



## DOPPLER EFFECT WORKSHEET 2020

### **Doppler Effect (relative motion between source and observer)**

(This section must be read in conjunction with the CAPS, p. 121–122.)

#### **With sound and ultrasound**

- State the Doppler effect as the change in frequency (or pitch) of the sound detected by a listener because the sound source and the listener have different velocities relative to the medium of sound propagation.
- Explain (using appropriate illustrations) the change in pitch observed when a source moves toward or away from a listener.
- Solve problems using the equation  $f_L = \frac{v \pm v_L}{v \pm v_s} f_s$  when EITHER the source or the listener is moving.
- State applications of the Doppler effect.

#### **With light – red shifts in the universe (evidence for the expanding universe)**

- Explain *red shifts* and *blue shifts* using the Doppler Effect.
- Use the Doppler effect to explain why we conclude that the universe is expanding.

## **DOPPLER EFFECT**

Doppler effect is the change in frequency (or pitch) of the sound detected by a listener because the sound source and the listener have different velocities relative to the medium of sound propagation.

## SUMMARY

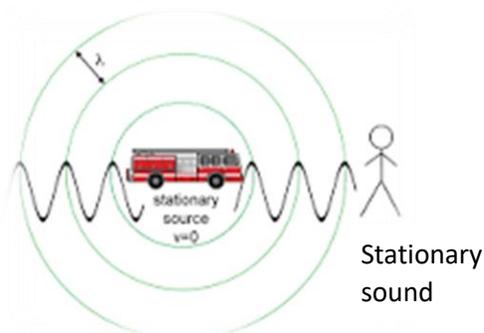
Factors affecting sound	Type of sound	
A large amplitude	Loud sound	
Small amplitude	Soft sound	
High frequency: Many vibrations per second	High pitch	$f = \frac{\text{number of waves}}{\text{time taken}}$
Low frequency: few vibrations per second	Low pitch	$f = \frac{\text{number of waves}}{\text{time taken}}$ $f = \frac{1}{T}$
		$T = \frac{\text{Time taken}}{\text{number of waves}}$

## RELATIONSHIP BETWEEN FREQUENCY AND WAVELENGTH

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

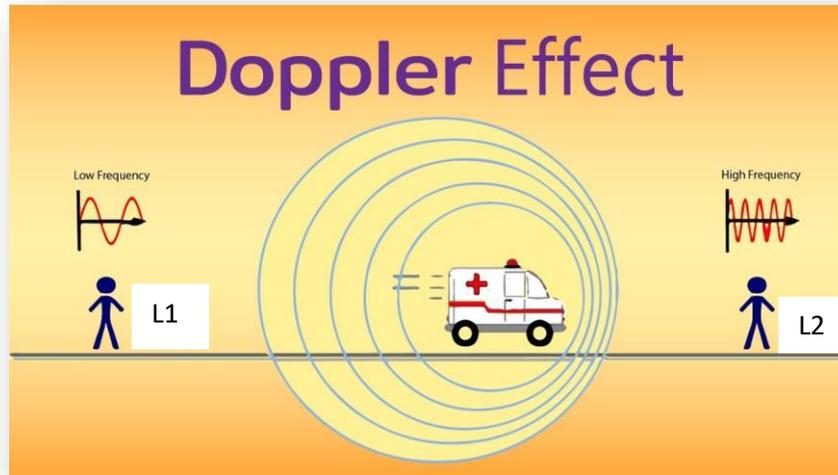
As the wavelength decreases the frequency increases ( $f \propto \frac{1}{\lambda}$ )

### Stationary source



Velocity of the sound waves moves the same in all directions.  
Wavelength ( $\lambda$ ) of the sound waves is the same in all directions.  
Then therefore the frequency heard or observed by the listener is will be the same as the frequency of the source of sound.

## Moving source



### Moving away

As the ambulance is moving away from the listener L1, the wavelengths are far apart and become longer resulting in waves and few waves will reach the listener per unit time, therefore the frequency decreases. Listener L1 will hear a lower pitch sound.  $f_L < f_s$

### Moving towards

As the ambulance is moving towards the listener L2, the wavelengths are compressed and become shorter resulting in waves compressed and more waves will reach the listener per unit time, therefore the frequency increases. Listener L2 will hear higher pitch sound  $f_L > f_s$

