GRADE 12

Physical Sciences

SELF STUDY GUIDE

DOPPLER EFFECT

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

Second Chance
Matric Support Programme

2030 NDP

NATIONAL EDUCATION COLLABORATION TRUST

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WOZA MATRICS
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TOGETHER WE CAN BEAT THE CORONAVIRUS

1. Introduction

The declaration of COVID-19 as a global pandemic by the World Health Organisation led to the disruption of effective teaching and learning in many schools in South Africa. The majority of learners in various grades spent less time in class due to the phased-in approach and rotational/ alternate attendance system that was implemented by various provinces. Consequently, the majority of schools were not able to complete all the relevant content designed for specific grades in accordance with the Curriculum and Assessment Policy Statements in most subjects.

As part of mitigating against the impact of COVID-19 on the current Grade 12, the Department of Basic Education (DBE) worked in collaboration with subject specialists from various Provincial Education Departments (PEDs) developed this Self-Study Guide. The Study Guide covers those topics, skills and concepts that are located in Grade 12, that are critical to lay the foundation for Grade 12. The main aim is to close the pre-existing content gaps in order to strengthen the mastery of subject knowledge in Grade 12. More importantly, the Study Guide will engender the attitudes in the learners to learning independently while mastering the core cross-cutting concepts.

2. How to use this Self Study Guide?

This book serves as a guide to understanding and to guide you through the topic of Doppler Effect as prescribed for the Grade 12 Physical Sciences subject. However, it does not replace your textbook and should be used in conjunction with the CAPS document as well as the examination guidelines. The authors have used their experience and focused their attention on the areas that learners seem to struggle with a lot. The book focuses more on the areas that are seen as a challenge, given learners' responses in the Grades 12 National examinations over the past few years.

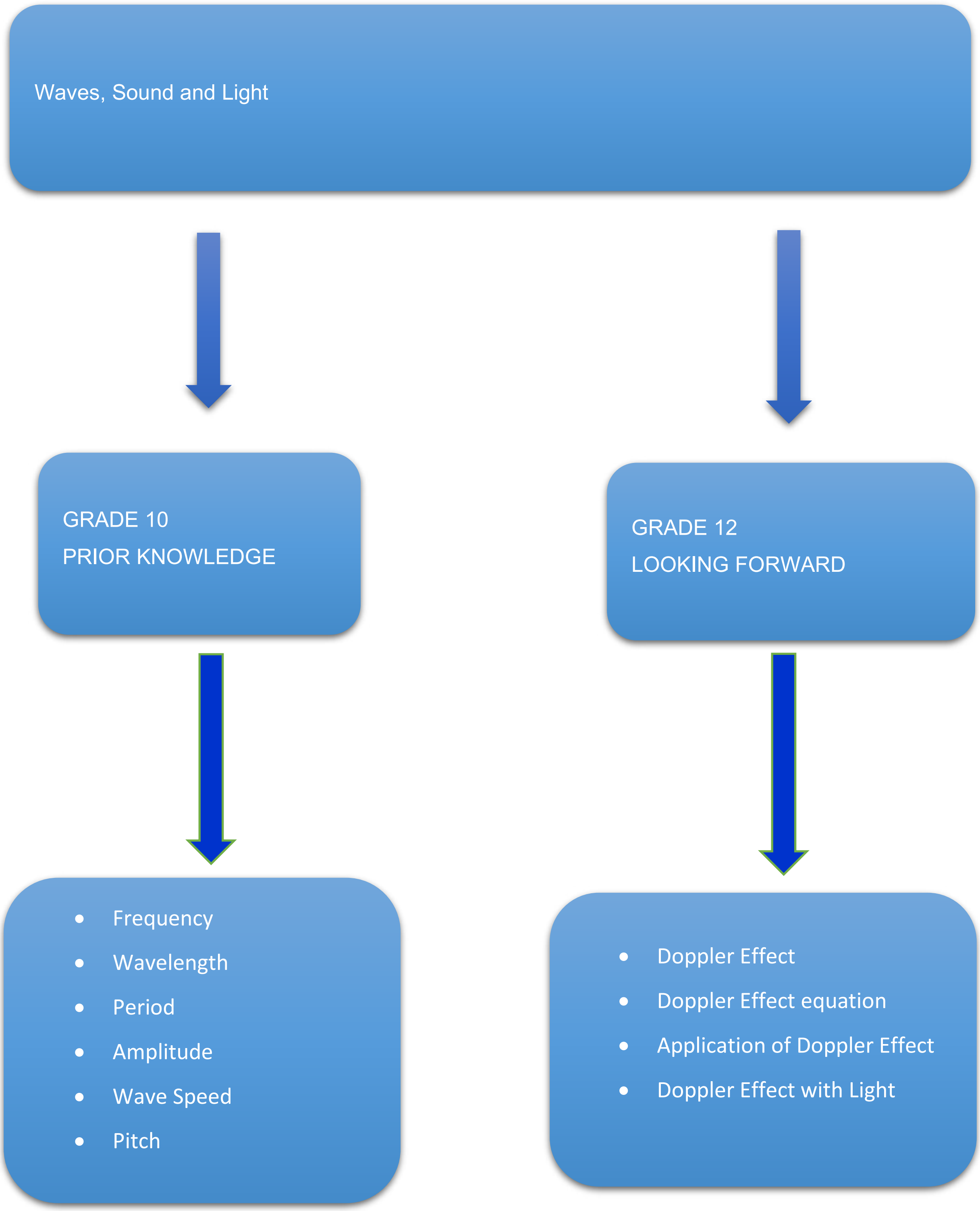
This guide aims to help explain the usual concepts in your regular textbook. It also offers more exercises and examples that serve as building blocks for your own understanding of what is expected of you in this subject. The book draws on the basic knowledge obtained in the lower grades and demonstrates how this knowledge fits in with the new material in Grade 12, starting from waves, sound and light in grade 10.

Use information learnt in other sections to solve the problem at hand. All the questions in this booklet have solutions. Some questions have been sourced from past papers, while the rest were sourced elsewhere. Study each question carefully and make sure you understand the steps taken to solve the question. Then try the rest of the questions without looking at the solutions. After completing an exercise, check your solutions in the answer section. Move on to the rest of the questions and try to understand why you were wrong if you got the answer wrong. The solutions to all exercises are provided in the last section of this booklet.

Be in possession of the formula sheet, there is no need to study the formulae off by heart. Formulae for Doppler effect will be provided in this guide.
Extracts from the examination guidelines will be included before exercises are given, use these guidelines to make sure you know what is expected of you in the examination.
Do not hesitate to ask your teacher if you struggle with any of the exercises.

3. Doppler Effect

3.1 Mind / Concept map



Waves, Sound and Light
GRADE 10

Frequency (f): The number of wave pulses per second.
The SI unit for frequency is hertz (Hz).
For example, most sirens produce sound with a frequency of 2 000 Hz. This means 2 000 waves pass a listener per second.

Period (T): **The time taken for one complete wave pulse.**
The SI unit for period is seconds (s).

Amplitude: The maximum displacement of a particle from its equilibrium position. The SI unit for amplitude is meters (m).

Wavelength (λ): The distance between two successive points in phase.
The SI unit for wavelength is meters (m). For example, the wavelength of the sound waves produced by a siren is approximately 0,19 m.
This means there is 0,19 m between two consecutive compressions in this sound wave.

Wave speed: The distance travelled by a point on a wave per unit time. The SI unit for speed is meters per second ($m \cdot s^{-1}$).

3.2 Objectives (Examination Guidelines Grade 10)

3.2.1 Wavelength, frequency, amplitude, period, wave speed

- Define a transverse wave as a wave in which the particles of the medium vibrate at right angles to the direction of motion of the wave.
- A transverse wave is a succession of transverse pulses.
- Define the terms wavelength, frequency, period, amplitude, crest and trough of a wave.
- Wavelength: The distance between two successive points in phase.
- Frequency: The number of wave pulses per second.
- Period: The time taken for one complete wave pulse.
- Amplitude: The maximum displacement of a particle from its equilibrium position.
- Crest: Highest point (peak) on a wave.
- Trough: Lowest point on a wave.
- Explain the wave concepts in phase and out of phase. In phase: Two points in phase are separated by a whole number (1; 2; 3; …) multiple of complete wavelengths. Out of phase: Points that are not separated by a whole number multiple of complete wavelengths.
- Identify the wavelength, amplitude, crests, troughs, points in phase and points out of phase on a drawing of a transverse wave.
- Use the relationship between frequency and period, i.e. $T = \frac{1}{f}$ and $f = \frac{1}{T}$, to solve problems.
- Define Wave speed : the distance travelled by a point on a wave per unit time.
- Use the wave equation $v = f\lambda$ to solve problems involving waves.

3.2.2 Frequency (f)

When referring to sound waves, frequency can be referred to as PITCH. For example, a sound wave with a higher pitch means the sound wave has a higher frequency.

