IB · DP · Physics

2 hours 14 questions

Structured Questions

9.5 Doppler Effect

9.5.1 The Doppler Effect / 9.5.2 Uses of The Doppler Effect / 9.5.3 The Doppler Equation

Easy (5 questions)	/63
Medium (4 questions)	/50
Hard (5 questions)	/36
Total Marks	**/149**

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Easy Questions

1 (a) Define the Doppler effect.

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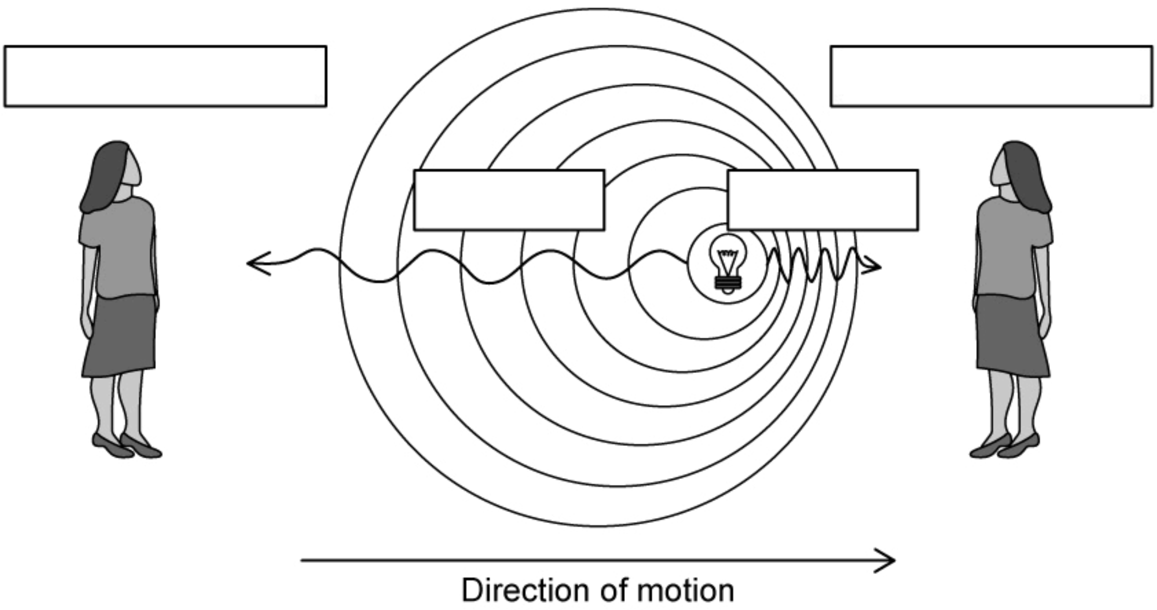
(3 marks)

(b) The diagram shows two people observing the same light source, which is in motion. The light is moving to the right.



Complete the boxes on the diagram with words or phrases from the list below.

higher frequency	lower frequency	phase difference	wavelength
blue shift	relative motion	star	red shift

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(4 marks)

(c) The following text is about the Doppler effect.

Complete the following sentences by circling the correct words:

When a source starts to move **away from / towards** the observer, the wavelength of the wave broadens.

For sound waves, sound therefore appears at a **higher / lower** frequency to the observer.

For light waves, the light shifts towards the **blue / red** end of the electromagnetic spectrum due to its **lower / higher** frequency.

When a source starts to move **away from / towards** the observer, the wavelength of the wave shortens.

For sound waves, sound therefore appears at a **higher / lower** frequency to the observer.

For light waves, the light shifts towards the **blue / red** end of the electromagnetic spectrum due to its **lower / higher** frequency.

This is because **blue / red** light has a longer wavelength than **blue / red** light.

(7 marks)

(d) State two uses of the Doppler effect.

(2 marks)

2 (a) Define redshift.

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(2 marks)

(b) For non-relativistic galaxies, Doppler redshift can be calculated using:

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f} = \frac{v}{c}$$

(i) State what is meant by a non-relativistic galaxy.

[1]

(ii) Define the symbols λ, f, v and c in the equation above.