Doppler effect equations

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

textbook

NB: Meaning for each symbol check on your

### For source of sound moving away

$$f_L = \frac{v - v_L}{v + v_s} f_s \text{ (smaller answer)}$$

$v_L = 0$  if source of sound is stationary

### For the source of sound moving towards

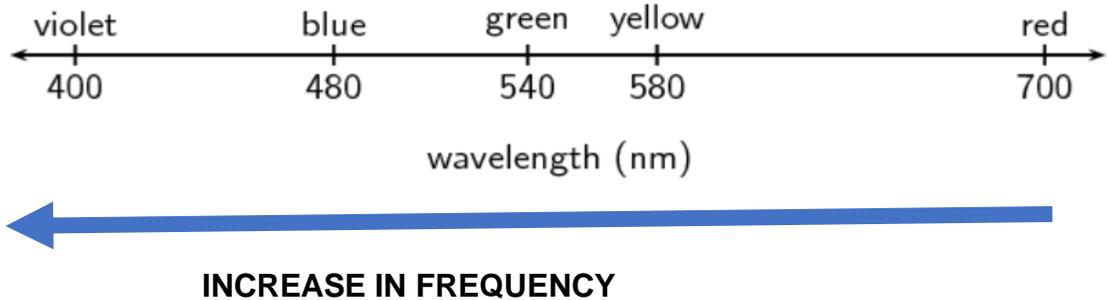
$$f_L = \frac{v + v_L}{v - v_s} f_s \text{ (larger answer)}$$

$v_L = 0$  if source of sound is stationary

## DOPPLER EFFECT AND LIGHT

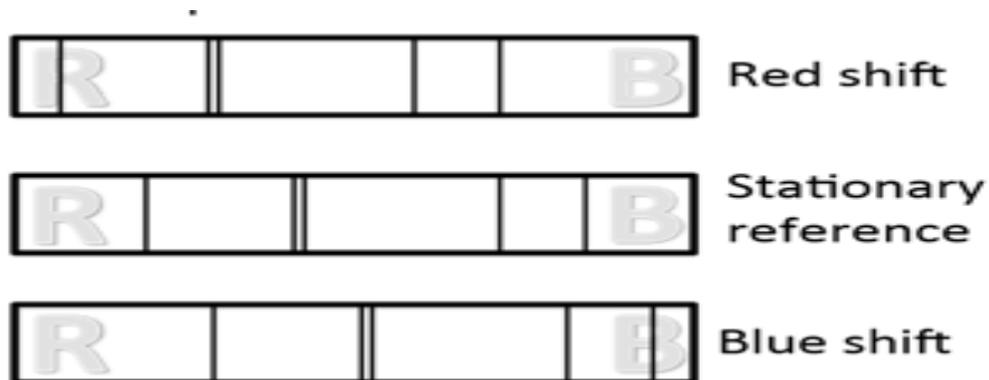
Doppler effect is also detected as a change in colour with light waves.

When the colour/frequency of light being emitted differs from the light observed, it is called a shift.



Red light has a longer wavelength whereas blue light has shorter wavelength and higher frequency.

Red shift and Blue shift



1. Blue shift: (Source of light moving towards observer)

Star (source of light) moves towards observer, waves with shorter wavelength and high frequency will be observed. Frequency of the light increases, shifting towards shorter wavelength (blue side) of the spectrum.

NB

If a star is moving towards the earth, there will be a shift of the spectrum lines to higher frequencies (shorter wavelength).

2. Red shift (Source of light(star) moving away from observer)

The waves of the longer wavelength and lower frequency will be observed. The frequency of the light decreases, shifting to towards the longer wavelength (red side) of the spectrum since red has a longer wavelength.

NB If a star is moving away from earth, there will be a shift of spectrum lines to lower frequencies (longer wavelength).

The greater the shift, the great the speed of the star.

The earth is expanding because of the red shift since most stars are moving away from earth. Distance between galaxies are increasing).

Steps to be followed for calculations.

Step 1: Collect data

Step 2 : Determine whether the source of sound is moving away or towards : ( $f_s < f_L$  or  $\lambda_s > \lambda_L$  towards or )  
 $f_s > f_L$  or  $\lambda_s < \lambda_L$  (away)

Step 3: Write down the formula as it is from data sheet.

Step 4: Calculate the unknown by substituting from the Doppler effect equation.

## WORKED EXAMPLES

1. A sound source, moving at a constant speed of  $240 \text{ m}\cdot\text{s}^{-1}$  towards a detector, emits sound at a constant frequency. The detector records a frequency of  $5\ 100 \text{ Hz}$ . Take the speed of sound in air as  $340 \text{ m}\cdot\text{s}^{-1}$ .

