Starter:

A wave transports energy from one place to another.

Mechanical waves require particles to transfer energy
(neighbouring particles bump into each other and set their neighbours moving).

Electromagnetic waves consist of changing electric and magnetic fields.
They can travel through a vacuum.

Frequency is measured in hertz (Hz).

wavespeed = frequency x wavelength

The oscillations in a longitudinal wave are parallel to the direction of energy transfer.

The oscillations in a transverse wave are perpendicular to the direction of energy transfer.

Wavelength is the shortest distance between two particles that are oscillating in phase.

It is measured in metres (m)

Period is the time taken for one complete oscillation of a particle in the wave.

It is measured in seconds (s).

Amplitude is the maximum displacement from the equilibrium position.

Frequency is the number of oscillations per second.

Progressive Waves

In this lesson:

- Describe, explain and apply the terms displacement, amplitude, period, **phase difference** and frequency of a waves
- Understand the difference between transverse and longitudinal waves

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AQA spec

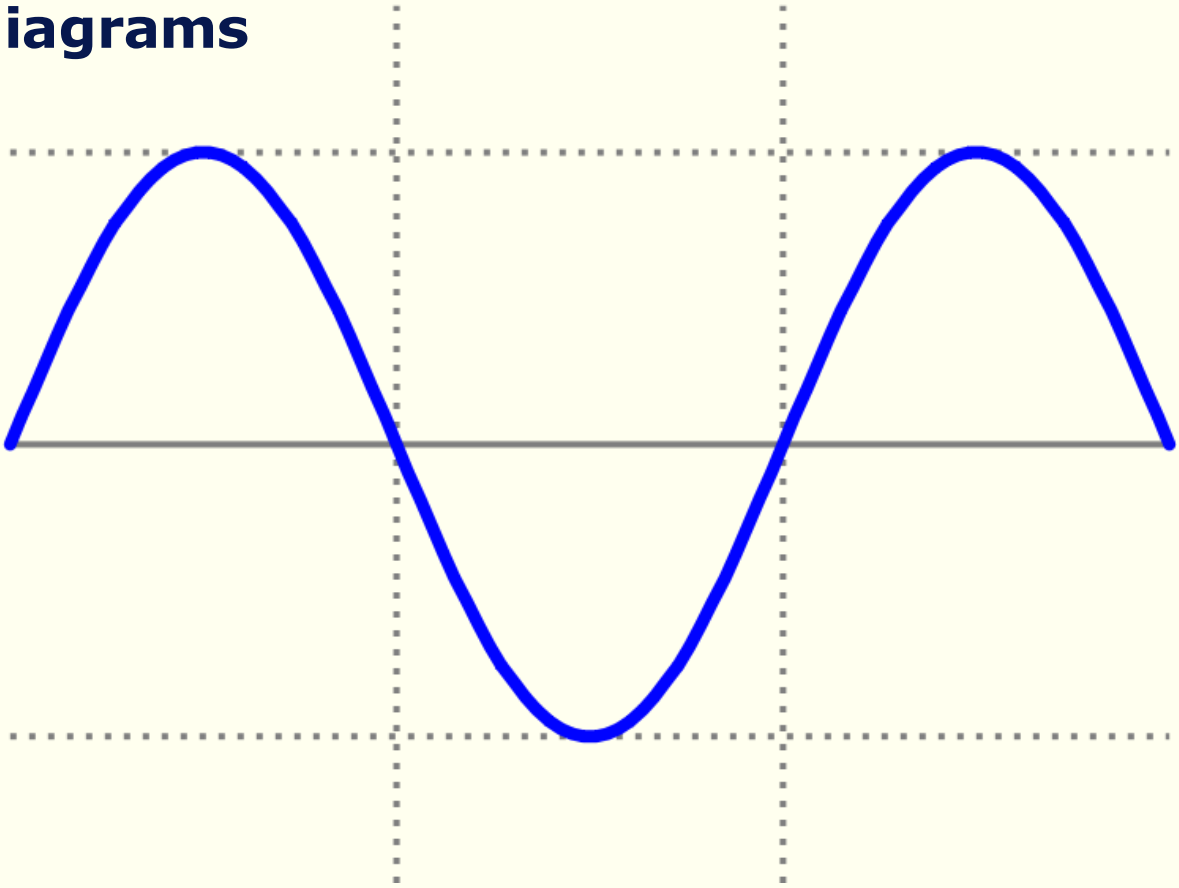
3.3.1.1 Progressive waves

Content
Oscillation of the particles of the medium; amplitude, frequency, wavelength, speed, phase, phase difference, $c = f\lambda$ $\quad f = \frac{1}{T}$ Phase difference may be measured as angles (radians and degrees) or as fractions of a cycle.

