

**WAVES: DOPPLER EFFECT AND BEATS QUESTIONS**

**QUESTION ONE (2017;1)**

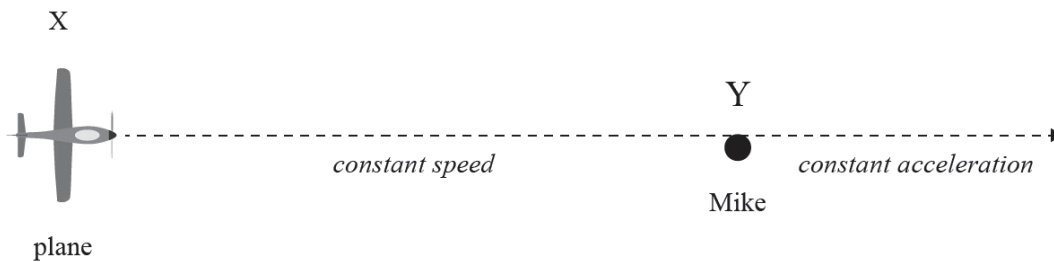
In 1845, Dutch physicist Buys Ballot demonstrated the Doppler effect by listening to musicians playing their instruments on a train as it passed by him.

One musician played a note on a clarinet. The speed of sound is  $341 \text{ m s}^{-1}$ .

- (c) When the train was approaching Ballot at a speed of  $5.00 \text{ m s}^{-1}$ , he heard a frequency of 139 Hz from the clarinet. Show that the frequency of the sound heard by the clarinet player would have been 137 Hz.
- (d) A second clarinet player was standing beside Ballot as the train approached. She produced the same frequency (137 Hz) as the clarinet player on the train, causing Ballot to hear beats. Explain why the sound wave reaching Ballot from the clarinet on the train did not have a frequency of 137 Hz, AND explain why Ballot heard beats, AND calculate the beat frequency.

**A RADIO-CONTROLLED PLANE (2016;2)**

Mike is flying his radio-controlled plane. The plane flies towards him at constant speed, and then away from him with constant acceleration, as shown in the diagram below. The plane is producing a constant frequency of 185 Hz. Assume the speed of sound in air is  $343 \text{ m s}^{-1}$ .



- (a) Describe and explain the frequency of the sound Mike hears when the plane is at position X.
- (b) Describe the frequency of the sound Mike hears when the plane is at position Y
- (c) Describe and explain the frequency of the sound Mike hears as the plane gradually accelerates away from him.
- (d) Calculate the speed of the plane when the sound waves being produced behind it have a wavelength of 2.00 m.

**THE WHIRLING BUZZER (2015;3)**

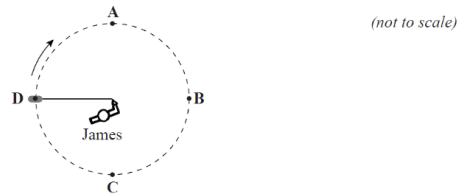
Speed of sound in air =  $3.43 \times 10^2 \text{ m s}^{-1}$

James attaches a buzzer to the end of a piece of string. James whirls the buzzer above his head in a horizontal circle of radius 1.02 m at a constant speed of  $16.0 \text{ m s}^{-1}$ . Sabina stands a long distance away and listens



- (a) Describe the motion of the buzzer when Sabina receives sound waves with the shortest wavelength
- (b) If the frequency emitted by the buzzer is 512 Hz, show that the lowest frequency heard by Sabina is 489 Hz

- (c) Sabina stands a very long way away from James and listens to the buzzer. The sound appears to be increasing in frequency as the buzzer travels from point C to point A. Explain why Sabina hears an increasing frequency between point C and point A. *You may want to use calculations to assist your answer.*