1.1 Calculate the wavelength of the sound emitted by the source.

Solution

Step1  $v_s = 240 \text{ m}\cdot\text{s}^{-1}$ ,  $v_L = 0 \text{ m}\cdot\text{s}^{-1}$  (detector stationary),  $f_L = 5100 \text{ Hz}$  (detected),  $v = 340 \text{ m}\cdot\text{s}^{-1}$ ,  $f_s = ?$  &

Step2 Source of sound moving towards the observer(detector) from the statement

Step3  $f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

Step4

$$f_L = \frac{v+v_L}{v-v_s} f_s$$
$$.5100 = \frac{340-0}{340-240} f_s$$
$$f_s = 1500 \text{ Hz}$$

$$f_s = \frac{v}{\lambda_s}$$
$$.1500 = \frac{340}{\lambda_s}$$
$$\lambda_s = 0.23 \text{ m}$$

- 2 The data below was obtained during an investigation into the relationship between the different velocities of a moving sound source and the frequencies detected by a stationary listener for **each** velocity. The effect of wind was ignored in this investigation

Experiment number	1	2	3	4
Velocity of the sound source (m·s <sup>-1</sup> )	0	10	20	30
Frequency (Hz) of the sound detected by the stationary listener	900	874	850	827

2.1 Write down the dependent variable for this investigation.

Ans Frequency (of sound detected by the listener (observer)).

2.2 Was the sound source moving TOWARDS or AWAY FROM the listener? Give a reason for the answer.

Ans Away from. Detected frequency of source decreases.

Hint: There is a decrease in the frequency of the sound detected by the observer from 900Hz to 827Hz

2.3 Use the information in the table to calculate the speed of sound during the investigation

Step 1 Use any interval

$$v_s = 0 \text{ m}\cdot\text{s}^{-1}, f_s = 900 \text{ Hz}, v_L = 0 \text{ (observer stationary)}, f_L = 874 \text{ Hz}, v = ?$$

Step 2 Away since there is decrease in the frequency observed.

Step 3  $f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

Step 4  $f_L = \frac{v - v_L}{v + v_s} f_s$   
 $874 = \frac{v - 0}{v + 10} 900$   
 $v = 336.15 \text{ m}\cdot\text{s}^{-1}$

2.4 The spectral lines of a distant star are shifted towards the longer wavelengths of light. Is the star moving TOWARDS or AWAY FROM the Earth?

Ans Away from the Earth.  
Hint: Red shift.

## ACTIVITIES

### QUESTION 1

1 Light reaching the Earth from a galaxy moving away is shifted towards ...

- A greater velocities.
- B higher frequencies.
- C longer wavelengths.
- D shorter wavelengths

(2)

2 A police car, with its siren on, is moving away at constant speed from a stationary observer. The siren emits a sound of constant frequency. Which of the following characteristics, associated with the sound emitted by the siren is/are CORRECT, as perceived by the observer?

- (i) The speed remains the same.
- (ii) The frequency increases.
- (iii) The wavelength increases.
- (iv) The frequency decreases.

A (iii) only

- B (i), (iii) and (iv)
- C (i) and (iii) only
- D (i) and (ii) only (2)
- 3 An observer runs towards a stationary sound source. As the observer approaches the source, its pitch appears to increase because the ...
- A loudness of the source appears to increase.
- B frequency of the source appears to increase.
- C frequency of the source appears to decrease.
- D wavelength of the source appears to increase. (2)

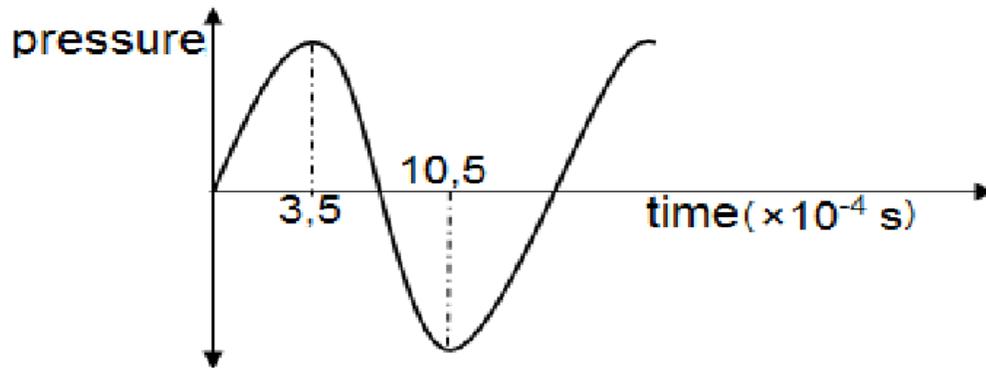
## QUESTION 2

A sound source on a car produces sound waves of frequency 850 Hz. A stationary observer measures the emitted frequency using a detector which can measure a maximum frequency of 800 Hz. He finds that the detector only registers a reading whilst the car is moving. (Ignore the effects of wind.)