3.3.1.2 Longitudinal and transverse waves

Content
Nature of longitudinal and transverse waves. Examples to include: sound, electromagnetic waves, and waves on a string. Students will be expected to know the direction of displacement of particles/fields relative to the direction of energy propagation and that all electromagnetic waves travel at the same speed in a vacuum.

Key diagrams



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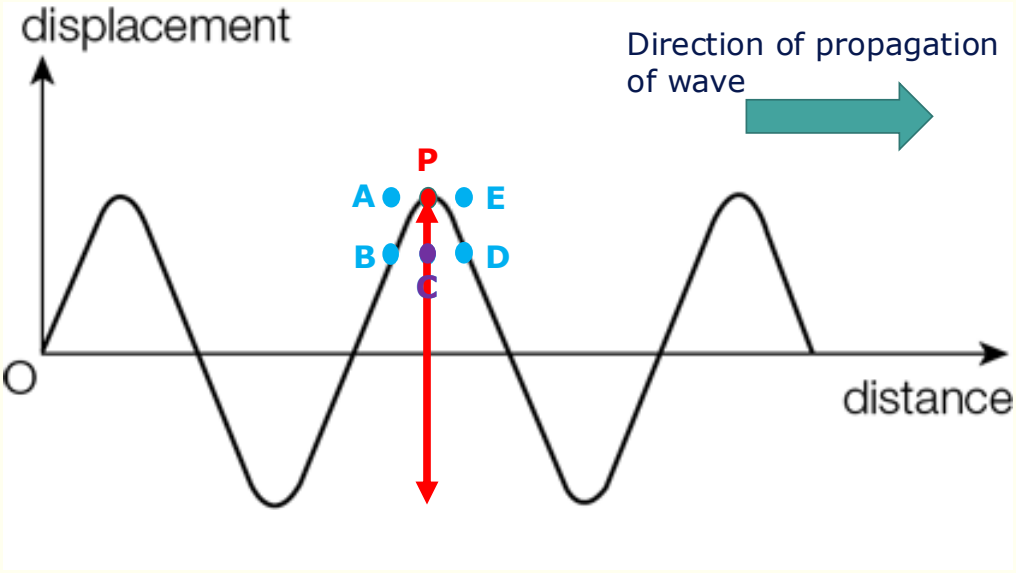
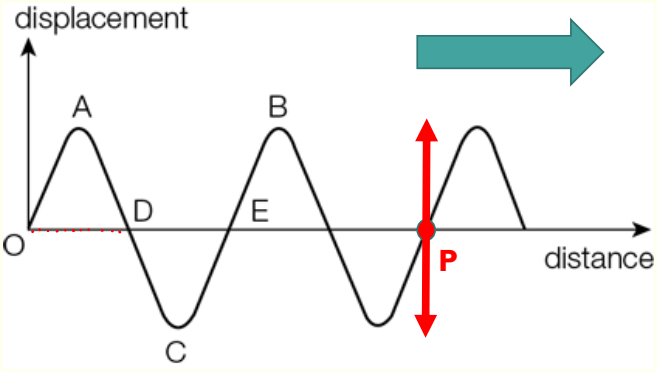


Where will particle P be a moment of time later?

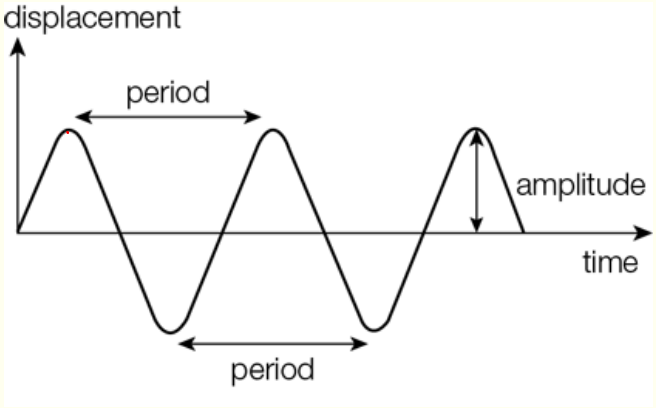
Position A, B, C, D or E?