The SI units for frequency is Hertz (Hz)

1 Hz = 1 s^{-1}

Formula for frequency:

$$\text{Frequency} = \frac{\text{total number of waves}}{\text{total time}} \quad \text{OR} \quad f = \frac{1}{T}$$

Example:

Six waves pass a point in 4 seconds. Calculate the frequency of the waves.

Solution:

$$\text{frequency} = \frac{\text{total number of waves}}{\text{total time}}$$

$$= \frac{6}{4}$$

$$= 1,5 \text{ Hz}$$

3.2.3 Period (T)

Period: The time taken for one complete wave pulse.

The SI units for period is seconds (s)

Formula for period:

$$\text{Period} = \frac{\text{total time}}{\text{total number of waves}} \quad \text{OR} \quad T = \frac{1}{f}$$

Example:

Eight waves pass a point in 4 seconds. Calculate the period of the waves.

Solution:

$$\text{Period} = \frac{\text{total time}}{\text{total number of waves}}$$

$$\text{Period} = \frac{4}{8}$$

$$= 0{,}5 \text{ s}$$

3.2.4 **Wave speed (v)**

Wave speed: the distance travelled by a point on a wave per unit time.

The speed of a wave measured in $m \cdot s^{-1}$

Formula for period:

$$v = f\lambda$$

v is the speed ($m \cdot s^{-1}$)

f is the frequency (Hz)

λ is the wavelength (m)

Example

Calculate the speed of a wave with a 10 cm wavelength and a frequency of 150 Hz.

Solution:

Convert 10 cm to metres by dividing by 100

$$v = f\lambda$$

$$= (150)(10 \times 10^{-2})$$

$$= 15 \text{ m} \cdot \text{s}^{-1}$$

Conversions

1 centimetre (cm) = 10 millimetre (mm)

100 centimetre (cm) = 1 metre (m)

1000 millimetre (mm) = 1 metre (m)

3.2.5 **Relationship between frequency and period.**

Frequency is inversely proportional to period.

$$f \propto \frac{1}{T} \quad \textbf{OR} \quad T \propto \frac{1}{f}$$

Example

1. Calculate the frequency of a wave that has a period of 0,1 seconds.
2. Calculate the period of a wave that has a frequency of 50 Hz.

Solutions:

1. $f = \frac{1}{T}$

$= \frac{1}{0{,}1}$

= 10 Hz

2. $T = \frac{1}{f}$

$= \frac{1}{50}$

= 0,02 s

3.2.6 Relationship between frequency and wavelength.

At constant speed, the frequency (f) of a wave is INVERSELY PROPORTIONAL to the wavelength (λ) of the wave.

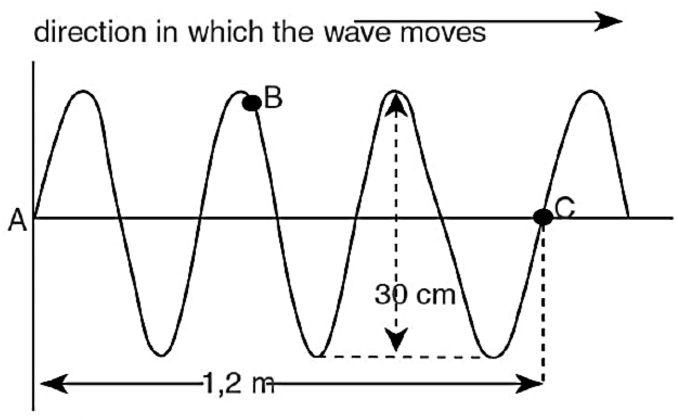
$$f \propto \frac{1}{\lambda}$$

In other words, if the wavelength of a sound wave is increased, then the frequency will decrease. (Fewer waves pass a point per second).

If the wavelength of a sound wave is decreased, then the frequency will increase. (More waves will pass a point per second).

Example

The following diagram represents a wave with a frequency of 10 Hz.



a. Calculate the wavelength of the wave.

b. Calculate how long it will take for four waves to move past point C.

c. Calculate the speed of the wave.

Solutions:

a. Length of 3 waves = 1,2 m

$$\lambda = \frac{1{,}2}{3}$$

$$= 0{,}4 \text{ m}$$

b. $$T = \frac{1}{f}$$

$$= \frac{1}{10}$$

$$= 0{,}1 \text{ s}$$

0,1s is for one wave, therefore for four waves the period is:

$$T = (0{,}1)\ (4)$$

$$= 0{,}4 \text{ s}$$

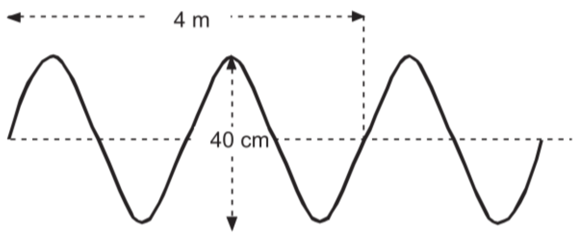
c. $$v = f\lambda$$

$$= (10)\ (0.4)$$

$$= 4 \text{ m}\cdot\text{s}^{-1}$$

Example

The wave motion takes 10 s to complete one full vibration.



a. How long does it take for 8 waves to move past a certain point?

b. What is the period of the wave motion?

c. Calculate the wavelength of the wave range.

d. Calculate the frequency of this wave range.

e. Calculate the speed of this wave range.

Solutions:

a. One wave takes 10 s, which means eight waves will take 80 s.

b. The period is 10 s

c. $2\lambda = 4$

$\lambda = 2$ m

d. $f = \frac{1}{T}$

$= \frac{1}{10}$

$= 0,1$ Hz

e. $v = f\lambda$

$= (0,1)(2)$

$= 0,2\ m \cdot s^{-1}$

3.3 Doppler Effect (Examination Guidelines Grade 12)

Doppler Effect (relative motion between source and observer)
Examination Guidelines 2021, DBE

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)

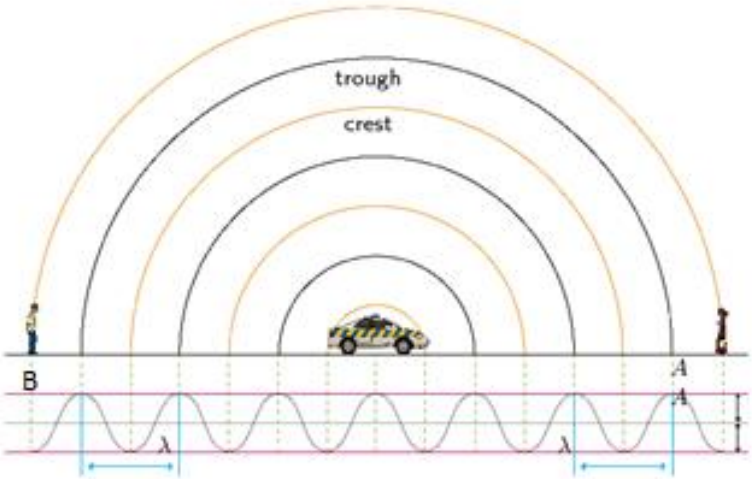
- **Explain 'red shifts'.**

Use the Doppler Effect to explain why we conclude that the universe is expanding.

A common example of the Doppler effect: When a car (or any object emitting a sound) passes by then a change in the pitch of the sound coming from the car is observed. As the sound source approaches you, the sound heard has a higher pitch (higher frequency) and as the sound source moves away from you, the sound heard has a lower pitch (lower frequency).This phenomenon is known as the **Doppler Effect**

IMPORTANT FACTS CONCERNING DOPPLER EFFECT

Both the SOURCE and LISTENER are STATIONARY

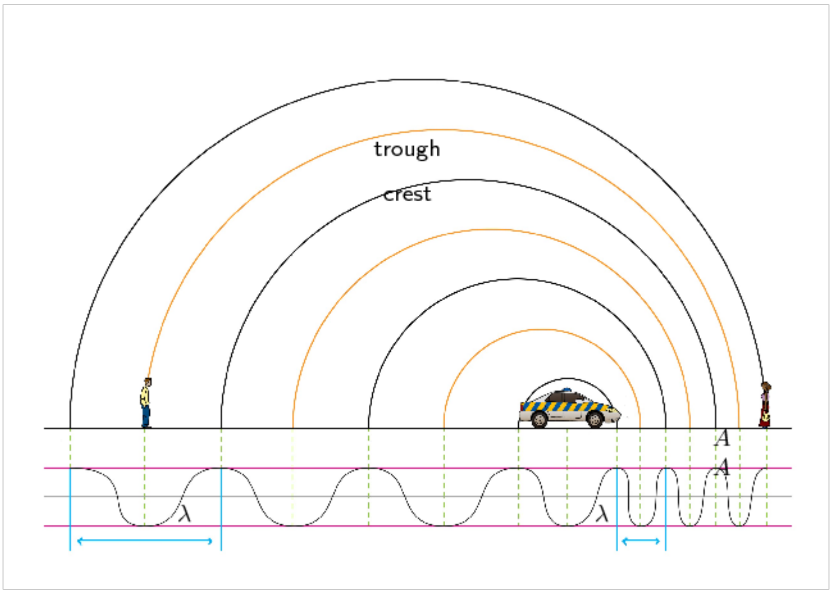


Consider a **STATIONARY** (the velocity is zero) police car. The siren of the police car is ON. The siren is the source (S) of the sound. The frequency of the source (f_s), the siren is
800 Hz. f_s = 800 Hz

There are **STATIONARY LISTENERS** at point A and point B.

