7.3 Doppler effect for sound waves

Candidates should be able to:

1 understand that when a source of sound waves moves relative to a stationary observer, the observed frequency is different from the source frequency (understanding of the Doppler effect for a stationary source and a moving observer is not required)

2 use the expression $f_o = f_s v / (v \pm v_s)$ for the observed frequency when a source of sound waves moves relative to a stationary observer

1 With which types of wave can the Doppler shift be observed?

A all types of wave

B light and sound waves only

C sound waves and water waves only

D sound waves only

2 A distant star is receding from the Earth with a speed of $1.40 \times 10^7\,\text{m s}^{-1}$. It emits light of frequency $4.57 \times 10^{14}\,\text{Hz}$. The speed of light is $3.00 \times 10^8\,\text{m s}^{-1}$.

The Doppler effect formula can be used with light waves.

What will be the frequency of this light when detected on Earth?

A $2.04 \times 10^{13}\,\text{Hz}$

B $4.37 \times 10^{14}\,\text{Hz}$

C $4.57 \times 10^{14}\,\text{Hz}$

D $4.79 \times 10^{14}\,\text{Hz}$

3 The warning signal on an ambulance has a frequency of 600 Hz. The speed of sound is $330\,\text{m s}^{-1}$. The ambulance is travelling with a constant velocity of $25\,\text{m s}^{-1}$ towards an observer.

Which overall change in observed frequency takes place between the times at which the ambulance is a long way behind the observer and when it is a long way in front of the observer?

A 49 Hz **B** 84 Hz **C** 91 Hz **D** 98 Hz

4 A man standing next to a stationary train hears sound of frequency 400 Hz emitted from the train's horn. The train then moves directly away from the man and sounds its horn when it has a speed of $50\,\text{m s}^{-1}$. The speed of sound is $340\,\text{m s}^{-1}$.

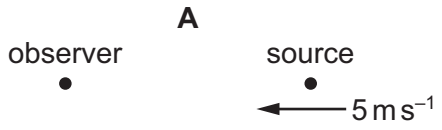
What is the difference in frequency of the sound heard by the man on the two occasions?

A 51 Hz **B** 69 Hz **C** 349 Hz **D** 469 Hz

5 A source of sound waves is travelling as shown.

In which situation would the stationary observer detect the largest decrease in the observed frequency?

A



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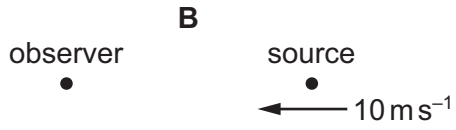

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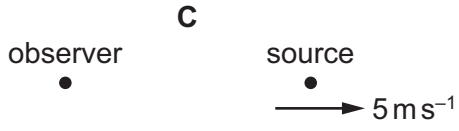

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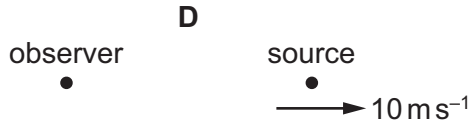


6 A car travelling in a straight line at a speed of $30\,m\,s^{-1}$ passes near a stationary observer while sounding its horn. The true frequency of sound from the horn is 400 Hz.

The speed of sound in air is $336\,m\,s^{-1}$.

What is the change in the frequency of the sound heard by the observer as the car passes?

A 39 Hz **B** 66 Hz **C** 72 Hz **D** 78 Hz

7 An ambulance travels along a straight road at a speed of $30.0\,m\,s^{-1}$. Its siren emits sound of frequency 2000 Hz. The speed of sound in the air is $340\,m\,s^{-1}$. The ambulance passes a man standing at the side of the road.

What is the frequency of the sound heard by the man as the ambulance moves towards him and as the ambulance moves away from him?

	frequency heard as ambulance moves towards man / Hz	frequency heard as ambulance moves away from man / Hz
A	1820	2180
B	1840	2190
C	2180	1820
D	2190	1840

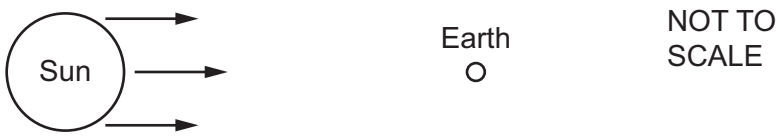
8 A high-speed train approaches a stationary observer at a speed of $80\,m\,s^{-1}$. The train's horn emits a sound of frequency 250 Hz.

The speed of sound is $340\,m\,s^{-1}$.

What is the observed frequency of the sound from the horn?