Key diagrams

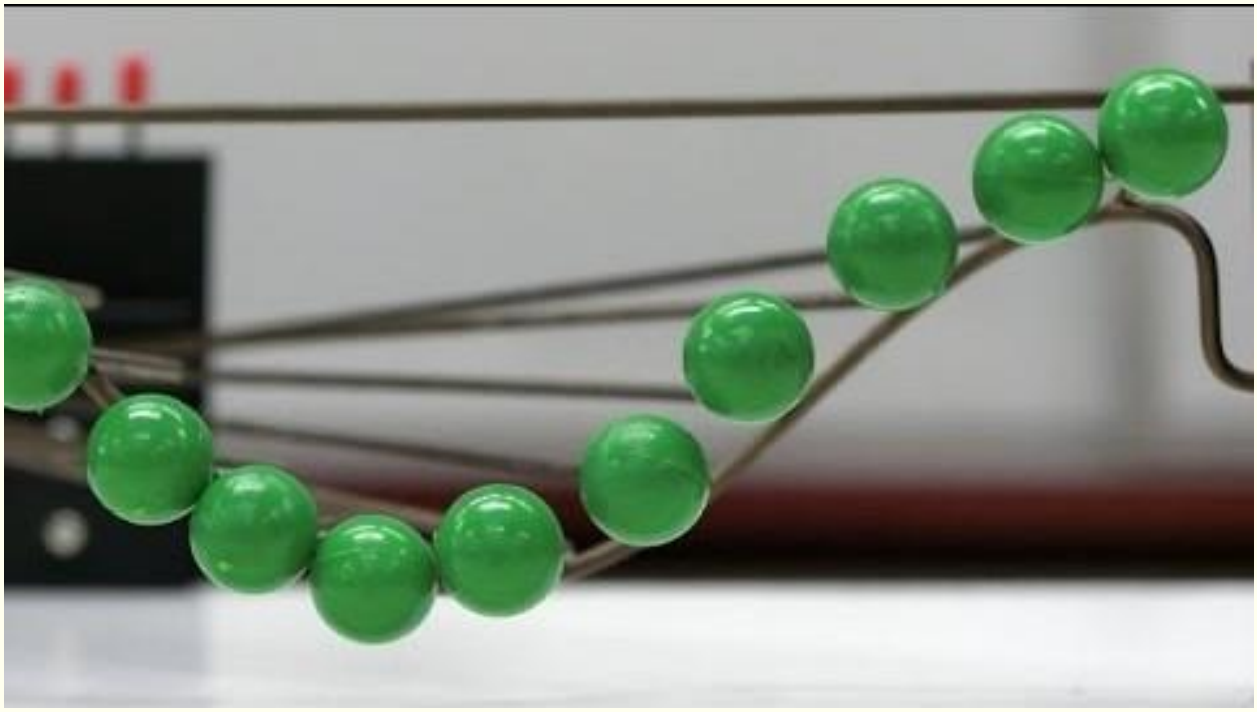
Direction of propagation of wave



"snapshot" of the whole wave at a specific time



Tracking the vibration of *one* point in the wave



Wave Equation

$$c = f\lambda$$

Wave speed = frequency × wavelength

Light travels through a vacuum at 3×10^8 ms^{-1}, green light has a wavelength of 500nm, find the frequency of green light.

Wave Equation

$c = f\lambda$ Wave speed = frequency × wavelength

Wave	Frequency	Wavelength	Speed	Medium
Sound	2000 Hz		340 m s^{-1}	Air
Yellow Light	3.6×10^{14} Hz	0.61 μm		Water
X-rays		0.1 nm		Air
Microwave	6 GHz			Vacuum
Water Ripples	8 Hz		400 mm s^{-1}	
Sonar	30 kHz	45 mm		Water
Radio Waves		0.8 m		
Ultrasound	3.5 MHz		1600 m s^{-1}	Body Tissue

Wave Equation

$c = f\lambda$ Wave speed = frequency × wavelength

Wave	Frequency	Wavelength	Speed	Medium
Sound	2000 Hz	0.17	340 m s^{-1}	Air
Yellow Light	3.6×10^{14} Hz	0.61 μm	2.196×10^{8} m s^{-1}	Water
X-rays	3 EHz	0.1 nm	3×10^{8} m s^{-1}	Air
Microwave	6 GHz	0.05 m	3×10^{8} m s^{-1}	Vacuum
Water Ripples	8 Hz	0.05 m	400 mm s^{-1}	Water
Sonar	30 kHz	45 mm	6.67×10^{5} m s^{-1}	Water
Radio Waves	0.375 GHz	0.8 m	3×10^{8} m s^{-1}	Vacuum
Ultrasound	3.5 MHz	0.457 mm	1600 m s^{-1}	Body Tissue

Period

$$T = \frac{1}{f}$$

Period = 1/frequency

Bottlenose dolphins produce sounds ranging from 0.2 to 150kHz. What is the corresponding range of periods?

Period

$$T = \frac{1}{f}$$ Period = 1/frequency

Find the period of a wave with frequency:

a) 25 kHz
b) 0.8 Hz
c) 1.21 GHz
d) 1 THz

Find the frequency of a wave with period:

a) 2 s
b) 1 day
c) 0.3 ns
d) 5.01 μs

Period

$$T = \frac{1}{f}$$ Period = 1/frequency

Find the period of a wave with frequency:

a) 25 kHz — 400 μs
b) 0.8 Hz — 1.25 s
c) 1.21 GHz — 0.826 ns
d) 1 THz — 1 ps

Find the frequency of a wave with period:

a) 2 s — 0.5 Hz
b) 1 day — 11.6 μHz
c) 0.3 ns — 3.33 GHz
d) 5.01 μs — 0.1996 MHz

LONGITUDINAL	
TRANSVERSE	

The diagram shows a snapshot of a wave on a rope travelling from left to right.