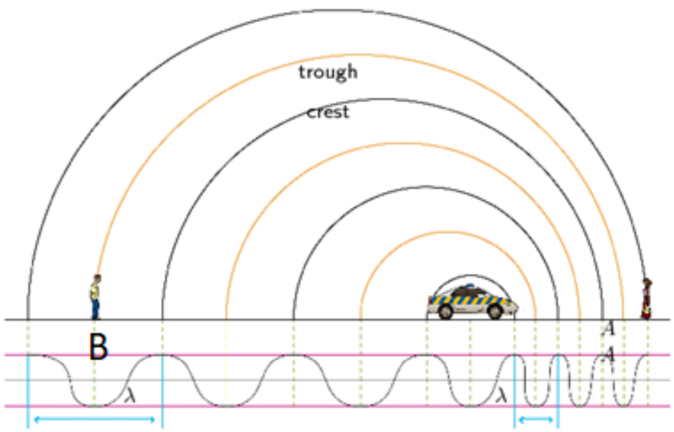
The frequency of the sound heard by the **STATIONARY LISTENERS** (f_L) is the SAME as the frequency of the **STATIONARY SOURCE** (f_s), because the wavelength of the sound waves remains the same in all directions.($f_L = f_s$)

The SOURCE IS MOVING TOWARDS A STATIONARY LISTENER at point A.



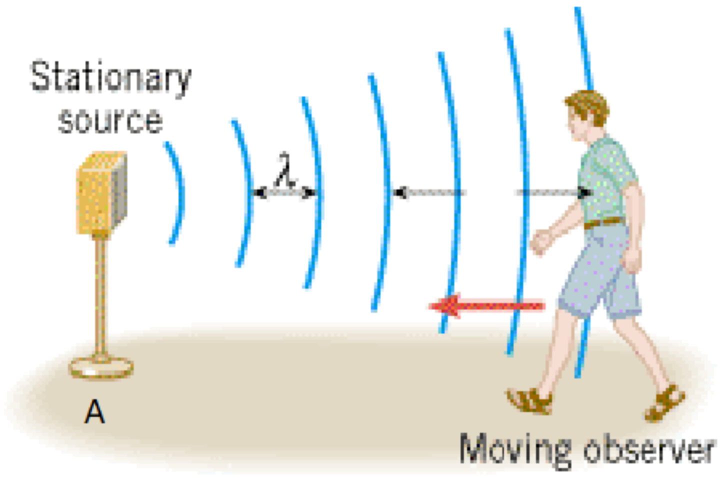
When **the source** of sound waves is **moving towards** a **stationary** listener, the **frequency detected** by the listener is **higher than** the frequency of the source **(**wavelength becomes **shorter**) because **more** wave-fronts are detected per second, ($f_L > f_s$).
Frequency is inversely proportional to wavelength

THE SOURCE IS MOVING AWAY FROM A STATIONARY LISTENER which is at point B.



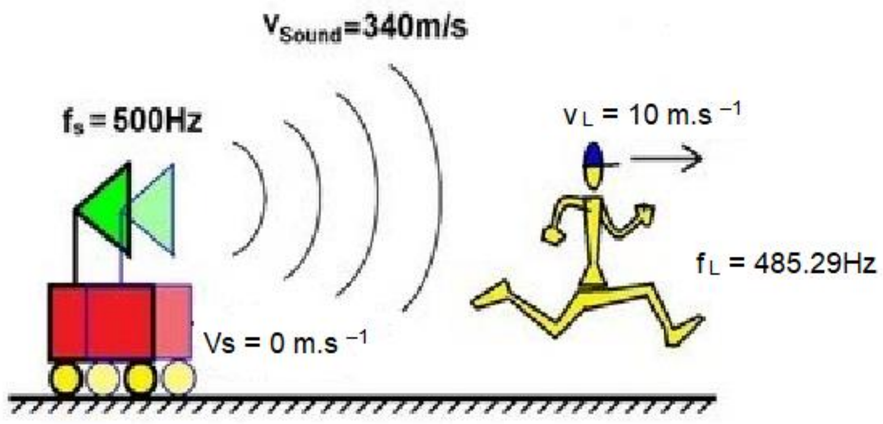
When **the source** of sound waves is **moving away** from a **stationary** listener, the **frequency detected** by the listener is **lower than** the frequency of the source **(**wavelength becomes **longer),** because **less** wave-fronts are detected per second,($f_L < f_s$).

THE LISTENER IS MOVING TOWARDS A STATIONARY SOURCE at point A:



When **the listener** is **moving towards** a stationary source at point A, the **frequency detected** by the listener is **higher than** the frequency of the source (wavelength becomes **shorter**), because **more** wave-fronts are detected per second. ($f_L > f_s$)

THE LISTENER IS MOVING AWAY FROM A STATIONARY SOURCE:



When **the listener** is **moving away** from a stationary source, the **frequency detected** by the listener is **lower than** the frequency of the source (wavelength becomes **longer**), because **less** wave-fronts are detected per second, ($f_L < f_s$).

3.4 Doppler Effect Equation

The frequency emitted by the source (f_s) is constant, only the frequency detected by the listener (observer) changes provided there is a relative motion between the source of sound waves and the listener**.** We can use the following equation to calculate the frequency heard by the listener (observer):

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

f_L = frequency heard by observer (listener), measured in Hertz (Hz)

f_S = frequency of source (Hz), measured in Hertz

v = speed of sound in medium, measured in meters per second ($m{\cdot}s^{-1}$)

v_L = speed of observer (listener), measured in meters per second ($m{\cdot}s^{-1}$)

v_s = speed of source, measured in meters per second ($m{\cdot}s^{-1}$)

Doppler expressions to use after writing the Doppler effect formula

Using the plus (+) or minus (–) signs depends on the relative motions of the source and observer.

When the source is moving TOWARDS a stationary listener: $f_L = \frac{v}{v - v_s} f_s$
When the source is moving AWAY from a stationary listener: $f_L = \frac{v}{v + v_s} f_s$
When the listener is moving TOWARDS a stationary source: $f_L = \frac{v + v_L}{v} f_s$
When the listener is moving AWAY from a stationary source: $f_L = \frac{v - v_L}{v} f_s$

Examples

Both the SOURCE and LISTENER are STATIONARY

The siren of a stationary ambulance emits waves at a frequency of 800 Hz. Determine the frequency of the sound heard by a stationary observer if the speed of sound in air is 340 m·s^{-1}.

Solution

f_L = ?

f_s = 800 Hz

v = 340 m·s^{-1}

v_L = 0 m·s^{-1}

v_s = 0 m·s^{-1}

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

$$= \frac{v}{v} fs$$

$$= \frac{340}{340} fs$$

f_L = fs

f_L = 800 Hz

When the **SOURCE** and the **LISTENER** are **STATIONARY**, the frequency observed by the **LISTENER** is the **SAME** as the frequency of the **SOURCE**.

The SOURCE is MOVING TOWARDS a STATIONARY LISTENER

An ambulance is moving towards a stationary listener with a velocity of 30 m·s^{-1}. The frequency emitted by the ambulance is 600 Hz. Calculate the frequency that the listener will detect, if the speed of sound in air is 340 m·s^{-1}.

Solution

f_L = ?

f_S = 600 Hz

v = 340 m·s^{-1}

v_L = 0 m·s^{-1}

v_s = 30 m·s^{-1}

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

Always start with the original formula

$$f_L = \frac{v}{v - v_s} f_s$$

The source is moving **TOWARDS** a stationary listener.

$$= \left(\frac{340}{340-30}\right) 600$$

f_L = 658,06 Hz

When the source is moving **TOWARDS** a stationary listener, the frequency observed by the listener is **HIGHER THAN** the frequency of the source.

The SOURCE is MOVING AWAY from a STATIONARY LISTENER:

An ambulance is moving away from a stationary listener with a velocity of 25 m·s^{-1}. The frequency emitted by the ambulance is 450 Hz. Calculate the frequency that the listener will detect, if the speed of sound in air is 340 m·s^{-1}.