[4]

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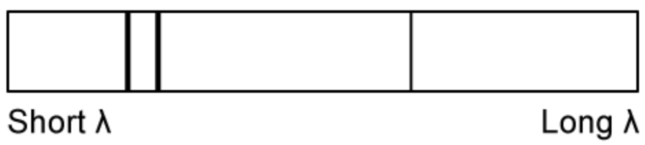
(5 marks)

(c) The shift in wavelength can be identified using spectral lines in an absorption spectrum.

The following absorption spectrum is generated using light from a source in a laboratory:



Sketch the spectrum obtained using light from a galaxy moving away from the Earth.

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(3 marks)

(d) An absorption line in the spectrum of light from a source in a lab in part (c) has a frequency of 5.783×10^{14} Hz. The same line in the spectrum of light from a distant galaxy has a frequency of 5.791×10^{14} Hz.

Calculate the speed of the distant galaxy in relation to the Earth.

(5 marks)

3 (a) This question is about redshift.

Complete the following sentences by filling in the correct words in the gaps:

After the discovery of Doppler redshift, astronomers began to realise that almost all the galaxies in the universe are _______.

This led to the idea that the universe is must be _______.

This caused the light waves to _______ _______ as they travel through space, shifting them towards the _______ end of the spectrum.

The more shifted the light from a galaxy is, the _______ the galaxy is moving away from Earth.

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(4 marks)

(b) The following equation is used for calculations where the observer is stationary and the source is moving:

$$f' = f\left(\frac{v}{v \pm u_s}\right)$$

Define each of the terms, f, f', v and u_s in the equation above and give the correct unit.

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(4 marks)

(c) State the equation used if the source is stationary and the observer is moving, defining any terms which differ from the equation in part (b).

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(2 marks)

(d) A distant galaxy is receding from the Earth at a velocity of 4.5×10^5 m s^{-1}. The galaxy emits light of frequency 5.5×10^{14} Hz.

Using the equation $f' = f\left(\frac{v}{v + u_s}\right)$, calculate the frequency of this light as observed from the Earth.

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(3 marks)

4 (a) The equation for the Doppler effect can be written as follows:

$$\lambda' = \lambda\left(1 \pm \frac{u_s}{v}\right)$$

Draw lines to match the symbol with the correct definition.

λ	Velocity of the source
λ'	Wavelength of the source
u_s	Wave velocity
v	Observed wavelength

(3 marks)

(b) State the conditions for the equation in part (a) which result in the term in brackets being:

(i) $1 - \frac{u_s}{v}$

[1]

(ii) $1 + \frac{u_s}{v}$

[1]

(2 marks)

(c) An ambulance is racing towards the scene of an emergency at a speed of 20 m $s^{-1.}$ The siren on the ambulance produces a sound of wavelength 0.2 m. The speed of sound in air is 340 m s^{-1}.

Using the equation in part (a), determine the wavelength of sound as heard by an observer at the scene.

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(3 marks)

(d) State and explain the effect of the wavelength of the sound calculated in part (c) with reference to what the observer hears.

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(2 marks)

5 (a) A team of naturalists are researching the movement of whales in the ocean. They plan to calculate the velocity of a whale using the Doppler effect. The whale pod is moving towards the research team.

State an equation which will allow the researchers to investigate the velocity of the whales using the frequency of sound in water using the following variables:

$$\lambda, \quad \lambda', \quad u_s, \quad v, \quad f, \quad f'$$

You may use each variable once, more than once or not at all.

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(2 marks)

(b) State and explain the difference between the sound produced by the whales and sound observed by the researchers.

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(2 marks)

(c) The whales are producing a monotone sound of frequency 50 Hz. The speed of sound in water is 1480 m s^{-1}. The whales are moving at 10 m s^{-1}.

Use the equation from part (a) to calculate the frequency of the sound from the whales as observed by the research team.

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(2 marks)

(d) The whales stop moving when they detect the boat. The researchers, not wanting to scare the whales, start to move away from the pod, accelerating over a period of time until reaching a steady speed of 20 m s^{-1}. The boat comes to a stop 500 m from the whale pod.