At the instant shown, point **P** is at maximum displacement and point **Q** is at zero displacement. Which one of the following lines, **A** to **D**, in the table correctly describes the motion of **P** and **Q** in the next half-cycle?

	P	Q
A	falls then rises	rises
B	falls then rises	rises then falls
C	falls	falls
D	falls	rises then falls

How many degrees are in a circle?

Why?

1. Babylonian Mathematicians

How many degrees are in a circle?

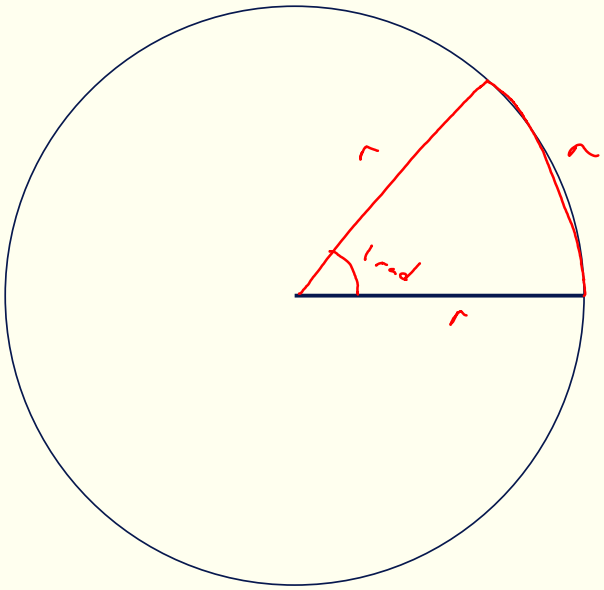
Why?

2. Sailors

Can we think of something better?

Yes!

One radian is the angle subtended from the centre of a circle which intercepts an arc equal in length to the radius of the circle.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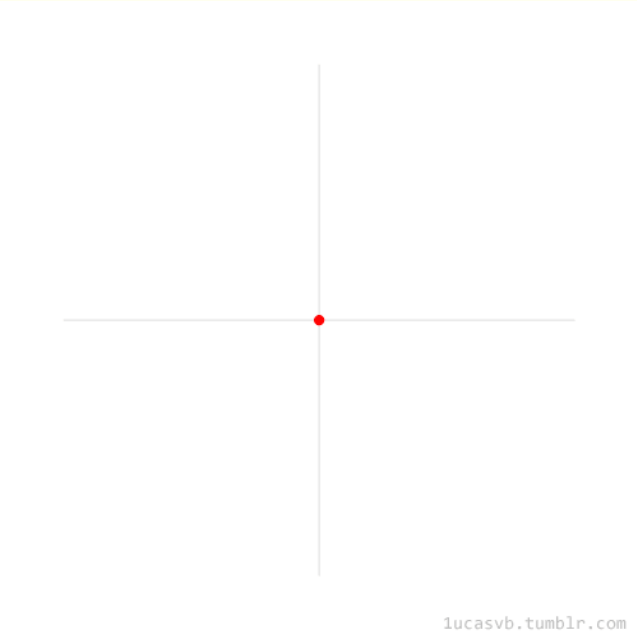
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Determine the angle (in radians) subtended at the centre of a circle of radius 3cm by each of the following arcs:

a) arc of length 6 cm
b) arc of length 3π cm
c) arc of length 1.5 cm
d) arc of length 6π cm