Solution

f_L = ?

f_S = 450 Hz

v = 340 m·s^{-1}

v_L = 0 m·s^{-1}

V_S = 25 m·s^{-1}

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

$$f_L = \frac{v}{v + v_s} f_s$$

The source is moving **AWAY** from a stationary listener.

$$= \left(\frac{340}{340+25}\right) 450$$

f_L = 419,19 Hz

When the source is moving **AWAY** from a stationary listener, the frequency observed by the listener is **LESS THAN** the frequency of the source.

The LISTENER IS MOVING TOWARDS A STATIONARY SOURCE:

A police car is in attendance at an accident scene. The police car is stationary and its siren is emitting a sound of frequency 1000 Hz. A taxi is travelling towards the accident scene at a velocity of 23 m·s^{-1}. Calculate the frequency of sound heard by the driver of the taxi when driving towards the scene. The speed of sound in air is 340 m·s^{-1}.

Solution

f_L = ?

f_S = 1000 Hz

v = 340 m·s^{-1}

v_L = 0 m·s^{-1}

v_S = 23 m·s^{-1}

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

$$f_L = \frac{v + v_L}{v} f_s$$

The listener is moving **TOWARDS** a stationary source.

$$= \left(\frac{340+23}{340}\right) 1000$$

$$f_L = 1067{,}65\ Hz$$

When the listener is moving **TOWARDS** the stationary sound source, the frequency observed by the listener is **HIGHER THAN** the frequency of the source.

WHEN THE LISTENER IS MOVING AWAY from A STATIONARY SOURCE:

A siren at a fire station emits sound of frequency 780 Hz. Calculate the frequency that the driver of a car will detect if he is travelling away from the fire station at 28 m·s^{-1}. The speed of sound in air is 340 m·s^{-1}.

Solution

f_L = ?

f_S = 780 Hz

v = 340 m·s^{-1}

V_L = 28 m·s^{-1}

V_S = 0 m·s^{-1}

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

$$f_L = \frac{v - v_L}{v} f_s$$

The listener is moving **AWAY** a stationary source.

$$= \left(\frac{340 - 28}{340}\right) 780$$

$$f_L = 715{,}76\ \text{Hz}$$

When the listener is moving **AWAY** from a stationary sound source, the frequency observed by the listener is **LESS THAN** the frequency of the source.

Example

The siren of a burglar alarm system has a frequency of 960 Hz. During a patrol, a security officer, travelling in his car, hears the siren of the alarm of a house and approaches the house at a constant velocity. A detector in his car registers the frequency of the sound as 1000 Hz. The speed of sound in air is 340 m·s^{-1}.

a. Name the phenomenon that explains the change in the observed frequency.

b. Calculate the speed at which the patrol car approaches the house. Use the speed of sound in air as 340m.s^{-1}.

Solution

a. Doppler Effect

b. $f_S = 960$ Hz

$f_L = 1000$ Hz

$v = 340$ m·s^{-1}

$V_S = 0$ m·s^{-1}

$v_L = ?$

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

$$f_L = \frac{v + v_L}{v} f_s$$

The listener is moving **TOWARDS** a stationary source.

$$1000 = \left(\frac{340 + v_L}{340}\right) 960$$

$$v_L = 14{,}17 \text{ m·s}^{-1}$$

Example

The whistle of a train emits sound waves of frequency 2000 Hz. A stationary listener measures the frequency emitted sound waves as 1880 Hz. The speed of sound in air is
340 m·s^{-1}.

a. Is the train moving AWAY FROM or TOWARDS the stationary listener?

b. Calculate the speed of the train.

c. Will the frequency observed by the passenger, sitting in the train, be GREATER THAN, EQUAL TO or SMALLER THAN 2000 Hz? Explain your answer?

Solutions

a. Away from the stationary listener.

b.

f_S = 2000 Hz

f_L = 1880 Hz

v = 340 m·s^{-1}

v_L = 0 m·s^{-1}

V_S = ?

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

$$f_L = \frac{v}{v + v_s} f_s$$

The source is moving **AWAY** from a stationary listener.

$$1880 = \left(\frac{340}{340 + v_S}\right) 2000$$

$$v_S = 21{,}70 \text{ m·s}^{-1}$$

c. Equal to

The passenger is moving at the speed of the train hence the frequency observed by the passenger is the same as the frequency emitted by the train.

Example

A fire truck, with its siren on, is moving at 20 m·s^{-1} towards a burning building. A person standing next to the road with a detector, measures the frequency of the sound emitted by the siren to be 550 Hz. The measured frequency is HIGHER than the frequency of the sound emitted by the siren.

a. Calculate the frequency of the siren if the speed of sound in air is 340 m·s^{-1}.

Solution

a. f_L = 550 Hz

f_S = ?

v = 340 m·s^{-1}

v_L = 0 m·s^{-1}

V_S = 20 m·s^{-1}

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

$$f_L = \frac{v}{v - v_s} f_s$$

The source is moving **TOWARDS** a stationary listener.

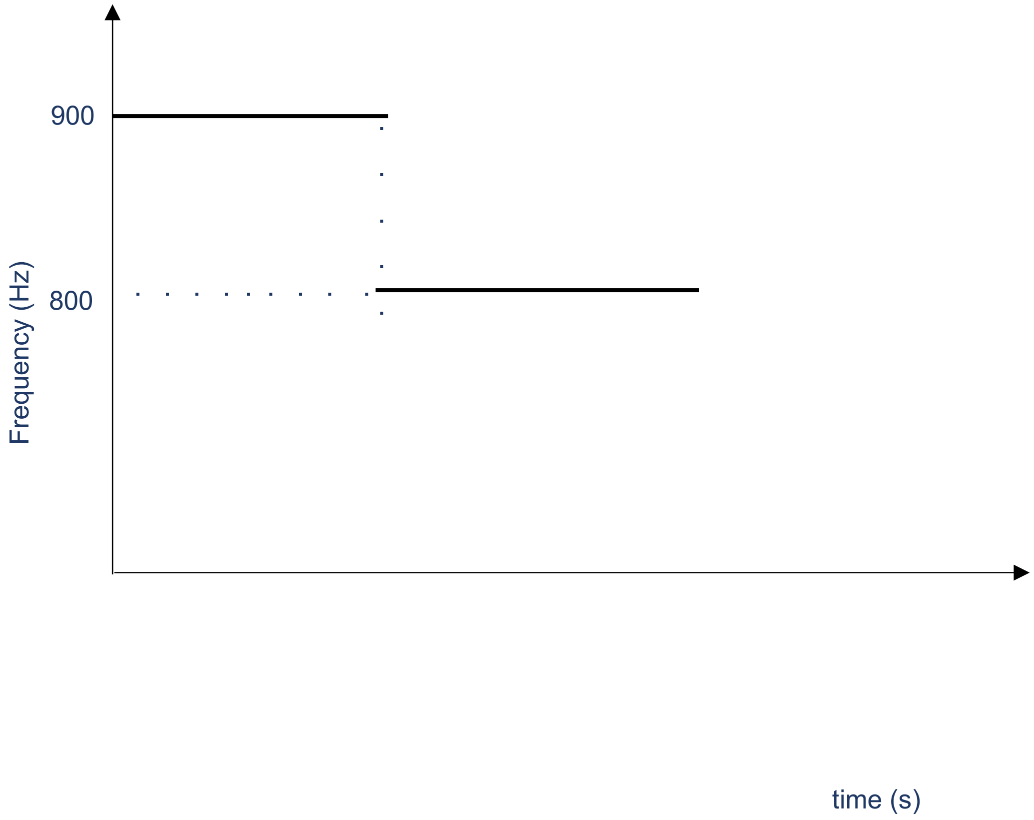
$$550 = \frac{340}{340 - 20} f_s$$

$$f_s = 517{,}65\ Hz$$

Example

An ambulance moving with 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.



a. Write down the frequency of the sound detected by listener as the ambulance:

(i) Approaches the listener.

(ii) Moves away from the listener.

b. Calculate the speed of the ambulance. Take the speed of sound in air to be 340 $m \cdot s^{-1}$.

Solutions

a.

(i) 900 Hz

(ii) 800 Hz

b.