A 190 Hz **B** 200 Hz **C** 310 Hz **D** 330 Hz

9 Light of a particular wavelength λ_s is emitted from the Sun. At any instant, a band of wavelengths ranging from less than λ_s to more than λ_s is observed on the Earth. This is caused by the Doppler effect.



What could be the explanation for this Doppler effect?

A The Sun is moving at right-angles to a line joining the Sun and the Earth.

B The Sun is moving away from the Earth.

C The Sun is moving towards the Earth.

D The Sun is rotating.

10 A train that is moving in a straight line along a railway track has a whistle that continuously emits sound of frequency *f*.

A woman standing by the side of the track hears sound of frequency 0.85*f*.

The speed of sound in the air is $340\,m\,s^{-1}$.

What is the velocity of the train?

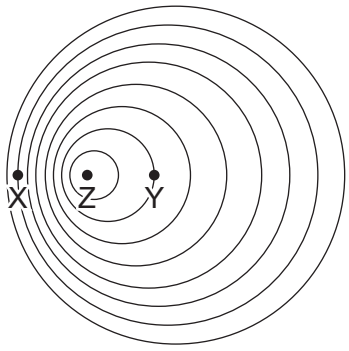
A $51\,m\,s^{-1}$ away from the woman

B $51\,m\,s^{-1}$ towards the woman

C $60\,m\,s^{-1}$ away from the woman

D $60\,m\,s^{-1}$ towards the woman

11 A source of sound of frequency *F* at point Z is moving at a steady speed. The pattern of the emitted wavefronts is shown.



Which row describes the frequencies of the sound heard by stationary observers at X and Y?

	frequency heard at X	frequency heard at Y
A	$<F$	$<F$
B	$<F$	$>F$
C	$>F$	$<F$
D	$>F$	$>F$

12 A car travelling at a steady speed in a straight line passes close to a stationary observer. The observer measures the frequency of the sound from the engine.

As the car approaches, the observed frequency is 220 Hz. When the car moves away, the observed frequency is 180 Hz.

The speed of sound in air is $340\,m\,s^{-1}$.

What is the speed of the car?

A $8.5\,m\,s^{-1}$ **B** $31\,m\,s^{-1}$ **C** $34\,m\,s^{-1}$ **D** $38\,m\,s^{-1}$

13 A vehicle carries a microwave transmitter that emits microwaves of a constant frequency. A stationary observer has a microwave receiver.

The vehicle moves directly towards the observer at constant speed. The observer detects microwaves of frequency F_o.

The vehicle then accelerates, still moving towards the observer, travels at higher steady speed for a time and then decelerates until it stops.

What is the variation in the frequency of the microwaves that are detected by the observer?

A The observed frequency will fall, then remain steady then return to the frequency F_o.

B The observed frequency will fall, then remain steady then rise to a higher frequency than F_o.

C The observed frequency will rise, then remain steady then fall to a lower frequency than F_o.

D The observed frequency will rise, then remain steady then return to the frequency F_o.

14 An astronomer observes the light from a star that is moving away from the Earth.

For the observed light, what has been increased due to the star's motion?

A amplitude

B frequency

C speed

D wavelength

15 A police car travels at a velocity of $30.0\,m\,s^{-1}$ directly towards a stationary observer. The horn of the car emits sound of frequency 2000 Hz. The speed of sound is $340\,m\,s^{-1}$.

What is the frequency of the sound heard by the observer?

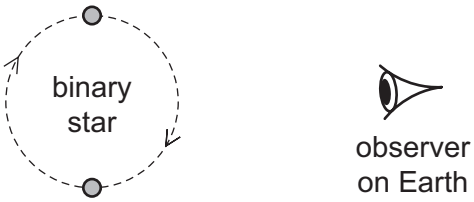
A 1840 Hz **B** 2000 Hz **C** 2180 Hz **D** 2190 Hz

16 A jet aircraft travels at a speed of $0.8v$ where v is the speed of sound. The aircraft approaches a stationary observer. The frequency of sound emitted by the aircraft is 100 Hz.

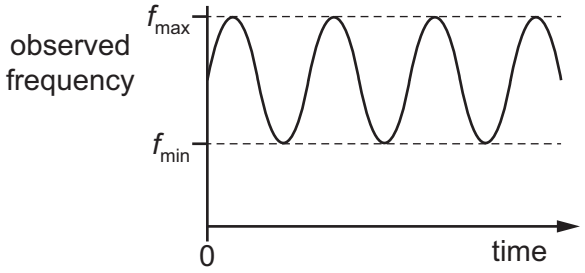
Which frequency does the observer hear?

A 56 Hz **B** 180 Hz **C** 400 Hz **D** 500 Hz

17 A binary star consists of two stars rotating around a common centre. Light from one of the stars is observed on the Earth.