Conversions

Radians to Degrees

Degrees to Radians

Key Values

Degrees	Radians
30°	
45°	
60°	
90°	
180°	
270°	
360°	

Calculators

1. Complete the table giving answers as exact values.

Degrees	Radians
135°	
15°	
96°	
333°	
	3π
	$3\pi/8$
	$7\pi/9$
	$4\pi/5$

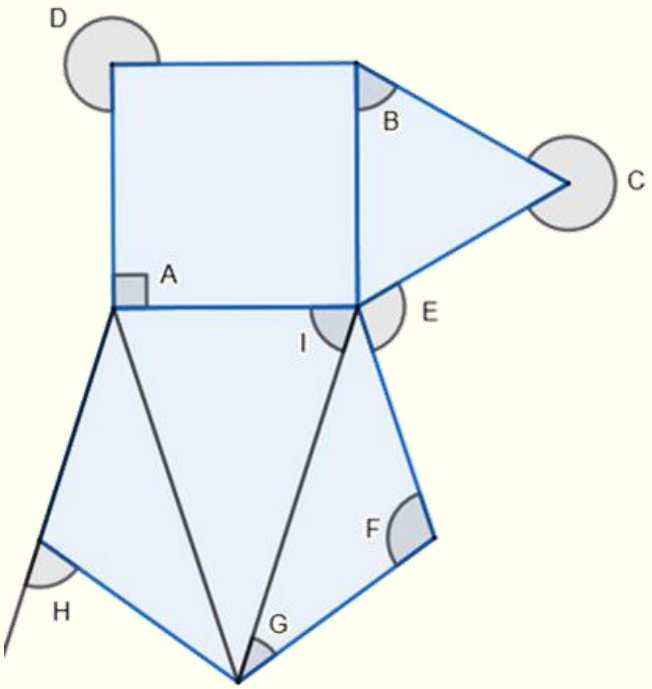
2. Complete the table giving answers to 2 d.p.

Degrees	Radians
17°	
49°	
124°	
200°	
	0.6
	2.1
	3.14
	1

3. Complete the table writing down all digits on your calculator display.

$x\ (rads)$	1	0.1	0.01	0.001	0.0001
$\sin(x)$					

4. Find the values of all the labelled angles within these regular polygons in radians.



1. Complete the table giving answers as exact values.

Degrees	Radians
135°	$\frac{3\pi}{4}$
15°	$\frac{\pi}{12}$
96°	$\frac{8\pi}{15}$
333°	$\frac{37\pi}{20}$
540°	3π
67.5°	$\frac{3\pi}{8}$
140°	$\frac{7\pi}{9}$
144°	$\frac{4\pi}{5}$

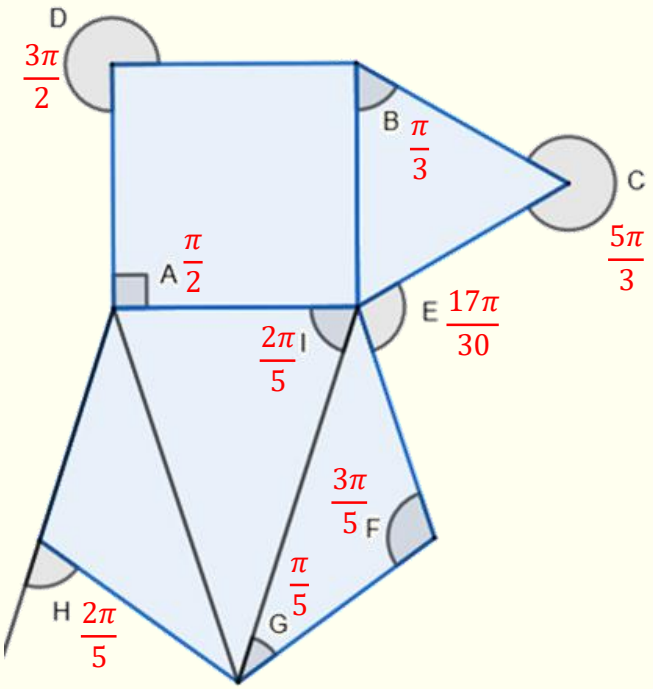
2. Complete the table giving answers to 2 d.p.

Degrees	Radians
17°	0.30
49°	0.86
124°	2.16
200°	3.49
34.38°	0.6
120.32°	2.1
179.91°	3.14
57.30°	1

3. Complete the writing down all digits on your calculator display.

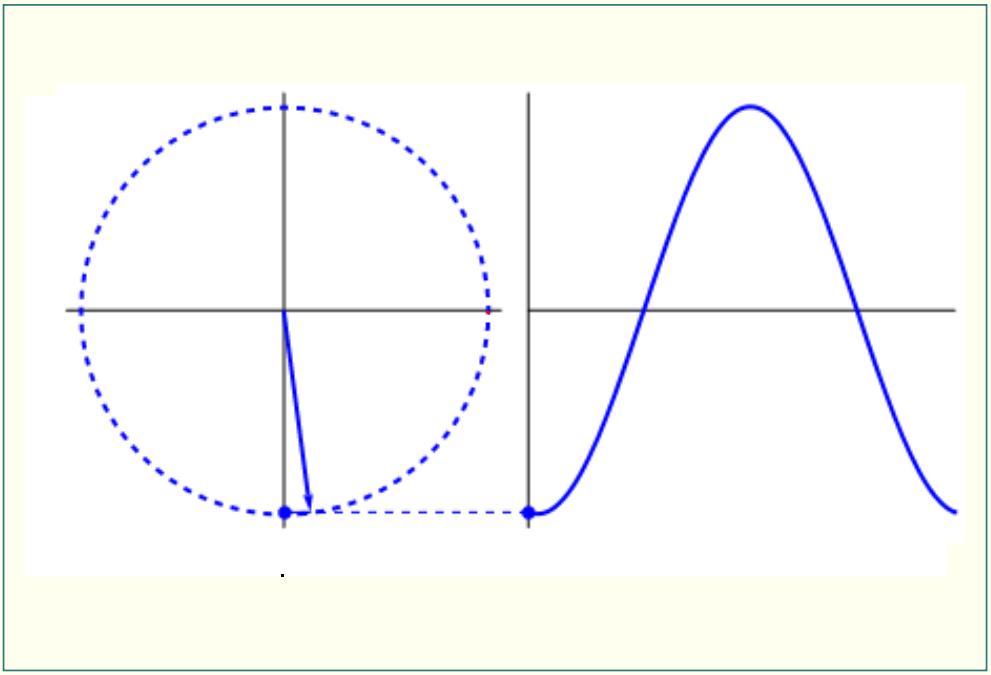
x (rads)	1	0.1	0.01	0.001	0.0001
$\sin(x)$	0.84147...	0.0998334...	0.00999983...	0.00099999999...	0.0000999999999...