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

$$f_L = \frac{v}{v - v_s} f_s$$

The source is moving **TOWARDS** from a stationary listener.

$$900 = \frac{340}{340 - vs} fs$$

$$340fs = 306\,000 - 900vs \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

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

$$f_L = \frac{v}{v + v_s} f_s$$

The source is moving **AWAY** from a stationary listener.

$$800 = \frac{340}{340 + vs} fs$$

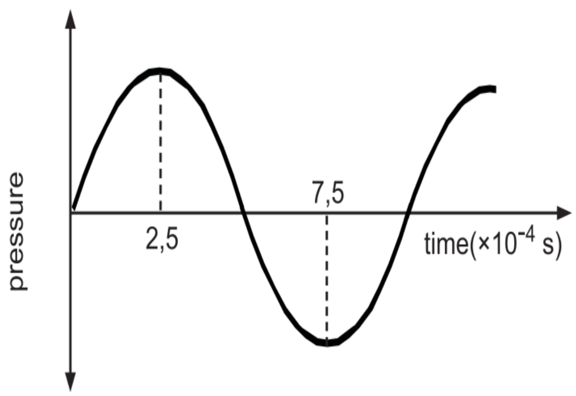
$$340fs = 272\,000 + 800v_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

306 000 —900vs = 272 000+800vs (since (1) = (2) = 340 fs)

$v_s = 20$ m·s^{-1}

Example

A man mounts a siren, which produces a constant frequency of 800 Hz, on the roof of his car. He drives at a constant speed up and down a straight road while a stationary listener measures the sound of the siren. At a certain stage of the journey the listener obtains the following pressure – time graph of the sound waves.



a. What is the period of the detected sound wave.

b. Calculate the frequency of the detected sound wave.

c. Calculate the speed of the moving car. Take the speed of sound in air as 340 $m \cdot s^{-1}$

d. While the car is stationary, the frequency of the siren is changed to 900 Hz. Will the wavelength of the detected sound wave INCREASE, DECREASE or REMAIN THE SAME? Explain the answer.

Solutions

a. 0,001 s OR 10×10-4 s

b.
$$f = \frac{1}{T}$$
$$= \frac{1}{0,001}$$
$$= 1000\ Hz$$

c.
$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$
$$f_L = \frac{v}{v - v_s} f_s$$
$$1000 = \left(\frac{340}{340 - v_s}\right) 800$$
$$v_s = 68\ m \cdot s^{-1}$$

d. Decreases. $f \propto \frac{1}{\lambda}$, if velocity stays constant ($v = f\lambda$)

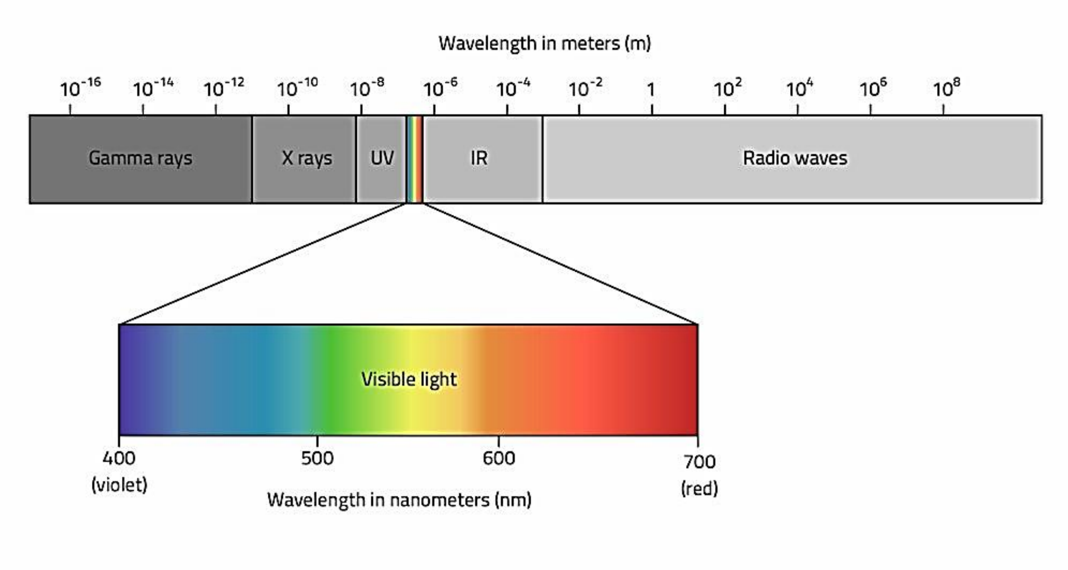
3.5 APPLICATION OF DOPPLER EFFECT

The **Doppler flow meter emits** and receives continuous ultrasound waves and then measures the change in the frequency and wavelength. It is used to measure how fast or slowly blood is moving through arteries and veins, which can indicate a circulatory problem.
(Measures the rate of blood flow).
Doppler is used to measure the heartbeat of a foetus in the womb.

3.6 DOPPLER EFFECT WITH LIGHT

Electromagnetic Spectrum

It is an arrangement of waves that have electric and magnetic components

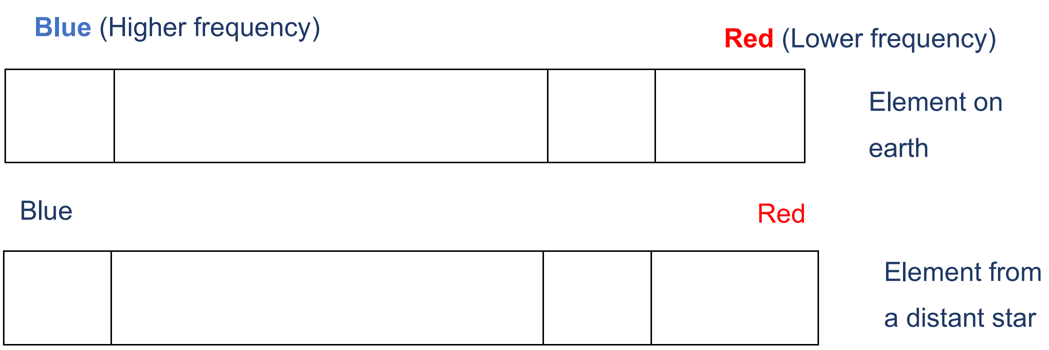


Big Bang Theory

The universe started as one big mass which exploded to form all the objects in the universe. Therefore all objects in the universe contain the same type of materials.

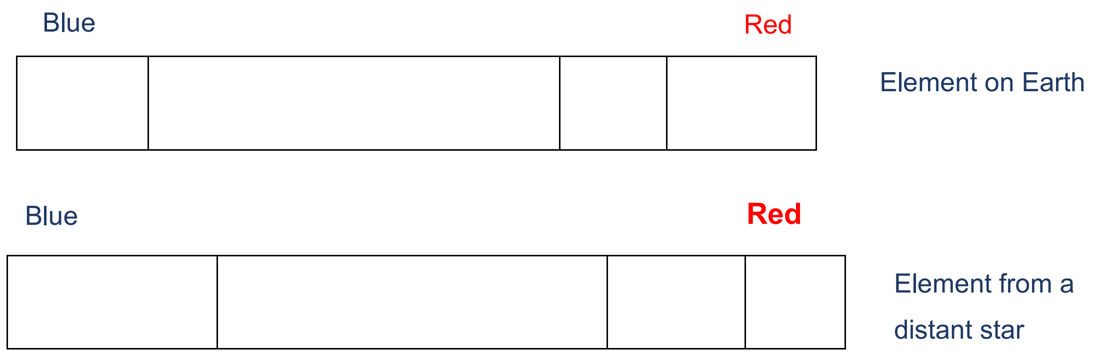
The atoms in these materials can be identified by their emission spectra (type of light they produce when they are hot.)

Stars in the universe produce their own light from the hot atoms on their surfaces. These atoms can be identified by comparing their emissions spectra with those of similar elements on earth.



When the light from the distant star is observed over a period of time, lines in the spectrum shift positions.

Red Shift

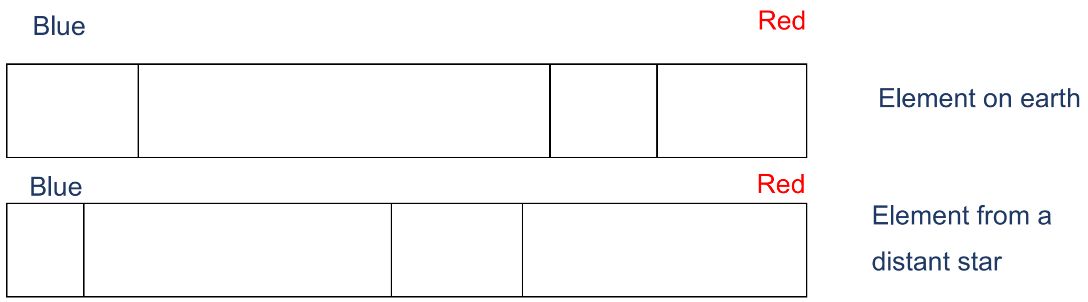


The spectral lines are no longer in the same position. The lines from a distant star have shifted towards the red end of the spectrum when compared with the element on earth. The spectral lines in the distant star have shifted to **lower frequencies** when observed from earth.

A shift to lower frequencies in waves means the objects are moving **away** from each other.

A red shift indicates that a star is moving away from earth and therefore the **universe is expanding**, the objects in the universe are moving away from the earth.