- (d) James wants Sabina to hear beats. He puts a second buzzer, which is also emitting a sound of frequency 512 Hz, on the ground. James again whirls the original buzzer above his head, but at a different speed. When the buzzer is at point A, James lets go of it, so the buzzer flies towards Sabina. Sabina hears a 10 Hz beat as James releases the string. Calculate the velocity of the buzzer at the point of release

**THE DOPPLER EFFECT (2014;3)**

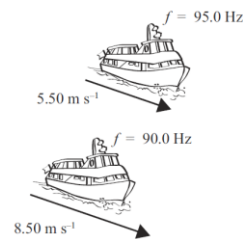
A tourist is watching a ferry boat coming towards her. The speed of the ferry is  $5.50 \text{ m s}^{-1}$ . The ferry sounds its horn, producing a note of frequency 95.0 Hz. The speed of sound in the air over the water is  $3.50 \times 10^2 \text{ m s}^{-1}$ .



- (a) Calculate the frequency of the note that the tourist hears.
- (b) Explain why the sound of the horn heard by the tourist does not have the same pitch as the sound emitted by the horn.



- (c) A second ferry, which is overtaking the first, also sounds its horn, producing a note of frequency 90.0 Hz. For a few moments, both ferries are the same distance from the tourist, quite close together, and both are sounding their horns. The tourist hears beats.



- (i) Calculate the frequency of the beats that are heard by the tourist.
- (ii) Describe what beats are and explain how they are created.

### THE DOPPLER EFFECT (2013;2)

An ambulance with its siren on drives towards a stationary police officer.

- (a) State the differences (if any) in the **velocity**, and in the **wavelength**, of the sound waves that are observed by the police officer compared to the ambulance driver.
- (b) The ambulance drives towards the police officer at constant speed. Explain why the frequency heard by the police officer does not change as the ambulance approaches.
- (c) The ambulance passes close by the police officer, and continues on past without changing speed. The frequency heard by the police officer changes from 960 Hz to 870 Hz. The speed of sound in air is  $343 \text{ m s}^{-1}$ . Determine the speed of the ambulance.
- (d) The driver of the ambulance then accelerates directly away from the police officer before coming to a sudden stop. Explain how the frequency of the sound heard by the police officer changes during this time.

### THE DOPPLER EFFECT (2012;2)

Jess and Tom have identical horns that both produce a frequency of 420 Hz. Tom stands beside the road, listening to Jess sound her horn as she rides away in a car. The speed of sound in the air is  $343 \text{ m s}^{-1}$ .

- (a) Calculate the Doppler shifted frequency of the horn, as heard by Tom, when Jess is travelling away at  $12.0 \text{ m s}^{-1}$ .

Jess's car changes to a new steady speed, and then Jess sounds her horn again. Tom sounds his horn too, and notices beats.

- (b) Explain the phenomenon of beats. Your answer could include:
  - What beats are
  - Why beats form
  - Why the beat frequency is the difference between the two incident wave frequencies.
- (c) When Tom sounds his horn, he hears a beat frequency of 6.00 Hz. Calculate the speed at which Jess is moving away from Tom.
- (d) Speed cameras measure the speed of a car by measuring the Doppler shift of a radio signal reflected from the car. Explain why a speed camera cannot measure the speed of the car at the moment when the car passes the camera.

**DOPPLER EFFECT (2011;3)**

Doppler ultrasound can be used to measure the speed at which blood flows along blood vessels. This is important in the detection of diseased blood vessels. Ultrasound has a frequency too high to be detected by human ears.

- (a) If a source of waves is moving **towards** a detector, explain why the wavelength detected by the detector is less than the wavelength of the source.
- (b) An ultrasound wave is sent along a blood vessel, and the moving blood cells reflect it. The blood cells **effectively** become a source of sound waves that is moving at the speed of the blood. The speed of sound in blood is  $1\,545\text{ m s}^{-1}$ . The blood cells reflect sound waves at a frequency of  $1.0522 \times 10^6\text{ Hz}$ . Because the cells are moving, the wavelength is Doppler shifted. The reflected sound is detected with a wavelength of  $1.4670 \times 10^{-3}\text{ m}$ . Calculate the speed of the blood cells.