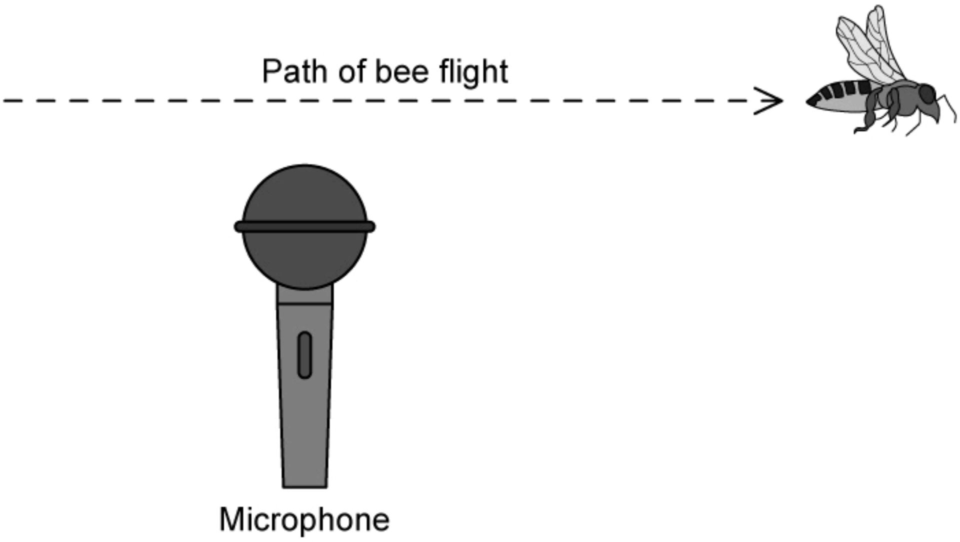
Order the phrases below from 1-3 to describe how the observed sound from the whales changes over this period.

The frequency of sound observed decreases gradually	
The sound observed is 50 Hz	
The sound observed is at a steady frequency lower than 50 Hz	

(3 marks)

Medium Questions

1 (a) A scientist is conducting an experiment on bees. They set up monitoring equipment near a hive, including a microphone which picks up the buzz from individual bees flying past.



A single bee flies at a constant speed in a straight line past the microphone, and the frequency of the buzz is detected.

Explain the sound pattern detected by the microphone as the bee moves towards and away from the microphone.

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(3 marks)

(b) The speed of the bee is 8.9 m s^{-1}. The maximum frequency of sound recorded by the microphone is 271 Hz. The speed of sound in air is 340 m s^{-1}.

(i) Calculate the frequency of sound produced by the bee.

[2]

(ii) Determine the minimum frequency recorded by the microphone.

[1]

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(3 marks)

(c) When bees are about to swarm, they produce a higher pitched buzz, known as 'piping'. The frequency of the piping sound is 550.0 Hz. The scientist moves the microphone closer to the hive during this process. Whilst they are moving the change in observed frequency is 3.4 Hz.

(i) Determine the speed at which the scientist walks towards the hive.

[3]

(ii) Explain the effect of any assumptions made in determining this speed.

[2]

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(5 marks)

(d) The swarm moves across the garden in which the hive is situated, travelling a distance of 13 m. The swarm is in flight for 2.1 s.

Calculate the wavelength of sound detected by the microphone during the flight of the swarm.

(4 marks)

2 (a) An ambulance siren emits two pure sounds. The lower of the two sounds has a frequency of 650 Hz. It is travelling towards a stationary observer at 13.4 m/s. The speed of sound in air is 340 m s^{-1}.

Calculate the change in frequency, Δf, between the source frequency and that heard by the observer.

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(2 marks)

(b) The ratio between the two frequencies emitted by the ambulance is 0.722.

(i) Determine the second frequency as heard by the observer.

[3]

(ii) Explain the effect a change in speed of the ambulance will have on the ratio between the two observed frequencies.

[2]

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(5 marks)

(c) As the ambulance approaches a red light at which a number of cars are stopped, it changes its siren to a single monotone sound which the car drivers observe as 700 Hz. The ambulance slows further to 5.3 m s^{-1}.

Calculate the wavelength of sound emitted by the ambulance.

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(3 marks)

(d) The ambulance pulls to a stop but continues to emit the 700 Hz tone. A car passes the ambulance. As it moves away the sound heard by the car driver has a frequency of 682 Hz.