- 2.1 State Doppler effect in words (2)
- 2.2 Must the car move TOWARDS or AWAY from the observer for the detector to register a reading? Explain the answer by referring to frequency or wavelength. (3)
- 2.3 Calculate the minimum speed at which the car must move for the detector to register the maximum reading. Take the speed of sound in air as  $340 \text{ m}\cdot\text{s}^{-1}$ . (5)
- 2.4 State ONE use of the Doppler effect in medicine. (1)

### QUESTION 3

A man mounts a siren on the roof of his car. The siren produces a constant frequency of 600 Hz. He drives the car at a constant speed up and down a straight road while a stationary listener takes some readings. After a while, the listener obtains the following pressure-time graph from the readings taken. (Take the speed of sound in air as  $340 \text{ m}\cdot\text{s}^{-1}$ )



- 3.1 State the Doppler Effect in words. (2)
- 3.2 Determine the period of the detected wave. (2)
- 3.3 Calculate the frequency of the detected sound wave. (3)
- 3.4 Calculate the speed of the moving car. (5)

#### QUESTION 4

In the diagram below, a police car with its siren blaring, stationed between two stationary observers.



- 4.1 How does the frequency detected by observer 1 compare to the frequency detected by observer 2 while the car is stationary? Choose from, GREATER THAN, LESS THAN or EQUAL TO. Give a reason for the answer. (2)
- 4.2 The police car starts to move in the direction indicated by the arrow in the diagram. How does the frequency detected by observer 1 compare to the frequency detected by observer 2? Choose from: GREATER THAN, LESS THAN or EQUAL TO. (1)
- 4.3 Draw a diagram to support the answer in QUESTION 4.2 (3)
- 4.4 NAME the phenomenon described in QUESTIONS 4.1 and 4.2 above (1)
- 4.5 Observer 1 registers a frequency of 1 730 Hz as the police car approaches at a constant velocity of  $25 \text{ m}\cdot\text{s}^{-1}$ . Take the velocity of sound in air as  $340 \text{ m}\cdot\text{s}^{-1}$ .
- 4.5.1 Calculate the frequency of the siren. (5)

#### QUESTION 5

Reflection of sound waves enables bats to hunt for moths. The sound wave produced by a bat has a frequency of 222 kHz and a wavelength of  $1,5 \times 10^{-3} \text{ m}$ .

- 5.1 Calculate the speed of this sound wave through the air. (3)
- 5.2 A stationary bat sends out a sound signal and receives the same signal reflected from a moving moth at a frequency of 230,3 kHz
- 5.2.1 Is the moth moving TOWARDS or AWAY FROM the bat? (1)

- 5.2.2 Calculate the magnitude of the velocity of the moth, assuming that the velocity is constant (6)

### QUESTION 6

A traffic officer is standing on the side of a road where the speed limit is  $100 \text{ km}\cdot\text{h}^{-1}$ . He hears the hooter of a car that is travelling at constant velocity on this road. The hooter emits sound waves of frequency  $433,64 \text{ Hz}$ .

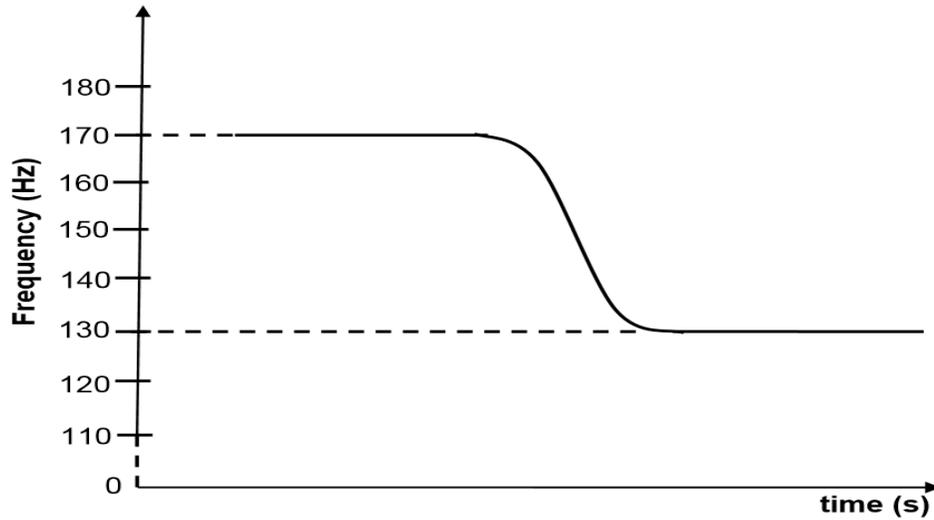
The wavelength of the sound waves detected by the traffic officer is  $0,72 \text{ m}$ . The speed of sound in air is  $340 \text{ m}\cdot\text{s}^{-1}$ .