The observed frequency of the light varies between a minimum frequency f_{min} and a maximum frequency f_{max}, as shown.



The rate of rotation of the binary star increases.

What is the change to f_{max} and the change to f_{min}?

	f_{max}	f_{min}
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

18 A police car has a two-tone siren emitting sound of frequencies of 700 Hz and 1000 Hz.

The police car is travelling at a speed of 40.0 m s^{-1} towards a stationary observer. The speed of sound in the air is 340 m s^{-1}.

What is the difference between the two frequencies of the sound that is heard by the observer?

A 268 Hz **B** 300 Hz **C** 335 Hz **D** 340 Hz

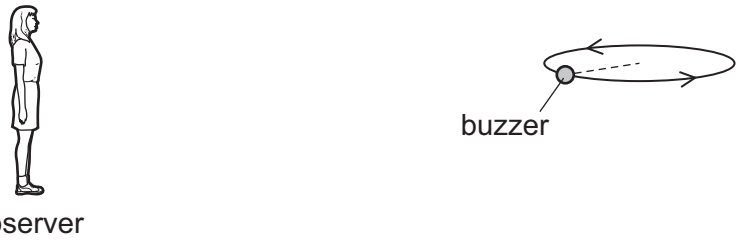
19 A bat flies directly towards a fixed ultrasound detector at a speed of 25.0 m s^{-1} emitting pulses of ultrasound of frequency 40.0 kHz.

The speed of sound in air is 330 m s^{-1}.

Which frequency does the ultrasound detector record?

A 37.0 kHz **B** 37.2 kHz **C** 43.0 kHz **D** 43.3 kHz

20 A buzzer emitting sound of frequency 846 Hz is attached to a string and rotated in a horizontal circle. The linear speed of the buzzer is 25.0 m s^{-1}.



The speed of sound is 340 m s^{-1}.

What is the maximum frequency heard by the observer?

A 783 Hz **B** 788 Hz **C** 908 Hz **D** 913 Hz

21 A stationary insect on the surface of water creates circular waves with its legs, as shown in diagram 1. The insect begins to travel to the right as shown in diagram 2.

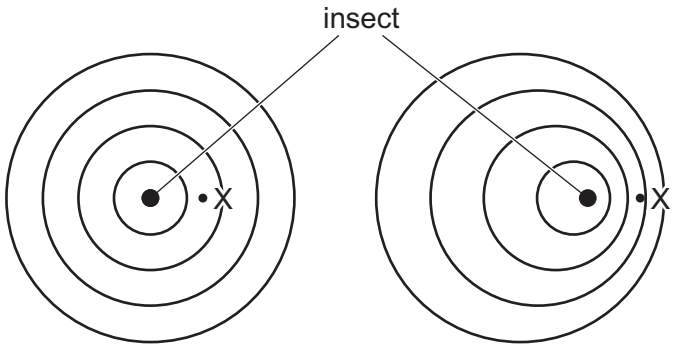


diagram 1 diagram 2

Which row describes the change to the waves at X caused by the movement of the insect?

	frequency	wave speed
A	decreases	increases
B	decreases	stays the same
C	increases	increases
D	increases	stays the same

22 In one of the first experiments to demonstrate the Doppler effect, a train was filled with trumpeters all playing a note of frequency 440 Hz. The difference in observed frequency of the note as the train directly approached a stationary observer was 22 Hz. The speed of sound was 340 m s^{-1}.

At which speed was the train moving?

A 15.4 m s^{-1} **B** 16.2 m s^{-1} **C** 17.0 m s^{-1} **D** 17.9 m s^{-1}

23 A toy motorboat moving with constant velocity v vibrates up and down on the surface of a pond. This causes the boat to act as a source of circular water waves of frequency 2.0 Hz. The speed of the waves is $1.5\,m\,s^{-1}$.

A man, standing at the edge of the pond, observes that the waves from the boat approach him with a frequency of 3.0 Hz.

The formula for Doppler effect calculations with sound waves may also be used for water waves.

What is a possible value of v?

	speed / $m\,s^{-1}$	direction
A	0.50	directly away from the man
B	0.50	directly towards the man
C	0.75	directly away from the man
D	0.75	directly towards the man

24 A motor boat vibrates in the water so that it produces water waves of frequency 0.20 Hz. The speed of these waves in the water is $20\,m\,s^{-1}$. The motor boat moves with a speed of $5.0\,m\,s^{-1}$ directly towards a stationary sailing boat.

The Doppler effect equation for sound waves also applies to water waves.

What is the frequency with which the waves hit the stationary sailing boat?

