CHRIST CHURCH GRAMMAR SCHOOL

YEAR 12

PHYSICS STAGE 3

MID YEAR EXAMINATION 2010

SOLUTIONS

A		
B		
C		
Total		/ 178 = %

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time for paper: three hours

Materials required/recommended for this paper

To be provided by the supervisor

Question/Answer Booklet
Formulae and Constants Sheet

To be provided by the candidate

Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set by the Curriculum Council for this course.

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any un-authorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short Answers	15	15	45	53	30%
Section Two: Problem-Solving	8	8	90	90	50%
Section Three: Comprehension	2	2	45	35	20%
					100

Instructions to candidates

Write your answers in this Question/Answer Booklet

Working or reasoning should be clearly shown when calculating or estimating answers.

You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

YEAR 12
PHYSICS STAGE 3
MID YEAR EXAMINATION 2010

Section One: Short Response

This section has **fifteen (15)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **45 minutes**.

Question 1 **(3 marks)**

State a type of wave that meets the following criteria:

(a) A transverse, non-mechanical wave (1 mark)

Any electromagnetic wave

(b) A longitudinal wave (1 mark)

Sound

(c) A transverse, mechanical wave (1 mark)

Ripples on the surface of water, waves of a string

Question 2 **(4 marks)**

A lightning bolt at the equator carries a current of 20.0 kA perpendicular to the Earth's surface.

(a) Determine the magnitude of the force per metre on the lightning bolt (B at equator = 30 μT).

(3 marks)

$$F = I\ell B \quad (1)$$
$$= (20.0 \times 10^{3})(1)(30 \times 10^{-6}) \quad (1)$$
$$= 0.600\ N \quad (1)$$

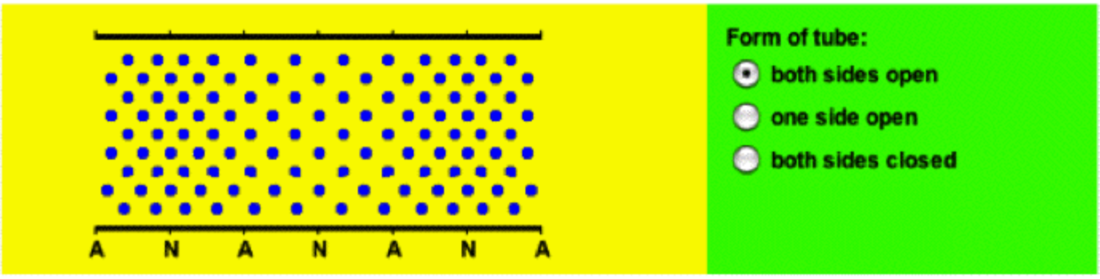
(b) Determine the direction of the force on the **electron current** if the electron current is directed straight up from the Earth.

(1 mark)

East

Question 3 **(4 Marks)**

The diagram below represents a tube open at both ends, supporting a *standing wave*.



(a) Which harmonic is represented in this diagram?

(1 mark)

3rd Harmonic

(b) Calculate the frequency of the standing wave represented if the effective length of the pipe is 1.80 m and the air is at 25.0°C.

(3 marks)

$$f_n = \frac{nv}{2L} \quad (1)$$

$$f_3 = \frac{(3)(346)}{(2)(1.80)} \quad (1)$$

$$f_3 = 288\,Hz \quad (1)$$

Question 4 **(3 marks)**

A non-ferromagnetic metal screwdriver is being used in a 2.00 T magnetic field. What is the maximum emf that can be induced along its 12.0 cm length when it moves at 6.00 ms^{-1}?

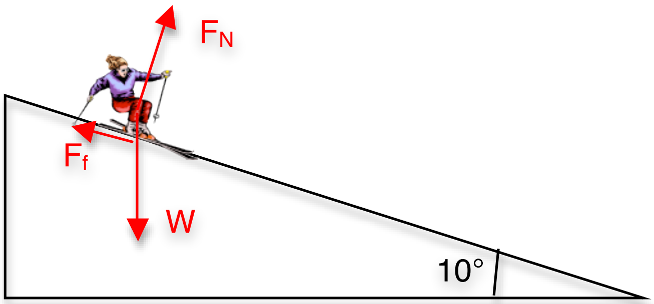
$$\varepsilon = v\ell B \quad (1)$$

$$= (6)(12.0 \times 10^{-2})(2) \quad (1)$$

$$= 1.44\ N \quad (1)$$

Question 5 **(6 marks)**

A 60.0 kg skier is heading down a 10.0° slope, as shown in the diagram below. The friction between her skis and the snow is 57.9 N.



(a) Draw a free body diagram showing and labeling all the forces acting on the skier.

(3 marks)

(b) Determine the magnitude of the acceleration of the skier down the slope.