Blue Shift (NOT EXAMINABLE)



When light from a distant star is observed over time the spectral lines tend to shift towards the blue end of the spectrum with higher frequency.

A shift towards a **higher frequency** means the objects are moving towards each other. Therefore when a blue shift is observed it means the star is moving **towards** the earth.

Scientists in the world have observed more of the red shift in stars than a blue shift, which means the **universe is expanding.** The objects in the universe are moving away from the earth.

SUMMARY OF HOW A RED SHIFT AND BLUE SHIFT OCCUR

The **red shift** occurs when the spectrum of a distant star (galaxy) moving away from the earth is shifted towards the red end of the spectrum.

We use the red shift to conclude that most stars are moving away from the earth and therefore the Universe is expanding.

The **Red shift**- phenomenon is observed when the light source is moving away from the earth.

The **blue shift** occurs when the spectrum of a distant star (galaxy) moving towards the earth is shifted towards the blue end of the spectrum. (NOT EXAMINABLE)

Blue shift- phenomenon observed when the light source is moving towards the Earth. (NOT EXAMINABLE)

Example

a. Spectral lines of star X at an observatory are observed to be red shifted.
Explain the term red shifted in terms of wavelength.

b. Will the frequency of the light observed from the star in question a, INCREASE, DECREASE or REMAIN THE SAME?

c. An observation of the spectrum of a distant star shows that it is moving away from the Earth.
Explain, in terms of the frequencies of the spectral lines, how it is possible to conclude that the star is moving away from the Earth

.

Solutions

a. The spectral lines are shifted towards the red end of the visible spectrum. The wavelength of the light emitted by the star is longer than expected.

b. Decrease

c. If the star is moving away from Earth, then the wavelengths of the spectral lines emitted by the star will be longer than expected.
The frequency of the emitted light will be lower than expected.

Example (NOT EXAMINABLE)

A study of spectral lines obtained from various stars can provide valuable information about the movement of the stars.

The two diagrams below represent different spectral lines of an element. Diagram 1 represents the spectrum of the element in a laboratory on Earth. Diagram 2 represents the spectrum of the same element from a distant star.

Diagram 1

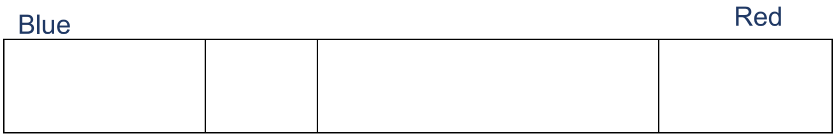
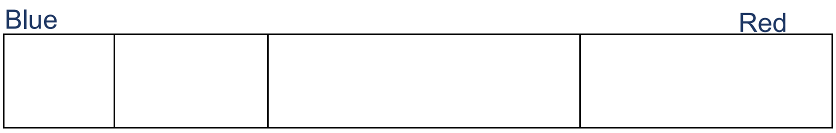


Diagram 2



a. Is the star moving towards or away from the Earth?

b. Explain the answer by referring to the shifts in the spectral lines in the two diagrams above.

c. Briefly explain the observations that enable scientists to tell that the universe is expanding.

Solutions

a. Towards the Earth

b. The spectral lines are shifted towards the blue end of the visible spectrum.
The wavelengths of the light emitted from the star is shorter than expected.
According to the Doppler Effect the waves in front of the moving star will be compressed.

c. Galaxies that are moving away from Earth emit light in which the spectral lines are shifted towards the red end of visible spectrum.
According to the Doppler Effect, these longer wavelengths of light indicate that the galaxy is moving away from Earth.

4. Exercises

4.1 Question 1 Multiple Choice Questions

1.1 A source of sound with a frequency 620 Hz is placed on a moving platform that approaches an educator at speed **v**. An educator hears sound with frequency $\mathbf{f_1}$. Then the source of sound is held stationary while the educator approaches it at the same speed of **v**. The educator hears sound with a frequency $\mathbf{f_2}$.

Which ONE of the following mathematical statements is CORRECT?

A $f_1 = f_2 > 620$ Hz

B $f_1 > f_2 > 620$ Hz

C $f_1 < f_2 > 620$ Hz

D $F_2 > f_1 > 620$ Hz (2)

1.2 The Doppler effect is observed……..

A only with sound waves

B only with light waves

C with both sound and light waves

D neither with light nor sound waves (2)

1.3 An observer runs towards a stationary sound source. As the observer approaches the source, the observed pitch increases because the observed ……

A loudness increases

B wavelength increases

C frequency increases

D frequency decreases (2)

1.4 The siren of a stationary train delivers sound waves of frequency 800 Hz. The train starts moving in such a way that the WAVELENGTH of the sound waves that reach a stationary listener, INCREASES. The frequency that the stationary listener hears, could possibly be…

A 750 Hz

B 800 Hz

C 850 Hz

D 1000 Hz (2)

1.5 The hooter of a car emits sound of constant frequency as the car moves away from a stationary listener. Which ONE of the following properties of the sound heard by the listener will NOT change?

A Velocity

B Frequency

C Both wavelength and frequency

D Both frequency and loudness (2)

1.6 Which ONE of the following is NOT an application of the Doppler effect?

A A light meter

B A blood flow meter

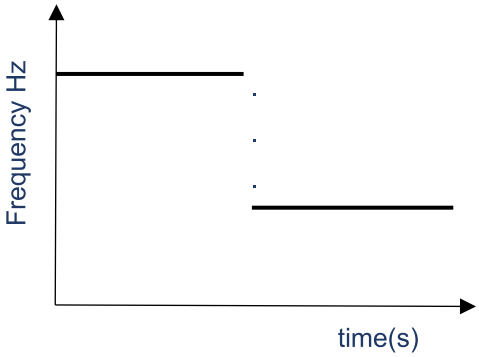
C Detecting the heartbeat of a foetus using ultrasound

D Measuring the speed of an approaching car using radar (2)

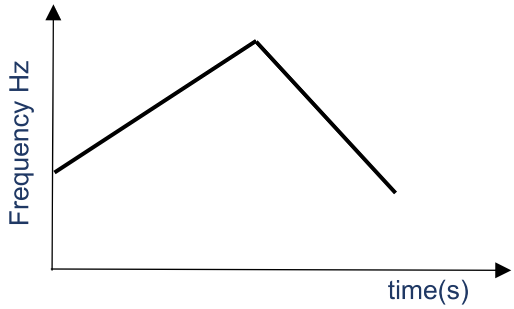
1.7 A source of sound approaches a stationary listener in a straight line at a constant velocity. It passes the listener and moves away from him in the same straight line at the same constant velocity.

Which ONE of the following graphs best represents the change in observed frequency against time?