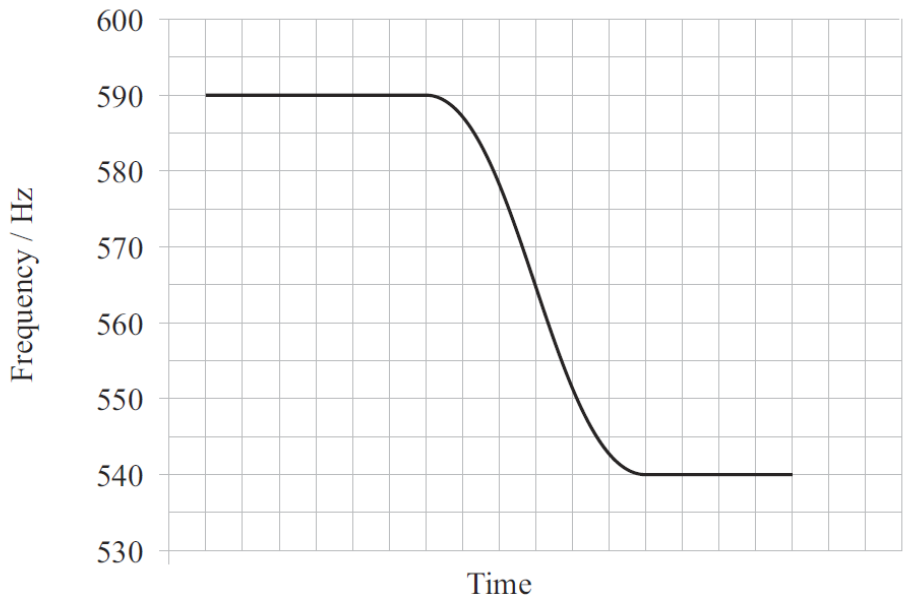
**STEAM WHISTLE (2010;1)**

Data to use:

Speed of sound in dry air at  $20^\circ\text{C} = 343\text{ m s}^{-1}$

Speed of sound in steam at  $200^\circ\text{C}$  at a pressure of  $7\text{ MPa} = 523\text{ m s}^{-1}$

- (c) A train passes a student at a steady speed, sounding its whistle with a full jet of steam. The frequency of the fundamental, measured by the stationary student, changes as shown.

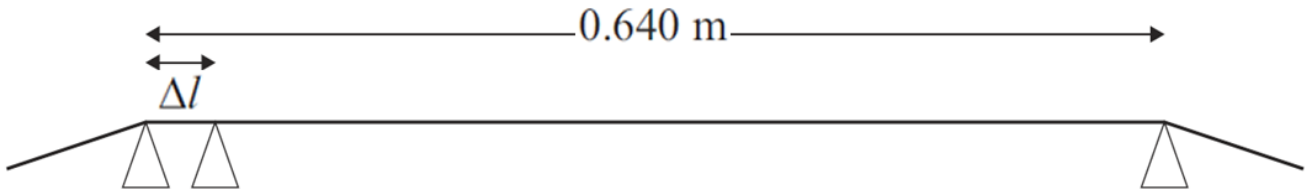


By calculating the true frequency of the whistle, or otherwise, show that the speed of the train is  $15.2\text{ m s}^{-1}$ .

**TUNING A GUITAR (2010;2)**

The 'A' string on a guitar has a weight and a tension which means that waves travel along the string at  $563 \text{ ms}^{-1}$ . The length of the string that is free to vibrate is  $0.640 \text{ m}$ . The fundamental frequency (1st harmonic) of the string is  $440 \text{ Hz}$ .

On a second guitar, an identical 'A' string, with the same tension and weight, is tuned to the same frequency. Without changing the tension, this second string is shortened by  $\Delta l$ . When both strings are plucked to sound their fundamental frequency, beats are detected at a frequency of  $20 \text{ Hz}$ .



