How can waves explain the behaviour of light?

Wave basics

Properties of mechanical waves

- **explain a wave as the transmission of energy through a medium without the net transfer of matter**
- **distinguish between transverse and longitudinal waves**
- **identify the amplitude, wavelength, period, and frequency of waves**
- **calculate the wavelength, frequency, period, and speed of travel of waves using:**

$v = f\lambda = \frac{\lambda}{t}$

Doppler effect

- **explain qualitatively the Doppler effect**

Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022	11		Wave properties	1	85%	Concept
	16		Sound concept	1	85%	Concept
2022 NHT	12		v = fλ	1	NA	Calculation
	15		Concept	1	NA	Concept
		12a	v = fλ	2	NA	Calculation
		12b	Wave properties	2	NA	
		12c	Wave properties	2	NA	
2021	13		Wave properties	1	55%	Concept
		14a	Moving source, graph	2	13%	Concept
		14b	Moving source, concept	1	81%	Concept
2021 NHT		11a	Transverse, period	1	NA	Calculation
		11b	Displacement of a point	3	NA	Concept
2020						
2019		12	v = fλ, period, sig fig	3	50%	Calculation
2019 NHT	13		Wave properties	1	NA	Concept
2018	10		Wave properties	1	80%	Concept
	11		Moving source	1	7%& 88%	Concept
		11a	v = fλ	1	92%	Calculation
		12a	c = fλ	1	72%	Calculation
2018 NHT		11a	c = fλ	1	NA	Calculation
		11d	Moving receiver	2		Concept
2017	15		Moving source	2	86%	Concept
		15a	v = fλ	1	88%	Calculation

Basic wave questions can be grouped into the following ideas.

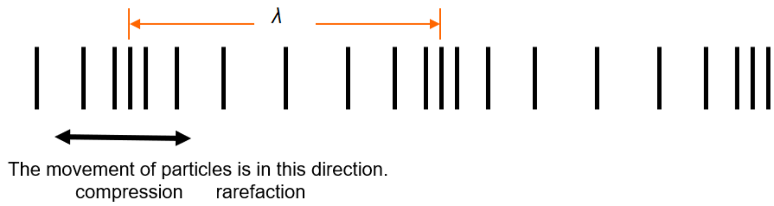
Wave concepts	Worked example 1
Longitudinal/transverse waves	Worked example 2
Applications of $v = f\lambda$, $c = f\lambda$	Worked example 3

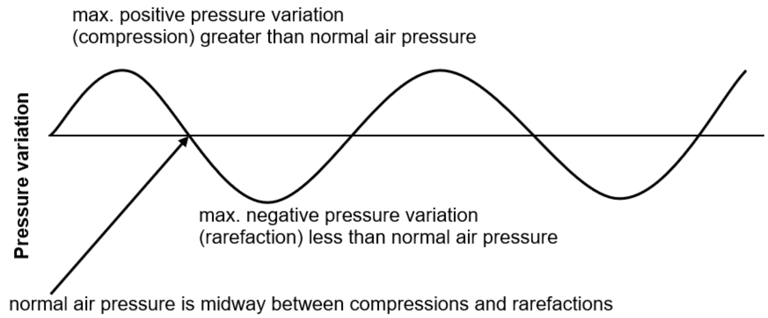
Doppler Effect questions can be grouped into the following ideas.

Basic concepts	Worked example 5
Source moving	Worked example 4
Receiver moving	Worked example 6

Longitudinal waves

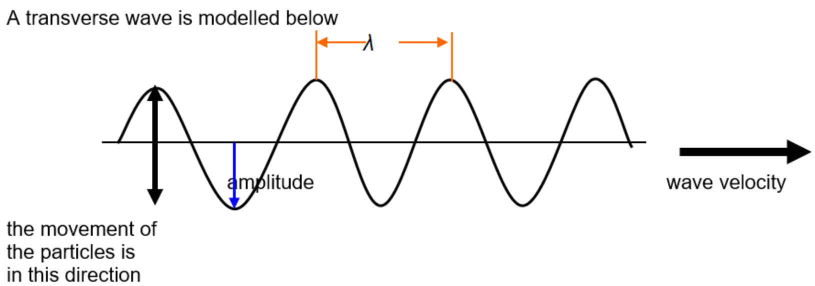
In longitudinal waves the vibration of the waves is in the same direction as the line of travel, the particles do not move forward, they vibrate around an equilibrium position. E.g. Sound waves.