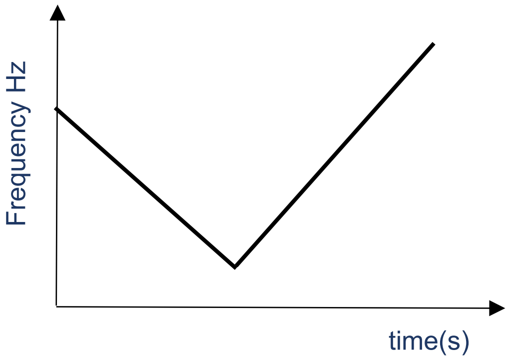
A



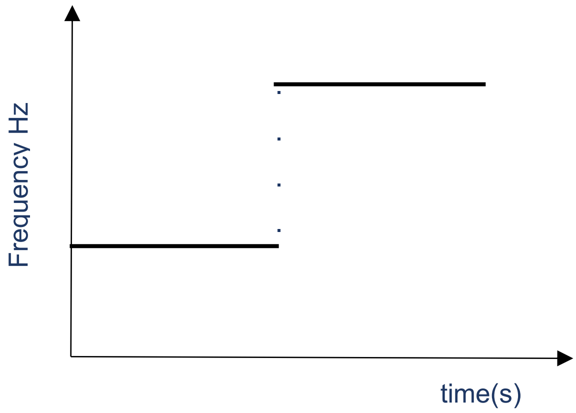
B



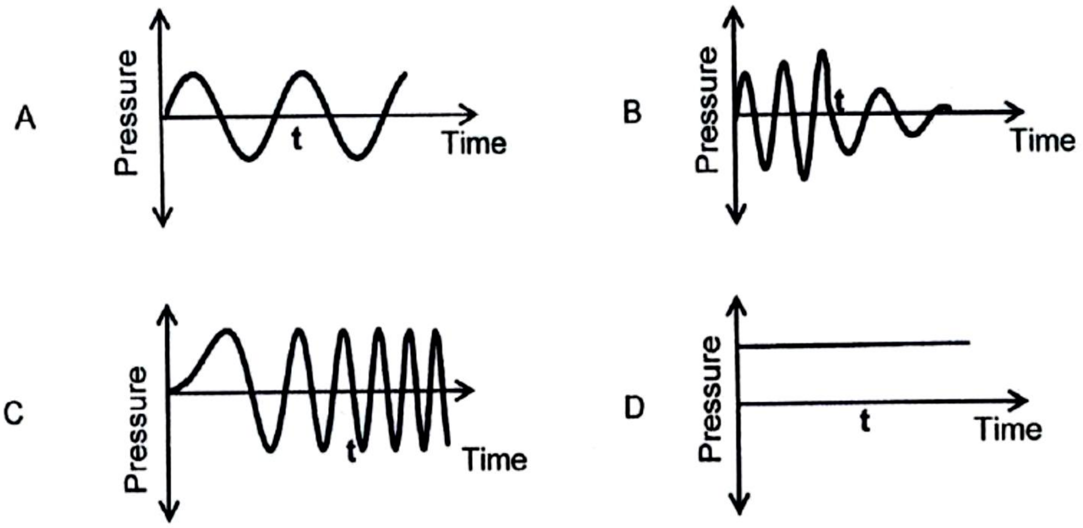
C



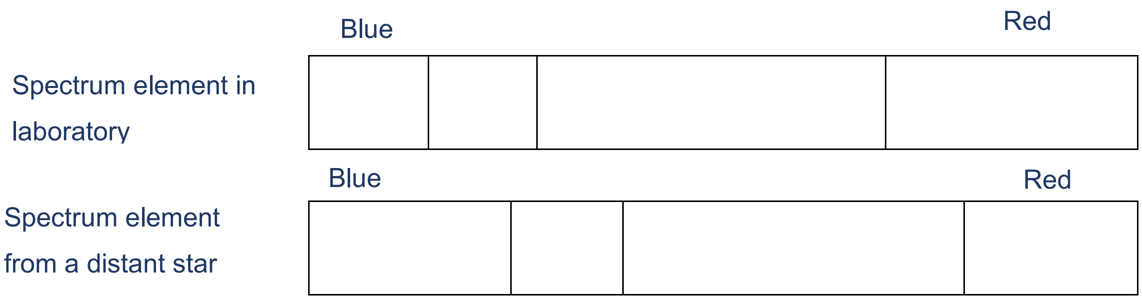
D



1.8 During an experiment a car produces a sound with a constant frequency of 800 Hz. The car moves with a constant velocity past a stationary listener at time t. Which ONE of the following pressure-time graphs below CORRECTLY represents the sound of the car, as observed by the listener?



1.9 Astronomers obtained the following spectral line of an element:



This observation confirms that the…

A star is moving away from the earth.

B star is moving towards the earth.

C universe is shrinking.

D star is undergoing no relative movement. (2)

1.10 The wavelengths of light emitted by a distant star appear shorter when observed from Earth. From this we can conclude that the star is …

A moving towards Earth and the light is blue shifted.

B moving towards Earth and the light is red shifted.

C moving away from Earth and the light is red shifted.

D moving away from Earth and the light is blue shifted. (2)

4.2 Structured Questions

Question 2

2.1 An ambulance is moving towards a stationary listener at a constant speed of 30 $m \cdot s^{-1}$.The siren of the ambulance emits sound waves having a wavelength of 0,28 m. Take the speed of sound in air as 340 $m \cdot s^{-1}$.

2.1.1 State the Doppler effect in words. (2)

2.2.2 Calculate the frequency of the sound waves emitted by the siren as heard by the ambulance driver. (3)

2.2.3 Calculate the frequency of the sound waves emitted by the siren as heard by the listener. (5)

2.1.4 How would the answer to QUESTION 2.2.3 change if the speed of the ambulance were LESS THAN 30 $m \cdot s^{-1}$? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

2.2 An observation of the spectrum of a distant star shows that it is moving away from the Earth. Explain, in terms of the frequencies of the spectral lines, how it is possible to conclude that the star is moving away from the Earth. (2)

Question 3

3.1 The siren of a stationary ambulance emits a note of frequency 1 130 Hz. When the ambulance moves at a constant speed, a stationary observer detects a frequency that is 70 Hz higher than that emitted by the siren.

3.1.1 State the Doppler effect in words. (2)

3.1.2 Is the ambulance moving towards or away from the observer? Give a reason for the answer.

(2)

3.1.3 Calculate the speed at which the ambulance is travelling. Take the speed of sound in air as 343 $m \cdot s^{-1}$. (5)

3.2 A study of spectral lines obtained from various stars can provide valuable information about the movement of the stars.

The two diagrams below represent different spectral lines of an element. Diagram 1 represents the spectrum of the element in a laboratory on Earth. Diagram 2 represents the spectrum of the same element from a distant star.

Diagram 1

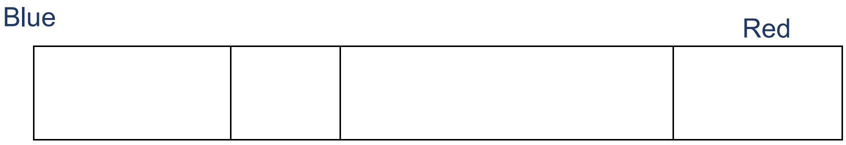
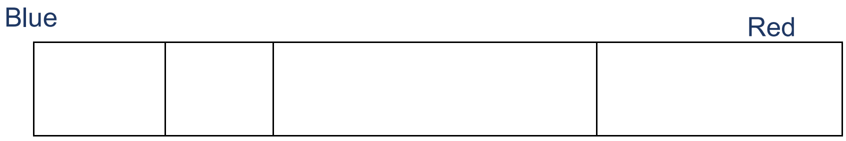


Diagram 2

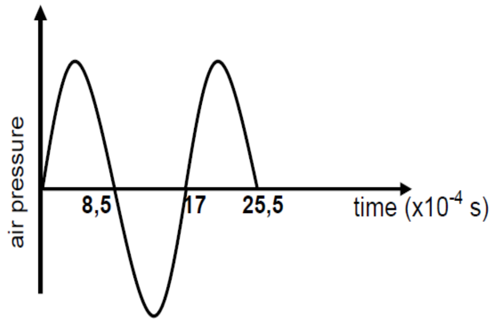


Is the star moving towards or away from the Earth? Explain the answer by referring to the shifts in the spectral lines in the two diagrams above. (2)

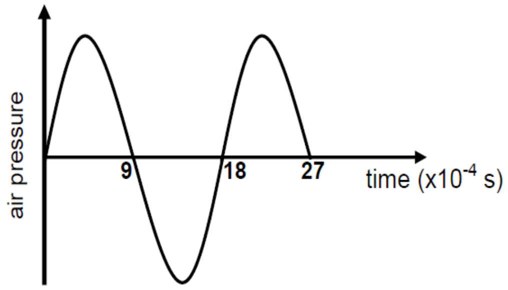
Question 4

The siren of a police car, which is travelling at a constant speed along a straight horizontal road, emits sound waves of constant frequency. Detector P is placed inside the police car and detector Q is placed next to the road at a certain distance away from the car. The two detectors record the changes in the air pressure readings caused by the sound waves emitted by the siren as a function of time. The graphs below were obtained from the recorded results.

GRAPH A: AIR PRESSURE VS TIME RECORDED BY DETECTOR P IN THE CAR



GRAPH B: AIR PRESSURE VS TIME RECORDED BY DETECTOR Q NEXT TO THE ROAD



4.1 Different patterns are shown above for the same sound wave emitted by the siren. What phenomenon is illustrated by the two detectors showing the different patterns? (1)

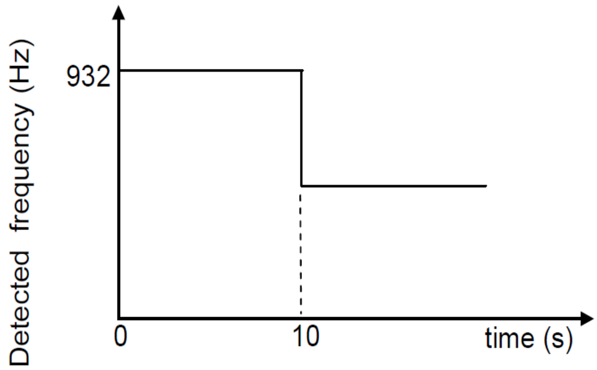
4.2 The police car is moving AWAY from detector Q.
Use the graphs and give a reason why it can be confirmed that the police car is moving away from detector Q. (1)

4.3 Calculate the frequency of the sound waves recorded by detector P. (3)

4.4 Use the information in the graphs to calculate the speed of the police car. Take the speed of sound in air as 340 $m \cdot s^{-1}$. (6)

Question 5

5.1 A patrol car is moving at a constant speed towards a stationary observer. The driver switches on the siren of the car when it is 300 m away from the observer. The observer records the detected frequency of the sound waves of the siren as the patrol car approaches, passes and moves away from him. The information obtained is shown in the graph below.