Determine the speed of the car as it drives away from the ambulance

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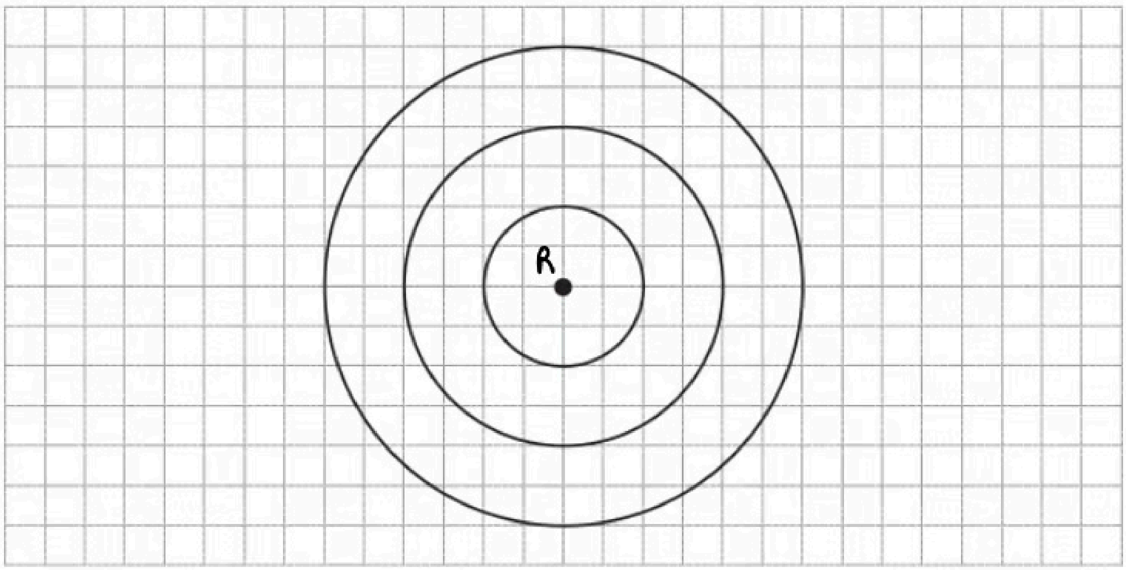
(2 marks)

3 (a) The diagram shows a stationary wave source, R, in water. The source produces waves with a constant frequency. The distance between each successive wavefront is equal to the wavelength of the waves produced by R.



The speed of the waves in water is v.

Sketch three successive wavefronts produced when the source is moving to the right at a speed of $0.75v$.

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(2 marks)

(b) A scientist sits on a boat to the right of the source and measures the frequency of the waves as they approach.

Explain the observations the scientist will make.

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(2 marks)

(c) The speed of the waves is 2.5 m s^{-1}. The wavelength of the waves as emitted by the source is 3.45 m.

Calculate the frequency of the waves as observed by the stationary boat.

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(2 marks)

(d) The boat starts to move. Source R is still moving at 0.75*v* to the right.

Discuss the effect the motion of the boat will have on the observed frequency of the water waves. Assume there is no acceleration.

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(4 marks)

4 (a) Every year, an alien species holds a race between two teams. One of the teams has green lights on its spaceships and the other has purple light. During the race the two ships approach a space station.

From the point of view of the space station commander, on the space station, the two colours appear to be identical. as the ships approach the station.

Explain how the commander knows which spaceship is travelling faster.

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(2 marks)

(b) The wavelength of light from the purple ship is 420 nm and from the green ship is 550 nm. The observed frequency of both ships from the space station is 405 nm.

(i) Determine the speed of the purple ship.

[2]

(i) Determine the ratio of speeds between the two ships.

[2]

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(4 marks)

(c) The green space ship enters the atmosphere of a planet near the spaceship for the victory ceremony, which has amassed a large crowd. It slows down to 0.005% of its speed during the race. As it nears the surface it emits a continuous tone of frequency 2320 Hz. The speed of sound in the atmosphere of this planet is 5690 m s^{-1}.

Calculate the frequency of sound observed by the crowd.

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(2 marks)

(d) The space station also has the capacity to detect light from other galaxies. In a laboratory, the frequency of electromagnetic radiation from a distant galaxy has been redshifted by 4.2×10^9 Hz. In the laboratory, the same light has a frequency of 1.9×10^{12} Hz.

(i) Calculate the speed of recession of the galaxy.

[1]

(ii) Discuss the implications of the recession of the galaxies in the universe.

