comparing two oscillations, reading a trace with its time-base and y-gain, and how intensity depends on power, area and amplitude. Syllabus 7.1, learning outcomes 2, 3 and 7.

You must be able to:

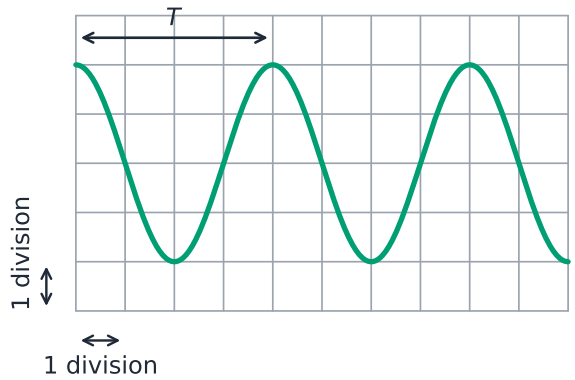
- calculate the phase difference between two points on a wave, or two oscillations, in degrees or radians
- read the period, frequency and amplitude of a signal from an oscilloscope trace
- use intensity = power ÷ area, including a point source that spreads its power over a sphere
- use intensity $\propto$ (amplitude)^2

1 Key knowledge and worked examples

■ **Key knowledge: phase difference**

Idea	Rule
phase difference	how far one oscillation is ahead of another, as a fraction of a cycle: one cycle = 360° = 2π rad
from a distance x along a wave	$\Delta\phi = \frac{x}{\lambda} \times 360°$
from a time difference t	$\Delta\phi = \frac{t}{T} \times 360°$
in phase / antiphase	0° or a whole number of wavelengths apart / 180°, half a wavelength apart

Key knowledge: the oscilloscope



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

- **time-base**: the time for one horizontal division; period T = (divisions for one cycle) $\times$ time-base, then $f = \dfrac{1}{T}$
- **y-gain**: the voltage for one vertical division; amplitude = (divisions from the centre line to a crest) $\times$ y-gain
- for a smaller uncertainty, measure across several cycles and divide

Key knowledge: intensity

Idea	Rule
intensity	the power per unit area, the area at right angles to the direction of travel: $I = \dfrac{P}{A}$, in W m^{-2}
a point source	its power spreads over a sphere of area $4\pi r^2$: $I = \dfrac{P}{4\pi r^2}$, so doubling r quarters I
amplitude	$I \propto (\text{amplitude})^2$: doubling the amplitude makes the intensity four times larger

Worked example: phase difference

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

1. **Two points** 0.30 **m apart** – $\Delta\phi = \dfrac{x}{\lambda} \times 360° = \dfrac{0.30}{0.80} \times 360° = 135°$, or $\frac{3}{4}\pi$ rad.

2. **Two oscillations whose crests are** 0.10 **s apart** – $\Delta\phi = \frac{t}{T} \times 360° = \frac{0.10}{0.40} \times 360° = 90°$.
3. **Points** 0.40 **m apart** – half a wavelength: antiphase, 180°.

■ **Worked example: reading the trace**

In the trace above the time-base is 0.20 ms per division and the y-gain is 5.0 mV per division.

1. **Period** – one cycle spans 4.0 divisions: $T = (\text{divisions}) \times (\text{time-base}) = 4.0 \times 0.20 \text{ ms} = 0.80 \text{ ms}$.
2. **Frequency** – $f = \frac{1}{T} = \frac{1}{0.80 \times 10^{-3} \text{ s}} = 1250 \text{ Hz}$.
3. **Amplitude** – crest to trough is 4.0 divisions, so the amplitude is 2.0 divisions: $A = (\text{divisions}) \times (\text{Y-gain}) = 2.0 \times 5.0 \text{ mV} = 10 \text{ mV}$.

■ **Worked example: a point source**

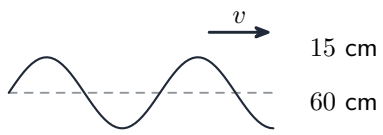
A small lamp radiates 60 W of light evenly in all directions.

1. **At** 2.0 **m** – intensity, $I = \frac{P}{4\pi r^2} = \frac{60}{4\pi \times 2.0^2} = 1.19 \text{ W m}^{-2}$.
2. **At** 4.0 **m** – $I \propto \frac{1}{r^2}$ and the distance doubles, so the area is four times as large: $I = 1.19 \times \left(\frac{2.0}{4.0}\right)^2 = 0.30 \text{ W m}^{-2}$.
3. **Amplitude** – $I \propto (\text{amplitude})^2$, so a quarter of the intensity means half the amplitude.
4. **Energy received** – a solar panel of area 0.50 m^2 in sunlight of intensity 800 W m^{-2} receives $P = IA = 400$ W, or 4000 J in 10 s.