5.1.1 Calculate the speed of the patrol car. (2)

5.1.2 The detected frequency suddenly changes at t = 10 s. Give a reason for this change. (2)

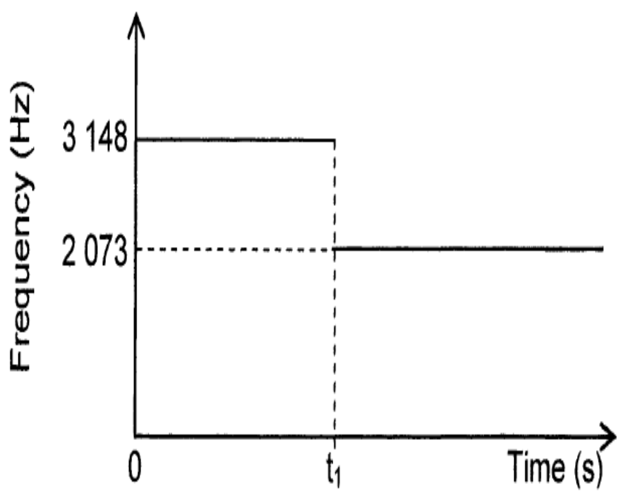
Take the speed of sound in air as 340 $m \cdot s^{-1}$. (4)

5.1.3 Calculate the frequency of the sound emitted by the siren.

5.2 State TWO applications of the Doppler effect. (2)

Question 6

The siren of a train, moving at a constant speed along a strait horizontal track, emits sound with a constant frequency. A detector placed next to the track, records the frequency of the sound waves. The results are shown in the graph below.



6.1	Define wavelength.	(2)
6.2	Does the detector record the frequency of 3 148 Hz when the train moves TOWARDS the detector or AWAY from the detector.	(1)
6.3	Calculate the speed of the train. Take the speed of sound in air as 340 $m \cdot s^{-1}$.	(6)
6.4	The detector started recording the frequency of the moving trains when the train was 350m away. Calculate time t_1 indicated on the graph above.	(2)

Question 7

An ambulance with its siren on, moves at constant velocity TOWARDS a person standing next to the road. The person measures a frequency which is 110% of the frequency of the sound emitted by the siren of the ambulance.

7.1	Name and state the phenomenon observed above	(3)
7.2	If the speed of sound in air is 340 $m \cdot s^{-1}$, calculate the speed of the ambulance	(5)
7.3	How will the frequency measured by the person be affected if the speed of the ambulance is increased? Write only INCREASE, DECREASE or REMAIN THE SAME.	(1)

5. Solutions to Exercises

Question 1

1.1.	B ✓✓
1.2	C ✓✓
1.3	C ✓✓
1.4	A ✓✓
1.5	A ✓✓
1.6	A ✓✓
1.7	A ✓✓
1.8	B ✓✓
1.9	A ✓✓
1.10	A ✓✓

Question 2

2.1.1 It is the (apparent) 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. ✓

2.1.2 $v = f\lambda$ ✓

$340 = f\,(0{,}28)$ ✓

$f_s = 1\ 214{,}29$ Hz ✓

2.1.3

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

$$f_L = \frac{v}{v - v_s} f_s$$

$$= \left(\frac{340\,\checkmark}{340 - 30\,\checkmark}\right) 1214{,}29\,\checkmark$$

$$= 1\ 331{,}80 \text{ Hz}\,\checkmark$$

2.1.4 Decreases. ✓

2.2 The spectral lines of the star are/should be shifted towards the lower frequency ✓ end, which is the red end (red shift) of the spectrum. ✓

Question 3

3.1.1 It is the (apparent) 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. ✓

3.1.2 Towards. ✓

Observed/detected frequency is greater than the actual frequency. ✓

3.1.3

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

$$f_L = \frac{v}{v - v_s} f_s$$

$$1200\,\checkmark = \left(\frac{343}{343 - v_s}\right)\checkmark 1130\,\checkmark$$

$$v_s = 20{,}01 \text{ m·s}^{-1}\checkmark$$

3.2 The star is approaching the earth. ✓

The spectral lines in diagram 2 are shifted towards the blue end/blue shifted. ✓

Question 4

4.1 Doppler Effect ✓

4.2 Q – records sound with longer period. ✓

4.3

$$f = \frac{1}{T} ✓$$
$$= \frac{1}{17 \times 10^{-4}} ✓$$
$$= 588,24 \text{ Hz} ✓$$

4.4

$$f = \frac{1}{T}$$
$$= \frac{1}{18 \times 10^{-4}} ✓$$
$$= 555,56 \text{ Hz}$$

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

$$f_L = \frac{v}{v + v_s} f_s$$

$$555,56 ✓ = \left(\frac{340}{340 + vs}\right) ✓\ 588,24 ✓$$

$$v_s = 20 \text{ m·s}^{-1} ✓$$

Question 5

5.1.1 $\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$ ✓

$300 = v_i\,(10)$ ✓

$v_i = 30$ m·s^{-1} ✓

5.1.2 Car/source (just) passes observer ✓✓

5.1.3

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

$$f_L = \frac{v}{v - v_s} f_s$$

$$932 ✓ = \frac{340}{340 - 30} fs ✓$$

$$fs = 849,76\ Hz ✓$$

5.2 Blood flow meter. ✓

Measuring the heartbeat of a foetus. ✓

Question 6

6.1 The distance between two successive points in phase. ✓✓

6.2 Towards the detector. ✓

6.3

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

$$f_L = \frac{v}{v - v_s} f_s$$

$$3148 = \frac{340}{340 - v_s} \text{fs} \checkmark$$

$$340\text{fs} = 1070320 - 3148v_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

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

$$f_L = \frac{v}{v + v_s} f_s$$

$$2073 = \frac{340}{340 + v_s} fs \checkmark\surd$$

$$340fs = 704\ 820 + 2073v_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Equate eqution 1 into equation 2

$$1\ 070\ 320 - 3148v_s = 704\ 820 - 2073v_s \ \checkmark\checkmark$$

$$5221v_s = 365\ 500$$

$$v_s = 70{,}01\ \text{m·s}^{-1} \checkmark$$

6.4

$$\Delta x = vi\Delta t + ½ a\Delta t2$$

$$350 = 70.01\Delta t \checkmark$$

$$\Delta t = 5s \checkmark$$

Question 7

7.1 Doppler Effect. ✓

It is the (apparent) 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. ✓

7.2

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

$$f_L = \frac{v}{v - v_s} f_s$$

$$\frac{110}{100} fs \checkmark = \frac{340}{340 - v_s} fs \checkmark\checkmark$$

$$v_s = 30{,}91\ \text{m·s}^{-1} \checkmark$$

7.3 Increase. ✓

6. Examination Tips

- Always copy the formulae from the formula sheet and write down the formula as it is from the formula sheet, and do not manipulate the formula.

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

- Determine whether the sound source is moving towards a stationary listener or the listener is moving towards a stationary source OR

  Determine whether the sound source is moving away from a stationary listener or the listener is moving away from a stationary source.
- White down the correct formula:

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

- Always attempt substitution, you will not be awarded a mark for the formula if substitution is not attempted.
- Substitute into the original formula and calculate the unknown variable.
- If the SI-units in the question differs, make use of conversions to obtain the correct SI-unit.
- To convert $km.h^{-1}$ to $m.s^{-1}$: $\frac{km.h^{-1}}{3.6}$
- If the question is based on a graph first interpret the graph.
- Always use un-rounded off values in your question – it will assist in the final answer being more accurate.
- Rounding off should only be done at the final answer of a calculation. One should

  not round off in each step as it leads to an incorrect answer. The instruction in the paper reads a ‘MINIMUM of TWO decimal digits’ and NOT a ‘MAXIMUM of TWO decimal digits’, you may leave your answer with more than TWO decimal digits.

7. General Examination Tips

As you prepare to write the examination, it is important to carefully understand the rules that govern certain aspects of your work, i.e.: definitions, rules, laws and concepts. Understand these definitions/ rules/ laws/ concepts very well. Understand what they mean, where they apply and when they apply - and also when and where they do not apply. Also, always:

1. Start with the questions that you know you are able to answer.
2. Read the question that you are working on carefully.
3. Understand what the question says and what is required of you.
4. Write down the information that you have.
5. Write down the information that you do not have.
6. Use existing information to derive what you need to solve the question.
7. All questions have hints that point to the answer.
8. Check your work by going through these steps again.

8. References

The following documents were used in the Development of this booklet:

- Physical Sciences Grade 10-12 CAPS document (DBE)
- Physical Sciences Examination Guidelines 2021 (DBE)
- Previous Grade 12 Question Papers (DBE)
- Grade 12 Preparatory Examination Papers (PEDs)
- Siyavula Grade 12 textbook
- NECT Grade 12 textbook
- Science clinic Grade 12

9. Acknowledgement

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