- (d) Calculate the change in length,  $\Delta l$ , of the second string.

**STRINGS AND STANDING WAVES (2009;1)**

- (d) Sarah has a six-stringed guitar. Each string is tuned to a different pitch.

The thickness and tension in two strings (numbers 2 and 3) are such that a travelling wave in string 3 moves 1.005 times faster than the wave in string 2 (so that  $v_3/v_2 = 1.005$ ). Both strings are the same length. When they are plucked, they both vibrate in their fundamental mode. The two sounds cause beats at a frequency of  $1.2 \text{ Hz}$ . Calculate the fundamental frequency of string 2.



### DOPPLER DUCK (2009;2)

A teacher wants to make a video that demonstrates the Doppler Effect. He uses a rubber duck to make circular ripples on a pond of still water. The teacher moves the duck up and down. Circular ripples spread out on the pond, as shown in the images below from two video clips.



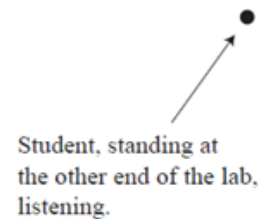
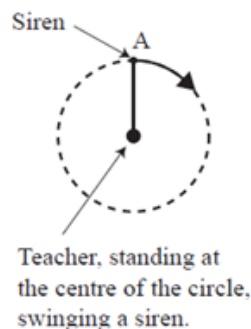
- (a) Explain why the ripples are circular.
- (b) In the right-hand image above, the teacher was moving the duck with a horizontal velocity in addition to its vertical oscillation.
- (i) Draw an arrow on the image below to show the direction of the duck's horizontal velocity.
- (ii) Explain how you can deduce the horizontal motion of the duck from the pattern of ripples.
- (c) Careful analysis of the second video clip shows that the ripples are travelling at  $0.400 \text{ ms}^{-1}$ , the teacher's hand moves up and down 19 times over 5.00 s, and the wavelength of the ripples behind the duck is 0.135 m. Use the information given to calculate:
- (i) The frequency at which the ripples move a small twig floating directly behind the duck.
- (ii) The horizontal speed of the duck.



### DOPPLER EFFECT (2008;2)

Speed of sound in air =  $3.40 \times 10^2 \text{ ms}^{-1}$

A teacher swings a siren on the end of a string in a horizontal circle. The diagram shows the situation viewed from above.



The siren is emitting a note of frequency 287 Hz.

- (a) When the siren is in position A, it is travelling towards the student. The frequency the student hears is greater than 287 Hz. Explain this increase in frequency.
- (b) The apparent frequency the student hears when the siren is at position A is 304 Hz. Calculate the speed of the siren. You may assume that the distance between the student and the teacher is great enough for the siren to be considered to be moving directly towards the student at this position.
- (c) Although the siren is moving, the teacher hears the true frequency of 287 Hz. Explain why.
- (d) The teacher now gets two identical sirens and sets them both to generate sound waves at a frequency of 287 Hz. She attempts to demonstrate beats to the student by moving one of the sirens away from the student at a steady speed. Calculate the speed at which the teacher must move the siren, in order to generate beats with a frequency of 5.0 Hz.

## THE DOPPLER EFFECT (2007;2)

The speed of sound in air is  $3.40 \times 10^2 \text{ ms}^{-1}$ .

Carlie plays her recorder on a float in a local parade. Carlie's friend Edward is in the crowd listening to Carlie play. At one point in the performance, Carlie plays the same note for several seconds.

- (a) Explain why, as the float travels towards Edward at a constant speed, the pitch of the note heard by Carlie is different to the pitch of the note heard by Edward.

When the float is traveling at  $1.2 \text{ ms}^{-1}$  the apparent frequency of the note that Edward hears is 673 Hz.