A 0.15 Hz **B** 0.16 Hz **C** 0.25 Hz **D** 0.27 Hz

25 The siren of a moving police car emits a sound wave with a frequency of 440 Hz. A stationary observer hears sound of frequency 494 Hz. The speed of sound in the air is $340\,m\,s^{-1}$.

What could be the speed and the direction of movement of the car?

A $37\,m\,s^{-1}$ directly towards the observer

B $37\,m\,s^{-1}$ directly away from the observer

C $42\,m\,s^{-1}$ directly towards the observer

D $42\,m\,s^{-1}$ directly away from the observer

26 A loudspeaker emitting a constant frequency of 2000 Hz is swung in a horizontal circle with a speed of $15.0\,m\,s^{-1}$.

A stationary observer is level with the loudspeaker and situated a long distance from the loudspeaker. The observer hears a sound of varying frequency. The maximum frequency heard is 2097 Hz.

What is the speed of the sound in the air?

A $294\,m\,s^{-1}$ **B** $309\,m\,s^{-1}$ **C** $324\,m\,s^{-1}$ **D** $330\,m\,s^{-1}$

27 A siren emits sound of frequency 1000 Hz. The siren moves at 20 m s^{-1} towards an observer who is standing still.

The speed of sound in the air is 330 m s^{-1}.

Which expression would correctly give the frequency heard by the observer?

A $\dfrac{1000 \times 330}{330 + 20}$

B $\dfrac{1000 \times 330}{330 - 20}$

C $\dfrac{1000\,(330 + 20)}{330}$

D $\dfrac{1000\,(330 - 20)}{330}$

1 **(a)** By reference to the direction of the propagation of energy, state what is meant by a *longitudinal* wave and by a *transverse* wave.

longitudinal: .....

.....

.....

transverse: .....

.....

.....

[2]

(b) The intensity of a sound wave passing through air is given by

$$I = Kv\rho f^2 A^2$$

where I is the intensity (power per unit area),
K is a constant without units,
v is the speed of sound,
ρ is the density of air,
f is the frequency of the wave
and A is the amplitude of the wave.

Show that both sides of the equation have the same SI base units.

[3]

(c) **(i)** Describe the *Doppler effect*.

.....

.....[1]

(ii) A distant star is moving away from a stationary observer.

State the effect of the motion on the light observed from the star.

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.....[1]

(d) A car travels at a constant speed towards a stationary observer. The horn of the car sounds at a frequency of 510 Hz and the observer hears a frequency of 550 Hz. The speed of sound in air is 340 m s^{-1}.

Calculate the speed of the car.

speed = ... m s^{-1} [3]

[Total: 10]

2 **(a)** State what is meant by the *frequency* of a progressive wave.

.....

.....

.....[2]

(b) A cathode-ray oscilloscope (c.r.o.) is used to determine the frequency of the sound emitted by a loudspeaker. The trace produced on the screen of the c.r.o. is shown in Fig. 4.1.

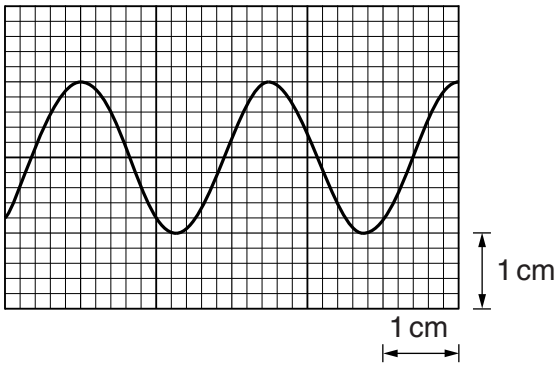

Fig. 4.1

The time-base setting of the c.r.o. is 250 μs cm^{-1}.

Show that the frequency of the sound wave is 1600 Hz.

[2]

(c) The loudspeaker in **(b)** emits the sound in all directions. A person attaches the loudspeaker to a string and then swings the loudspeaker at a constant speed in a horizontal circle above his head.

An observer, standing a large distance away from the loudspeaker, hears sound of maximum frequency 1640 Hz. The speed of sound in air is 330 m s^{-1}.

(i) Determine the speed of the loudspeaker.

speed = ... m s^{-1} [2]

(ii) Describe and explain, qualitatively, the variation in the frequency of the sound heard by the observer.

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.....[2]

[Total: 8]

9702/21/M/J/17/Q5

3 **(a)** Describe the Doppler effect.

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.....

.....[1]

(b) A car travels with a constant velocity along a straight road. The car horn with a frequency of 400 Hz is sounded continuously. A stationary observer on the roadside hears the sound from the horn at a frequency of 360 Hz.
The speed of sound is 340 m s^{-1}.