4. Find the values of all the labelled angles within these regular polygons in radians.



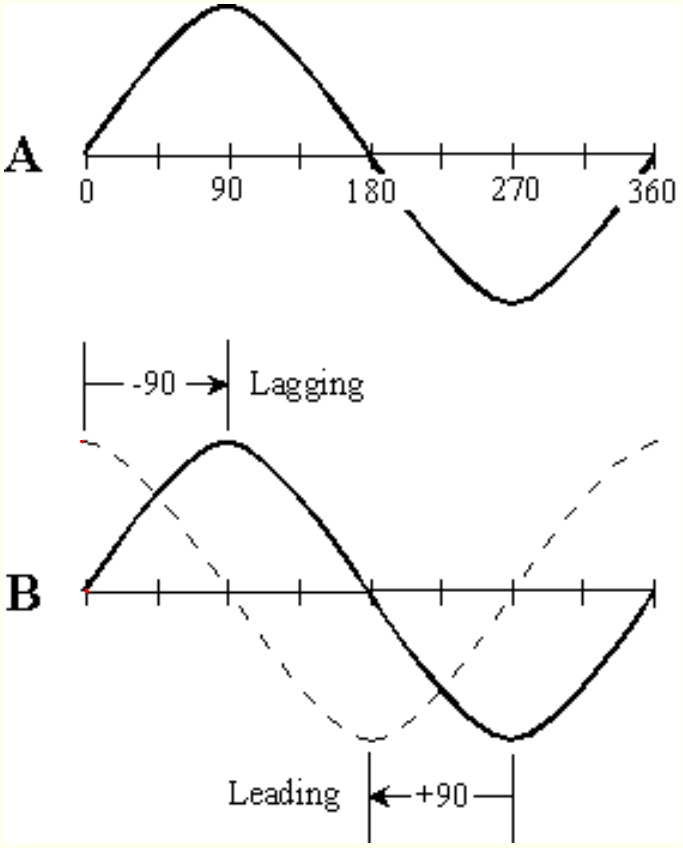
What is phase?

- We can describe how far into the wave cycle we are using the idea of phase
- Phase is measured as an angle
- A full cycle corresponds to an angle of 360º or 2π radians

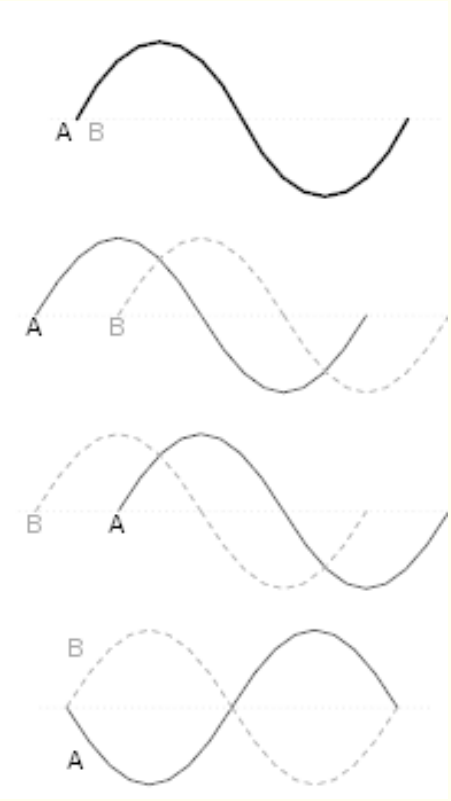


Phase difference

- Expressed as an angle
- It could be the phase difference between two different points on the same wave (A)
- or between two different waves (B)



What is the phase difference between wave A and wave B?