- (b) Re-arrange an appropriate formula to find an expression for the true frequency of the source and use this re-arranged formula to calculate the frequency of the note Carlie plays.
- (c) Even though there is only a small difference in these two frequencies, explain why neither Carlie nor Edward hear beats in this situation.

Fale is further down the street and hears a different part of the performance. As the float passes Fale, the apparent wavelength of a note he hears when the float is moving towards him changes to a different apparent wavelength when the float is moving away from him. The difference in the apparent wavelengths of the note he hears is 0.0032 m. The apparent wavelength,  $\lambda'$  in the Doppler effect can be calculated from:

$$\lambda' = \lambda \left( \frac{v_w \pm v_s}{v_w} \right)$$

- (d) If the speed of the float is still  $1.2 \text{ ms}^{-1}$  as it passes Fale, calculate the frequency of the note emitted by the recorder.

## REMOTE CONTROL CARS (2006;1)

Speed of sound in air =  $3.40 \times 10^2 \text{ ms}^{-1}$

David has been given a remote-control car for his birthday. It has a red light on top, and a siren that produces a single note with a frequency of 265 Hz.



When playing with the car, David notices that the frequency of the note produced by the siren seems to change as the speed and direction of the car changes.

- (a) State the name that is given to this effect.
- (b) On one occasion the car is moving away from David. As it slows down and stops he notices the frequency of the sound changes. Explain the changes in frequency that David hears as the car slows down and stops.
- (c) Explain why there is a noticeable change in the frequency of the sound from the siren, but not a noticeable change in the colour of the red light, as the car changes speed and direction.
- (d) Calculate the apparent frequency of the sound from the siren when the car is moving towards David at a speed of  $15.0 \text{ ms}^{-1}$ . Give your answer to the correct number of significant figures.
- (e) David's cousin, Emma, has an identical car. As they are playing with the cars, they notice that when one car is moving away from them and the other is stationary, the sound they hear beats with a frequency of 10 Hz. Calculate the speed of the moving car.



### USING A PIPE TO MAKE MUSIC (2005;1)

A child's toy consists of a long, flexible, plastic pipe, open at both ends. Holding the pipe at one end, the other end can be swung around so that a standing wave is set up in the pipe, and a musical note heard. If the pipe is swung slowly the 1st harmonic (fundamental) frequency is heard. If the pipe is swung at a faster speed, the note changes to the 2nd harmonic (1st overtone) frequency. Even faster swinging produces the 3rd harmonic (2nd overtone).



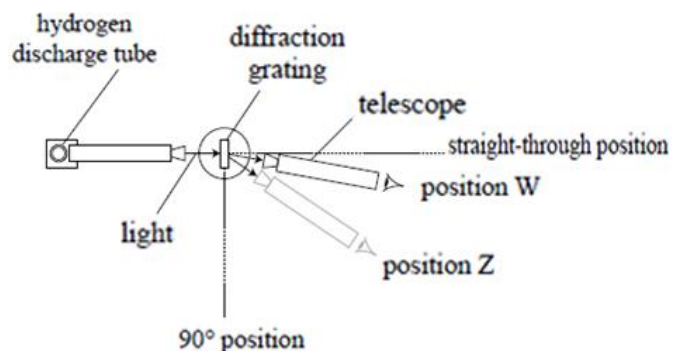
Jessica swings her pipe in such a way that the 3rd harmonic (2nd overtone) is heard. The frequency of the note is 685 Hz. The speed of sound in air is  $3.4 \times 10^2 \text{ ms}^{-1}$ .

Swinging the pipe causes waves with a range of frequencies to be generated in the pipe.

- (g) Joe swung a similar pipe at the same time as Jessica was swinging hers, and his pipe also produced the 3rd harmonic frequency note. There was a 9.0 Hz beat in the sound they heard. Show that the difference in the length of the two pipes is 1 cm.