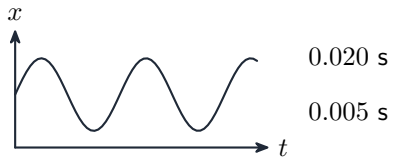
2 Practice

Now use the methods above.

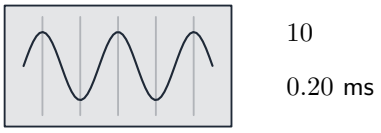
2.1 Two points on a wave are 15 cm apart, and the wavelength is 60 cm. Calculate the phase difference between the oscillations of the two points. [2]



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]



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]

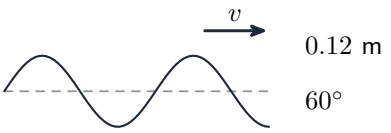


2.4 A laser beam of power 2.0 mW has a cross-sectional area of 1.5 mm^2. Calculate the intensity of the beam. [2]

3 Exam-style questions

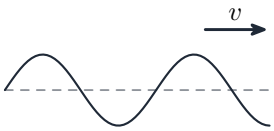
3.1 Two points on a progressive wave are 0.12 m apart. The phase difference between their oscillations is 60°. What is the wavelength? [1]

- [ ] **A** 0.020 m
- [ ] **B** 0.36 m
- [ ] **C** 0.72 m
- [ ] **D** 7.2 m

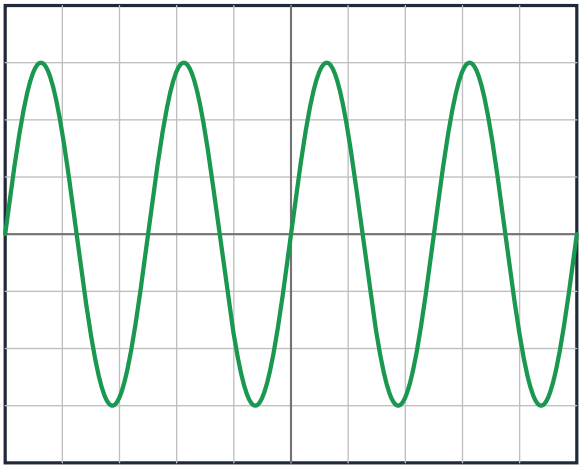


3.2 The amplitude of a progressive wave falls to one third of its value, and the frequency does not change. What fraction of the original intensity remains? [1]

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



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.



(a) Determine the period of the signal. [2]

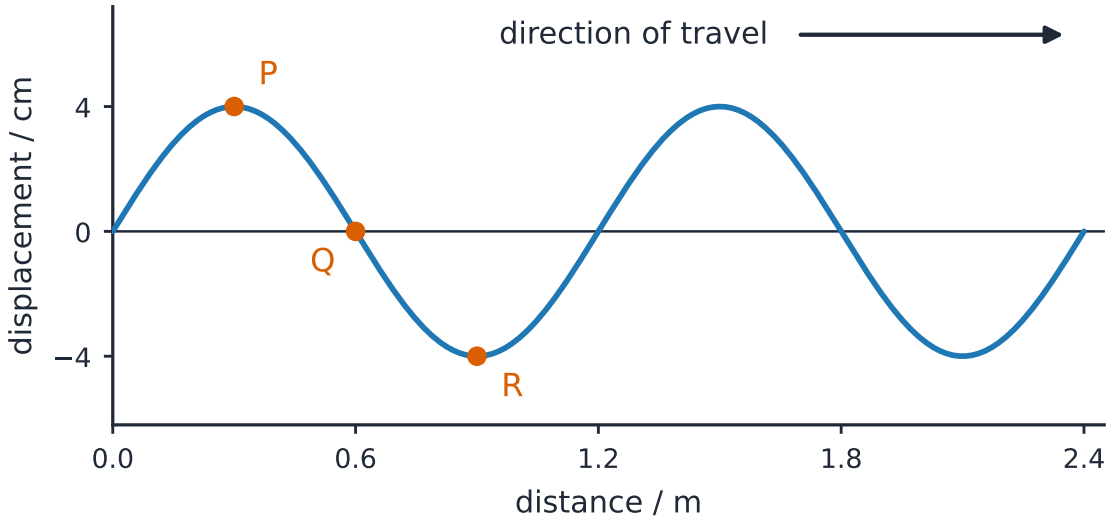
(b) Calculate the frequency of the sound from the loudspeaker. [1]

(c) Determine the amplitude of the signal. [1]

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

(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]

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.



(a) Calculate the frequency of the wave. [2]

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

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

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

(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]

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

(a) Define intensity. [1]

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

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

(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]