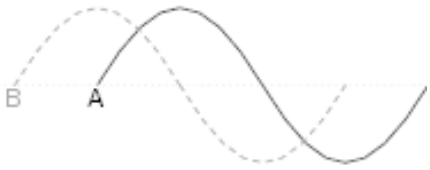
HINT

- By how much of one cycle does one wave lead the other?
- What fraction of one circle is this?
- How many radians is this?

What is the phase difference between wave A and wave B?

The waves are completely in phase
Phase difference = 0

Wave B leads A by ¼ of a cycle
Phase difference = ¼ x 360° = $\frac{\pi}{2}$



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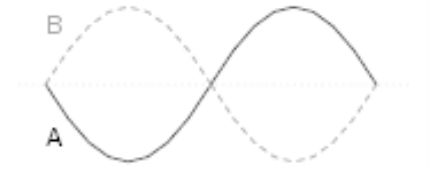


Wave A leads B by ½ of a cycle
Phase difference = ½ x 360° = π

HINT

- By how much of one cycle does one wave lead the other?
- What fraction of one circle is this?
- How many radians is this?

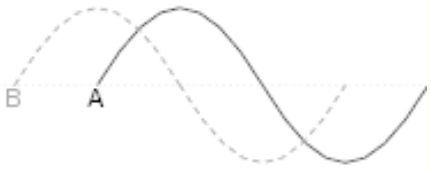
What is the phase difference between wave A and wave B?

The waves are completely in-step
Phase difference = 0°

In Phase

Wave B leads A by ¼ of a cycle
Phase difference = ¼ x 360° = 90°

Out of phase by 90°



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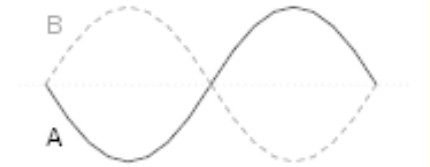
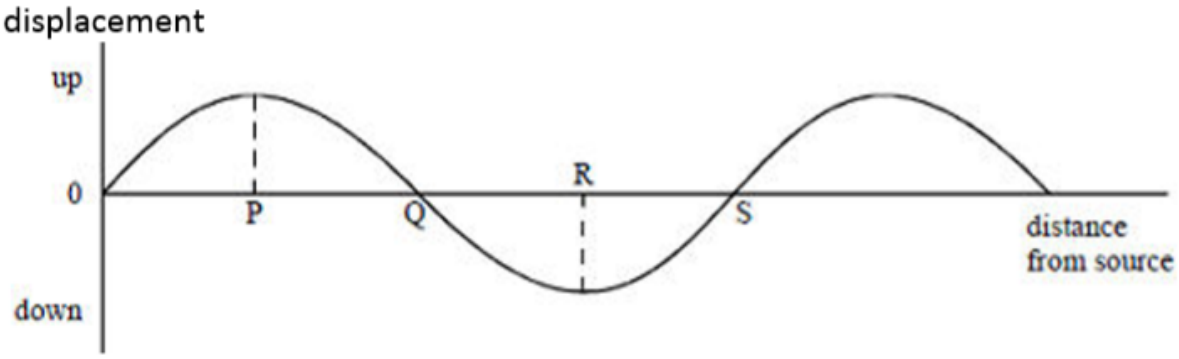


Wave A leads B by ½ of a cycle
Phase difference = ½ x 360° = 180°

In Anti-Phase



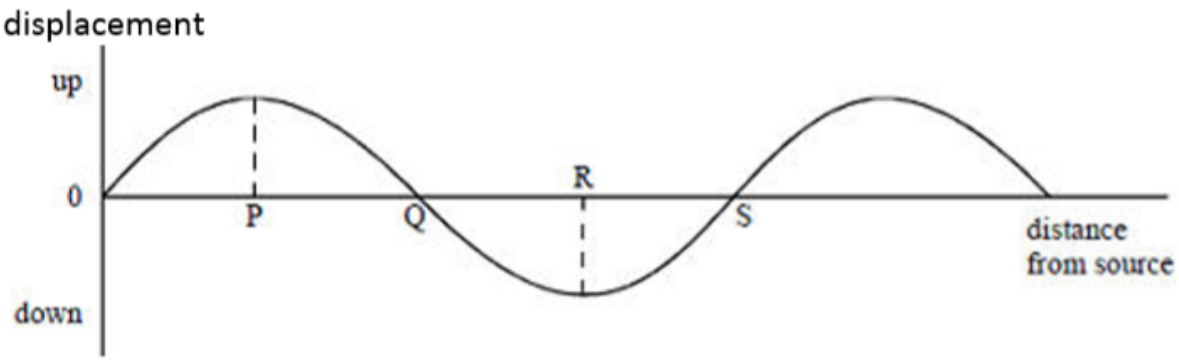
The graph shows, at a particular instant, the variation of the displacement of the particles in a transverse progressive water wave, of wavelength 4 cm, travelling from left to right. Which one of the following statements is **not** true?