Transverse waves

When waves vibrate up and down in a direction perpendicular to the direction of motion of the wave. e.g. water waves, where the motion of the water particles is at right angles (up and down) to the direction of the wave (forward), light.



Waves can be characterised by key quantities: speed, frequency, period and wavelength.

Frequency

Frequency is a measure of how rapidly the source of the wave is vibrating. The frequency (f) is defined as the number of vibrations per second. The units for frequency are Hertz, Hz, cycles per sec.

Period (T)

The period is the length of time required for one full cycle of the wave to be complete. Frequency is the number of cycles per second, $\therefore f = \frac{1}{T}$, where T is the period, the time taken for 1 cycle.

Speed (v)

The speed of the wave is obviously how fast the wave is travelling. Sound waves propagate at about 330 m s^{-1}. The speed of light in a vacuum is 3×10^8 m s^{-1}. For a uniform medium, the speed is constant. The frequency, amplitude and wavelength of a wave do not change its speed.

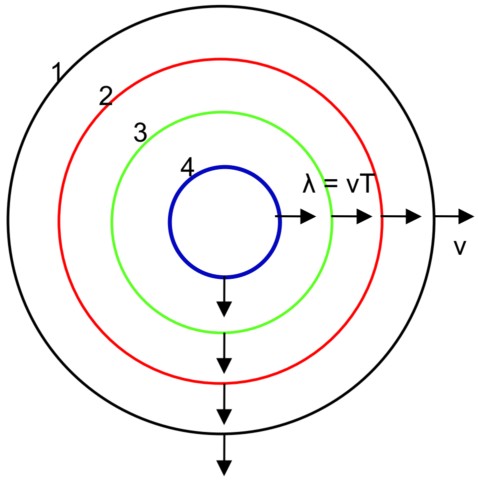
Wave equation

The wave equation links the velocity of the wave to the frequency and the wavelength.

$$\mathbf{v = f\lambda = \frac{\lambda}{T}}$$ where v is in m s^{-1}, f is in Hz, λ is in metres and T in seconds.

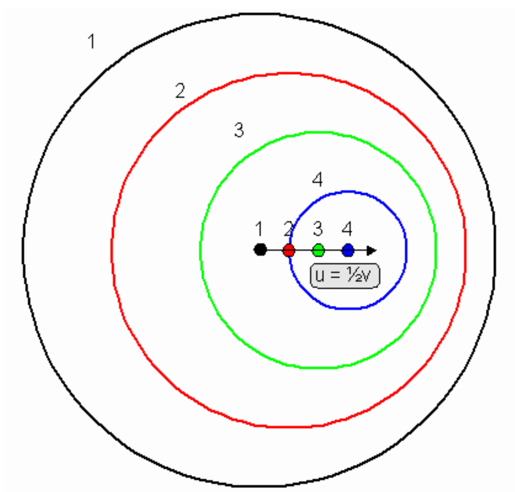
The Doppler Effect

If a wave source is stationary, then the waves will travel away from the source at the same speed in all directions. The wave fronts will be circular.



The Doppler effect is when the source of the sound wave is moving with respect to the observer.

As the source moves away from the observer there is an apparent increase in the wavelength and a decrease in the frequency.

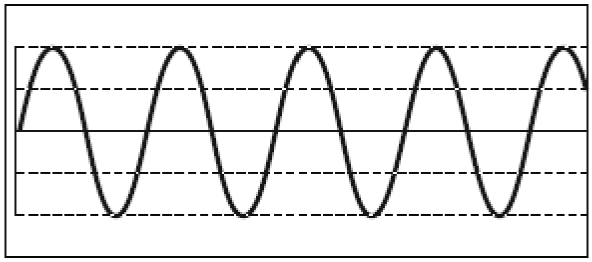


As the source moves towards the observer, there is an apparent shortening of the wavelength and hence an increase in the frequency.