- 6.1 Calculate the frequency of the detected sound wave (3)
- 6.2 State the Doppler-effect in words. (2)
- 6.3 Is the car travelling towards or away from the traffic officer? Give a reason for the answer (2)
- 6.4 Is the car exceeding the speed limit? Support your answer by means of a calculation (6)
- 6.5 How will the frequency of the sound waves detected by the traffic officer be affected if the car travels at a lower constant velocity? Choose from GREATER THAN, LESS THAN or THE SAME AS. (1)

### QUESTION 7

A police car moving at a constant velocity with its siren on, passes a stationary listener.

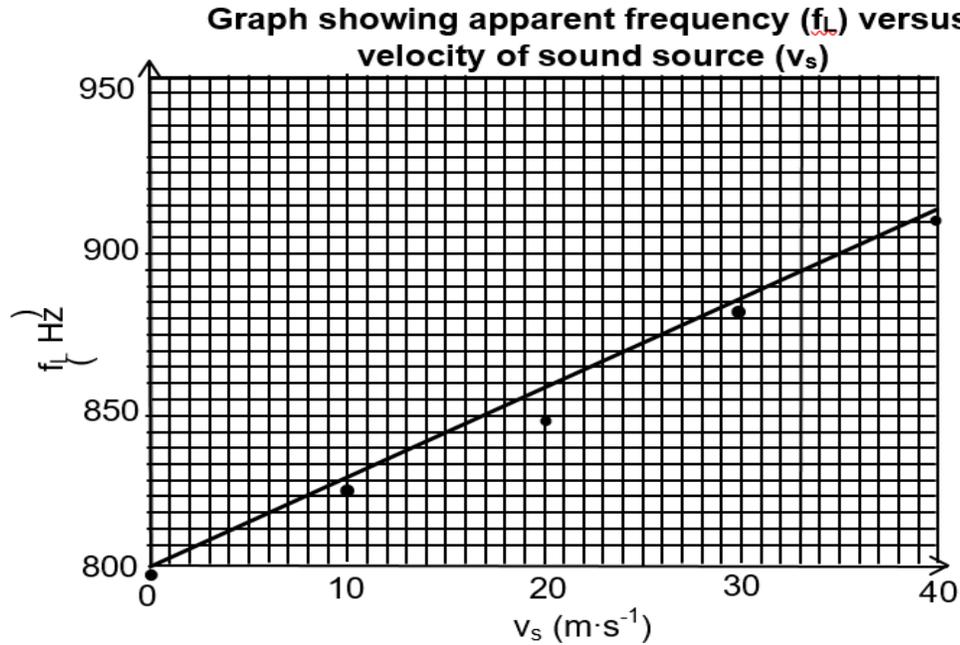
The graph below shows the changes in the frequency of the sound of the siren detected by the listener.



- 7.1 State the Doppler Effect in words (2)
- 7.2 Write down the frequency of the sound detected by the listener as the police car:
- 7.2.1 Approaches the listener (1)
- 7.2.2 Moves away from the listener (1)
- 7.2.3 Calculate the speed of the police car. Take the speed of sound in air to be  $340 \text{ m}\cdot\text{s}^{-1}$  (5)

### QUESTION 8

The graph below shows the relationship between the apparent frequency ( $f_L$ ) of the sound heard by a STATIONARY listener and the velocity ( $v_s$ ) of the source travelling TOWARDS the listener.



- 8.1 Use the information in the graph to calculate the speed of sound in air. (5)
- 8.2 Sketch a graph of apparent frequency ( $f_L$ ) versus velocity ( $v_s$ ) of the sound source if the source was moving AWAY from the listener. It is not necessary to use numerical values for the graph. (2)