A The distance PS = 3 cm.

B The particle velocity at Q is a maximum.

C The particle at S is moving downwards

D Particles at P and R are in phase.



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Two points on a progressive wave differ in phase by $\frac{\pi}{4}$. The distance between them is 0.5 m, and the frequency of the oscillation is 10 Hz. What is the minimum speed of the wave?

A $0.2\ \text{m s}^{-1}$

C $10\ \text{m s}^{-1}$

C $20\ \text{m s}^{-1}$

D $40\ \text{m s}^{-1}$

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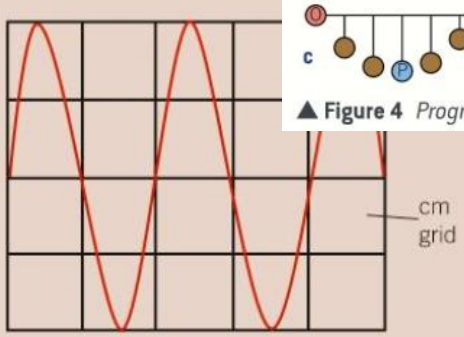
Kerboodle 4.2

Summary questions

1 Sound waves in air travel at a speed of 340 m s^{-1} at 20 °C. Calculate the wavelength of sound waves in air which have a frequency of **a** 3400 Hz **b** 18 000 Hz.

2 √x Electromagnetic waves in air travel at a speed of 3.0×10^8 m s^{-1}. Calculate the frequency of light waves of wavelength **a** 0.030 m **b** 600 nm.

3 √x Figure 5 shows a waveform on an oscilloscope screen when the y-sensitivity of the oscilloscope was 0.50 V cm^{-1} and the time base was set at 0.5 ms cm^{-1}. Determine the amplitude and the frequency of this waveform.



▲ Figure 5

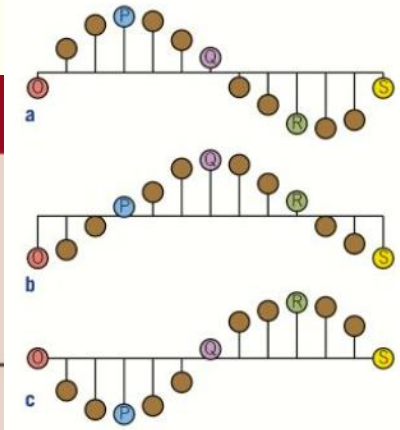
4 **a** For the waves in Figure 4, measure

i the amplitude and the wavelength

ii the phase difference between P and R

iii the phase difference between P and S.

b What would be the displacement and direction of motion of Q three-quarters of a period after the last snapshot?



▲ **Figure 4** *Progressive waves*

Finished? Try these Isaac Physics questions:
https://isaacphysics.org/questions/waving_along & https://isaacphysics.org/questions/electromagnetic_frequencies

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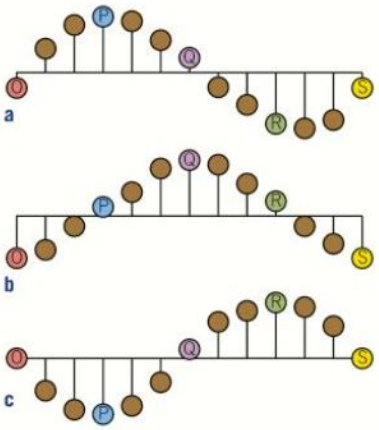

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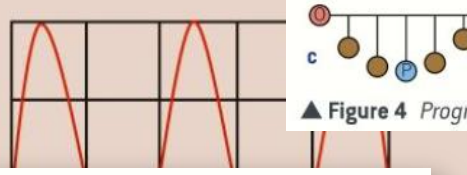

4.2

1 **a** 0.10 m **b** 1.9×10^{-2} m
2 **a** 10 GHz **b** 5.0×10^{14} Hz
3 1.0 V, 1.0 kHz
4 **a** **i** amplitude = 8 mm, wavelength = 47 mm
ii 180° **iii** 270°
b +8 mm

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For more explanation of phase look at the following:

- Phase and Phase difference – A level physics online video
- Kerboodle Animation: Radians and phase difference
- Collins 5.2, Looking in detail at waves, p. 87-88

Consolidation

Practice questions:

- Q1b Interpreting progressive waves
- Q2a ZigZag Summary Questions (skip Q6)
- ESQ 01 Waves from SharePoint
- ESQs Waves Basics from Exampro

Something to try at home (optional):

L1 Measuring the speed of waves in water.

A neutrino walks through a bar.