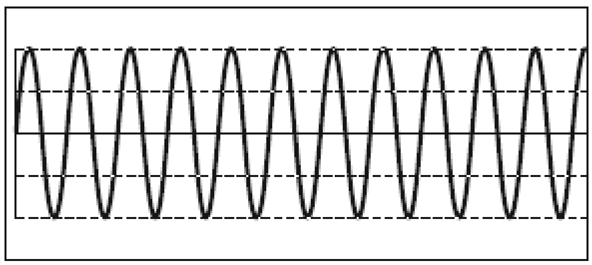
Since the medium the wave is travelling in doesn't change, the speed of the wave remains constant. The wavefronts remain circular but the centre of the circle moves.
Using v = f λ, as the wavelength increases the frequency must decrease if v is constant.

Worked example 1: Waves: Basic concepts.

A loudspeaker connected to a signal generator is placed near a microphone. The microphone is connected to an oscilloscope. The display on the screen of the oscilloscope is shown below.



The student varies the settings on the signal generator, but the oscilloscope controls are unaltered. The display on the screen now is shown below.



2013 Question 9, 2 marks

The sound entering the microphone (compared with the earlier situation) is best described as

A. of smaller intensity.

B. of greater wavelength.

C. having a greater frequency.

D. travelling at a greater speed.

Solution

The period has decreased, therefore the frequency has increased. The height of the wave remained constant, therefore it was not louder.

∴ C (ANS), (88%)

Current study design:

2022 NHT Question 12b

2022 NHT Question 12c

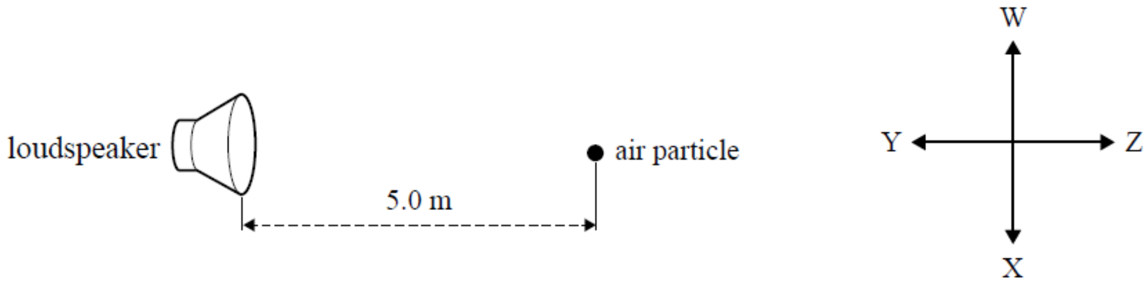
2021 Question 13 (55%)

2021 NHT Question 11a

2021 NHT Question 11b

2019 NHT Question 13

Worked example 2: Waves: Longitudinal/transverse waves.



Consider an air particle initially at rest 5.0 m in front of a loudspeaker, as shown above. The speed of sound in air in these conditions is 330 m s^{-1}.

2015 Question 2, 2 marks

Which one of the following best describes the subsequent motion of this particle when the loudspeaker is emitting a sound of frequency 30 Hz?

A. It moves in direction Z at a constant speed of 330 m s^{-1}.

B. It oscillates about its rest position in direction WX 30 times per second.

C. It oscillates about its rest position in direction YZ 30 times per second.

D. It oscillates about its rest position in direction YZ at an average speed of 330 m s^{-1}.

Solution	**Current study design:**
This is a basic definition. Sound is a longitudinal wave. The particle will vibrate about a mean position in the direction YZ, 30 times every second. ∴ **C (ANS), (79%)**	**2022 Question 11 (85%)** **2018 Question 10 (59%)**

Worked example 3: Waves: Application v =fλ, c = fλ.

A sound engineer, Dan, is setting up for a concert in a large stadium. In order to test the acoustics of the stadium, he sets up a single speaker in the middle of the stage. This speaker transmits sound equally in all directions. Using a signal generator and amplifier attached to the speaker, he sets the frequency of the sound to 500 Hz. Take the speed of sound to be 350 m s^{-1}.