Determine the magnitude v, and the direction, of the velocity of the car relative to the observer.

v = ...m s^{-1}

direction .....

[3]

[Total: 4]

4 **(a)** Define the *frequency* of a sound wave.

.....

.....[1]

(b) A sound wave travels through air. Describe the motion of the air particles relative to the direction of travel of the sound wave.

.....

.....[1]

(c) The sound wave emitted from the horn of a stationary car is detected with a microphone and displayed on a cathode-ray oscilloscope (c.r.o.), as shown in Fig. 5.1.

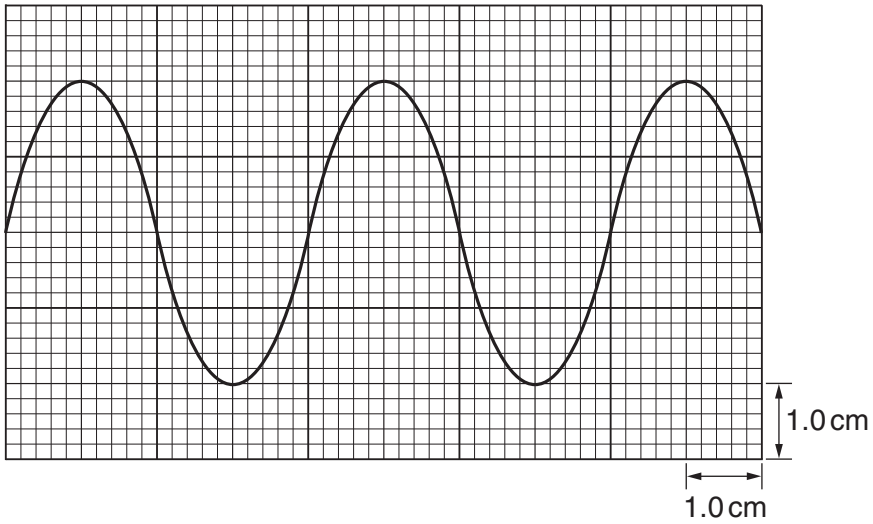

Fig. 5.1

The *y*-axis setting is 5.0 mV cm^{-1}.
The time-base setting is 0.50 ms cm^{-1}.

(i) Use Fig. 5.1 to determine the frequency of the sound wave.

frequency = ... Hz [2]

(ii) The horn of the car sounds continuously. Describe the changes to the trace seen on the c.r.o. as the car travels at constant speed

1. directly towards the stationary microphone,

.....

.....

2. directly away from the stationary microphone.

.....

.....

[3]

[Total: 7]

9702/22/F/M/17/Q4

5 **(a)** State what is meant by the *Doppler effect*.

.....

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.....[2]

(b) A child sits on a rotating horizontal platform in a playground. The child moves with a constant speed along a circular path, as illustrated in Fig. 4.1.

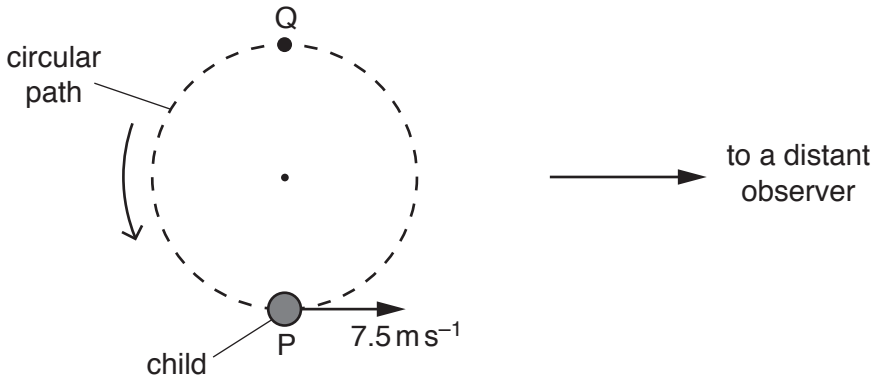

Fig. 4.1

An observer is standing a long distance away from the child. During one particular revolution, the child, moving at a speed of $7.5\,m\,s^{-1}$, starts blowing a whistle at point P and stops blowing it at point Q on the circular path.

The whistle emits sound of frequency 950 Hz. The speed of sound in air is $330\,m\,s^{-1}$.

(i) Determine the maximum frequency of the sound heard by the distant observer.

maximum frequency = ... Hz [2]

(ii) Describe the variation in the frequency of the sound heard by the distant observer.

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.....[2]

[Total: 6]