### EMISSION SPECTRA (2005;2)

When a high voltage electrical discharge is applied to hydrogen at low pressures, light is emitted. This light is passed through a diffraction grating that has  $6.1 \times 10^3$  lines per cm, and a spectrum of coloured lines is viewed through the telescope of a spectrometer. There are several different order spectra that can be viewed. Each order is made up of 4 coloured lines; red, green / blue, purple and violet. The following is a diagram of a spectrometer from above, showing how the telescope rotates about the position of the diffraction grating.



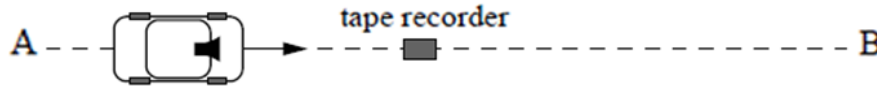
- (f) The atoms of hydrogen in a discharge tube are in rapid motion in random directions. Although each may emit a well-defined frequency, in practice the light received by the detector is a band of frequencies. Using the Doppler Effect, explain why this happens.
- (g) The expected frequency of the violet line is  $7.32 \times 10^{14}$  Hz. Analysis of the violet band of light received by the detector showed that light of frequency  $7.36 \times 10^{14}$  Hz was also present. Calculate the component of the velocity, in the direction of the spectrometer, of the hydrogen atoms that produced the frequency  $7.36 \times 10^{14}$  Hz. The speed of light is  $3.00 \times 10^8 \text{ ms}^{-1}$ . Ignore any relativistic effects.



**AN EXPERIMENTAL VALUE FOR THE SPEED OF SOUND (2004;1)**

Some students were given the task of designing an experiment to measure the speed of sound. To do this they were given an air horn that sounded a single note of frequency 426 Hz.

The experiment they designed involved driving a car from A to B at a constant speed over a tape recorder, with the horn sounding.

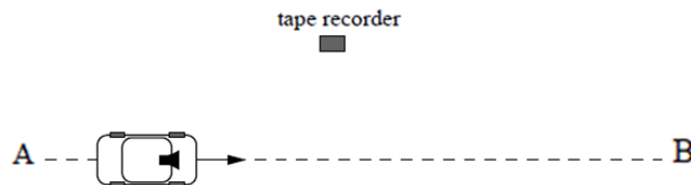


The students carried out several trials. For each trial, they made a recording of the sound of the horn as the car moved from A to B and noted the speed of the car. Back at school, the students determined the frequency of the notes they had recorded. The students observed that the recorded pitch of the sound from the horn as it moved toward the tape recorder was different from the pitch as the horn moved away from the recorder.

(a) What is this phenomenon called?

For one of the trials, the speed of the car was noted as  $31 \text{ km h}^{-1}$  ( $8.6 \text{ m s}^{-1}$ ). Two notes from the horn were recorded. The higher-pitched note had a frequency of 437 Hz.

- (b) By rearranging the appropriate formula, show that this data gives a speed of sound of  $340 \text{ m s}^{-1}$ .
- (c) Explain why there is a difference in the frequency of the two notes recorded.
- (d) Calculate the frequency of the lower-pitched note of the two that were recorded.
- (e) On one occasion, the path AB of the car was some distance from the recorder, as shown in the diagram below. In the recording for this run, the students noticed the change in pitch was gradual rather than sudden. Explain why this is so.
- (f)



To find the frequency of the notes they had recorded, the students compared the recordings to the sound produced by a speaker connected to a variable frequency (signal) generator. The students noticed that sometimes, when they were listening to both sounds at the same time, there was a regular variation in the loudness of the sound. This phenomenon is known as 'beats'.

- (g) Explain, using physical principles, how beats are produced.
- (h) For one of the trials, when the recorded note was sounded at the same time as the signal generator note, a beat frequency of 5.0 Hz was heard. The signal generator note had a frequency of 425 Hz.
  - (i) What does this indicate about the frequency of the recorded note?
  - (ii) When the signal generator frequency was increased the beat frequency decreased. Explain how this information enables the frequency of the sound on the recording to be found.