[4]

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(5 marks)

Hard Questions

1 (a) A car passes a stationary police car which is emitting a pure tone. The speed of the car is 130 km h^{-1}.

Determine the frequency change of the sound heard by the driver as a percentage of the original frequency from the police car, f

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(3 marks)

(b) On the return journey, the driver of the car hears a tone of wavelength 0.607 m. Their speed is 78% of the outward speed.

Determine the frequency of sound emitted by the police car.

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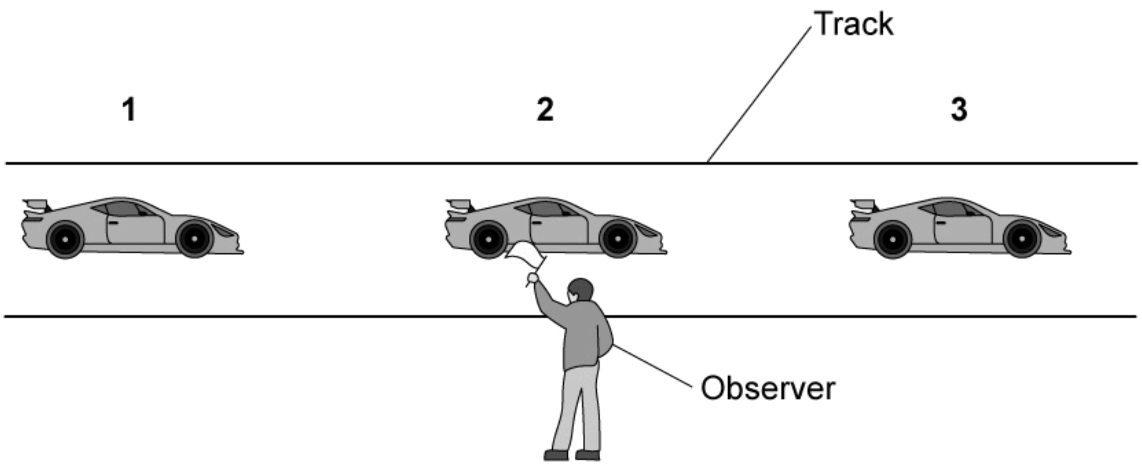
(2 marks)

2 (a) A racing car is travelling at 300 km h^{-1} on a race track.



The stationary observer hears a frequency of sound of 1550 Hz from the exhaust as the car approaches them (position 1). You can assume the speed of sound to be 340 m s^{-1}.

Determine the frequency of sound heard by:

(i) A stationary observer standing next to the track as the car passes (position 2)
.

[1]

(ii) A stationary observer standing next to the track behind the current position of the car (position 3).

[1]

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(2 marks)

(b) The car from part (a) opens its Drag Reduction System (DRS) increasing its top speed by 10 km h^{-1}. It then overtakes another car which is travelling at 300 km h^{-1}.

The equation which can be used when both source and observer are moving is:

$$f' = f\left(\frac{v \pm u_o}{v \pm u_s}\right)$$

The frequency of the sound emitted by the car exhaust is directly proportional to the speed.

Calculate the maximum and minimum frequency of sound heard from the faster car, as heard by the driver of the car being overtaken during this manoeuvre.

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(4 marks)

(c) A scientist is doing some experiments on sound from the safety of the stands. An air horn emits a sound of frequency 450 Hz. The sound of the horn reflects off the car, which is moving away from the scientist, who measures the frequency as being 420 Hz.

Calculate the speed of the car.

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(3 marks)

3 (a) A train is travelling at 45 m s^{-1} and blows a whistle at a frequency of 750 Hz. A person is waiting at a level crossing for the train to pass. Take the speed of sound in air as 340 m s^{-1}.

Calculate the frequency observed by the person:

(i) In still air.

[1]

(ii) When the wind is blowing at 10 m s^{-1} towards the train and away from the person.

[2]

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(3 marks)

(b) After the train passes the level crossing, it slows down as it approaches a tunnel. Wind is funnelled down the tunnel towards the train reaching a velocity of 27 m s^{-1}. The observer at the level crossing hears the whistle at a frequency of 729 Hz.

Calculate the new speed of the train.

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(2 marks)

(c) After exiting the tunnel, the train stops at a station. The observer from part (a) is now walking to the platform to catch the train at a speed of 1.5 m s^{-1}. The human ear can distinguish between frequency differences of around 3.6 Hz.