2016 Question 2, 2 marks

The wavelength of the signal is closest to

A. 0.07 m

B. 0.70 m

C. 1.43 m

D. 2.34 m

Solution

Use v = f λ

∴ 350 = 500 × λ

∴ λ = 0.7 m

∴ B (ANS), (91%)

Current study design:

2022 NHT Question 12

2022 NHT Question 12a

2019 Question 12 (50%)

2018 Question 11a (92%)

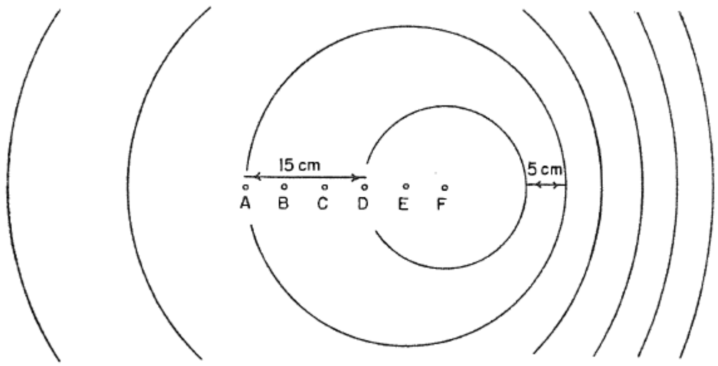
2018 Question 12a (72%)

2018 NHT Question 11a

2017 Question 15a (88%)

Worked example 4: The Doppler Effect: Source moving.

An eye dropper is used to release six drops into a still pool of water at a constant frequency, 2.0 s^{-1}, whilst the dropper is **moving** in a straight line at **constant speed**. Successive drops hit the water at distance 5.0 cm apart.



1975 Question 48, 1 mark

What is the speed, *v,* of the dropper?

Solution	Current study design:
Use v = f × λ, where f = 2.0 and λ = 5.0 ∴ v = 2.0 × 5.0 **∴ 10 cm s^{-1} (ANS), (76%)**	**2021 Question 14a (13%)** **2021 Question 14b (81%)** **2018 Question 11 (7% & 88%)** **2017 Question 15 (86%)**

Worked example 5: The Doppler Effect: Basic concepts.

1975 Question 50, 1 mark

Distances between successive waves to the left and right of point F are shown on the diagram.

If the dropper had ***not moved****,* what would have been the wavelength of the resulting wave pattern?

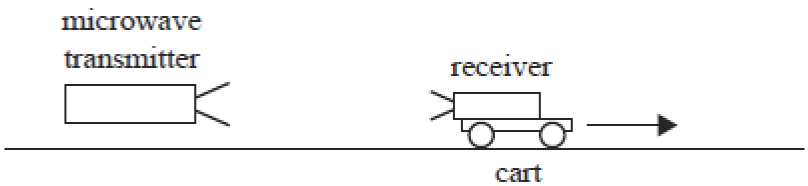
Solution	Current study design:
The wavelength of the wave with a stationary source is the average wavelength of the waves created by a moving source. Therefore the average of 5 and 15 = 10 cm **∴ 10 cm (ANS), (79%)**	**2022 Question 10 (85%)** **2022 NHT Question 15**

Worked example 6: The Doppler Effect: Receiver moving.

With the transmitter set to a wavelength of 3.0 cm, the students place the receiver on a cart.

With the cart stationary, the receiver measures the wavelength to be 3.0 cm exactly.

The cart is now set moving away from the transmitter, as shown below.



2018 NHT Question 11d, 2 marks

Will this movement increase, decrease or leave unchanged the wavelength as measured by the receiver on the cart? Explain your answer and name the physical principle involved.

Solution

This question is trying to get you to answer using the Doppler effect. There is a problem with the question because for the receiver to measure the wavelength it needs to find the position of two crests simultaneously and then measure the distance between them.

If the question had asked about the frequency, it would have been possible to say that since the receiver was moving away, and microwaves were travelling at *c* then since the distance from the source was increasing, then the frequency was decreasing.

Using $c = f\lambda$, this would mean a longer wavelength.

This answer really requires three points for the two marks.

- Increase
- Explanation
- Doppler Effect.

Current study design:

2018 NHT Question 11d