Show that the change in frequency of the train's whistle, as heard by the running observer, can be considered negligible.

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(2 marks)

(d) Once the train has left the station, it travels down a line with two tracks. Another train is approaching on the opposite track with a speed of 7.6 m s^{-1}. The speed of the departing train is 83% of the speed of the second train.

When both observer and source are moving, the following equation can be used to determine the new frequency:

$$f' = f\left(\frac{v \pm u_o}{v \pm u_s}\right)$$

Calculate the frequency of the whistle as observed by a passenger on the approaching train as a percentage of f.

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(3 marks)

4 (a) A ship is using low frequency sonar to map the sea bed. It sends out a pulse of sound which startles a nearby school of fish. The fish start to swim away at a speed of 20 km h^{-1}. The ship then sends out a second pulse with a wavelength that is 15 cm less than that of the original pulse. The fish perceive the two pulses to have the same frequency.

Determine the wavelength of the initial pulse.

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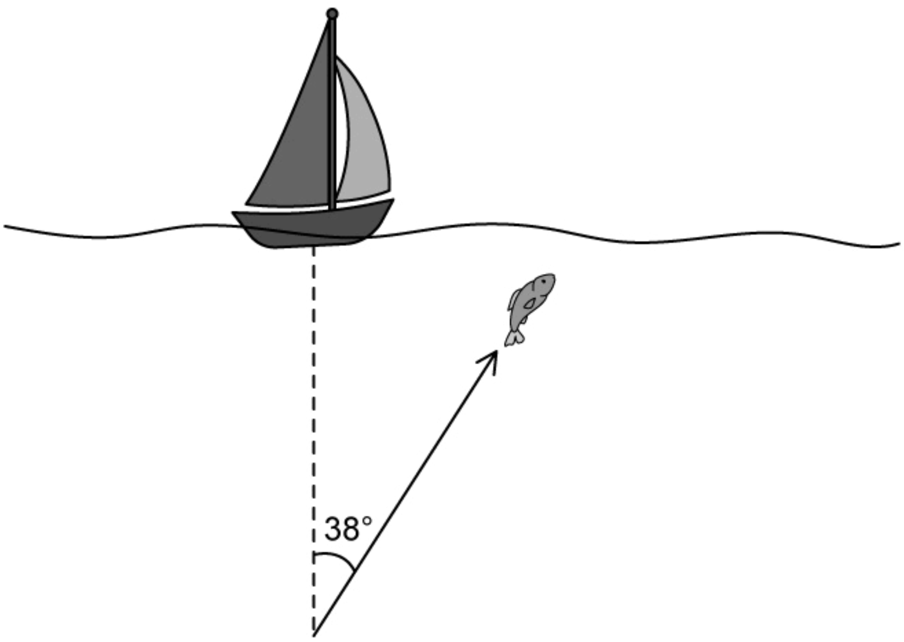
(3 marks)

(b) The school of fish approach a second ship which is emitting the same frequency of pulse as the first ship. They approach this boat at an angle of 38 °.



Calculate the frequency of sound as observed by the fish, f'.

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(3 marks)

(c) The boat uses the stars to navigate. The captain uses a diffraction grating on her telescope to observe the light from a nearby asteroid she has spotted. She observes a spectral absorption line with a frequency of 673.7 nm.

The absorption line for that element is given as 673.8 nm from tests in the laboratory.

Through use of a calculation, explain why the captain might be concerned.

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(3 marks)

5 (a) Two stars, A and B, in a binary system move in an anti-clockwise direction. Both stars emit light with wavelength, $\lambda = 5.89 \times 10^{-7}$ m, which reaches an observer on Earth. In the laboratory, the light is shown to fluctuate between wavelengths of 5.86×10^{-7} m and 6.02×10^{-7} m.

Assume they orbit in a circle around their common centre of mass.

Draw a diagram which indicates the position of the stars relative to the Earth when:

(i) There is no redshift.

[1]

(ii) The wavelength is recorded as 5.86×10^{-7} m from both stars.

[2]

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(2 marks)

(b) The radius of orbit of star B is 4.98×10^{11} m.

Calculate the time taken for one orbit of star A about the common centre of mass.

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(1 mark)