(3 marks)

$$\Sigma F = mg\sin\theta - F_f = ma \quad (1)$$

$$(60)(9.8)(\sin 10) - 57.9 = (60)(a) \quad (1)$$

$$a = 7.37 \times 10^{-1}\ ms^{-2} \quad (1)$$

Question 6 **(3 marks)**

When a guitar string is sounded with a 440 Hz tuning fork, a beat frequency of 3.00 Hz is audible. When sounded with a 445 Hz tuning fork, a beat frequency of 8.00 Hz is audible. Determine the vibrational frequency of the guitar string.

$$f_b = |f_2 - f_1| \quad (1)$$

$$3 = |440 - f_1|$$

$$f_1 = 443\ or\ 437\ Hz$$

$$f_b = |f_2 - f_1|$$

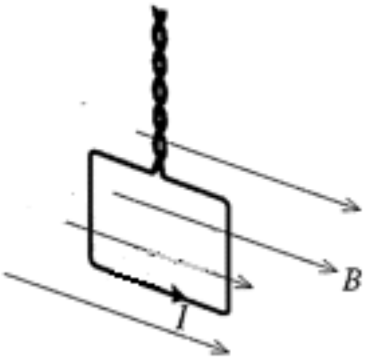
$$8 = |445 - f_1|$$

$$f_1 = 453\ or\ 437\ Hz$$

$$\therefore f_{guitar} = 437\ Hz \quad (1)$$

Question 7 **(1 mark)**

A single-turn coil of wire is placed in a uniform magnetic field *B*, so that the plane of the coil is parallel to the field, as shown in the diagrams below. The coil can move freely. An electric current *I* flows around the coil in the direction shown.

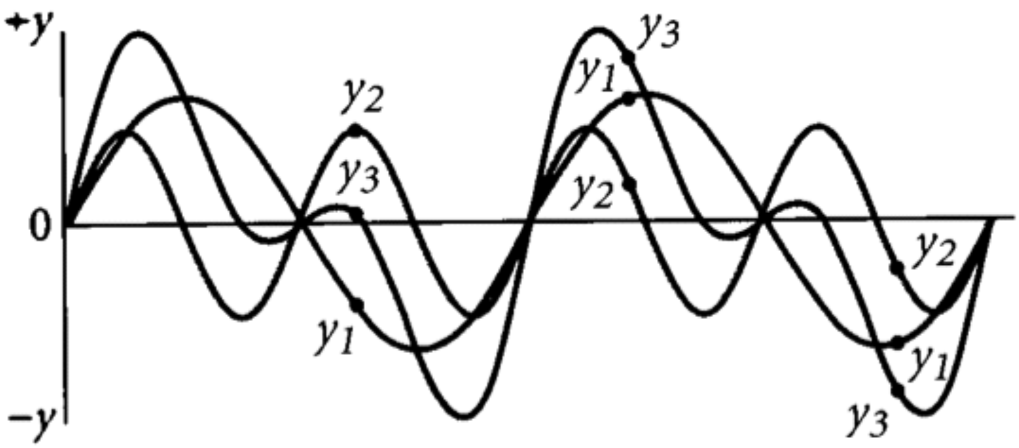


In which direction does the coil begin to move (looking down from above)? Circle your chosen response.

Anticlockwise Clockwise The coil does not move

Question 8 **(1 mark)**

Look at the following graph of two superimposing waveforms.

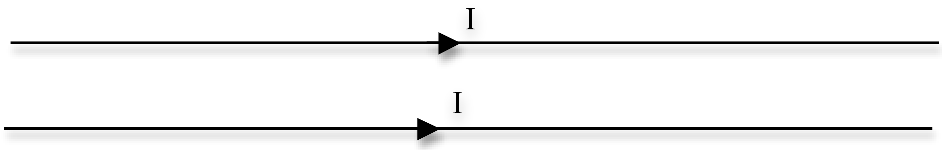


Use the superposition principle to determine which waveform is the resultant of the other two. Circle your chosen answer.

y1 y2 y3

Question 9 **(3 marks)**

Two parallel wires are separated by a distance of 0.75 m. Both currents flow in the same direction along the wires.



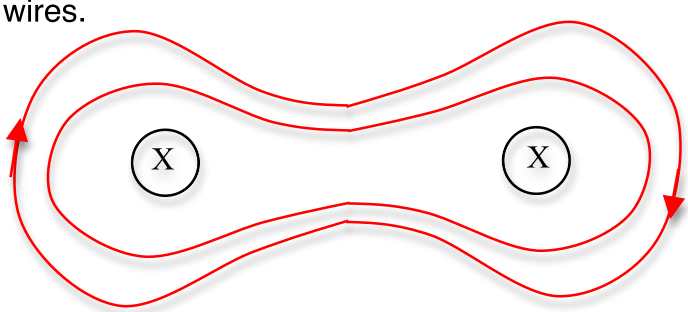
(a) Do these wires experience an attractive or repulsive force?

(1 mark)

Attractive

(b) Complete the diagram below showing the magnetic field surrounding these wires.

(2 marks)



1 mark – correct shape 1 mark – correct direction

Question 10 **(6 marks)**

A 45 000 kg rocket acquires a speed of 6400 kmh^{-1} one minute after launch.

(a) What is the rocket's kinetic energy at the end of this first minute?

(3 marks)

$$E_K = \frac{1}{2}mv^2 \quad (1)$$

$$= \frac{1}{2}(45000)(1780)^2 \quad (1)$$

$$= 7.13 \times 10^{10} J \quad (1)$$

(b) What is the average power expended during this first minute (ignore frictional and gravitational forces)

(3 marks)

$$P = \frac{W}{t} = \frac{\Delta E}{t} \quad (1)$$

$$= \frac{7.13 \times 10^{10}}{60} \quad (1)$$

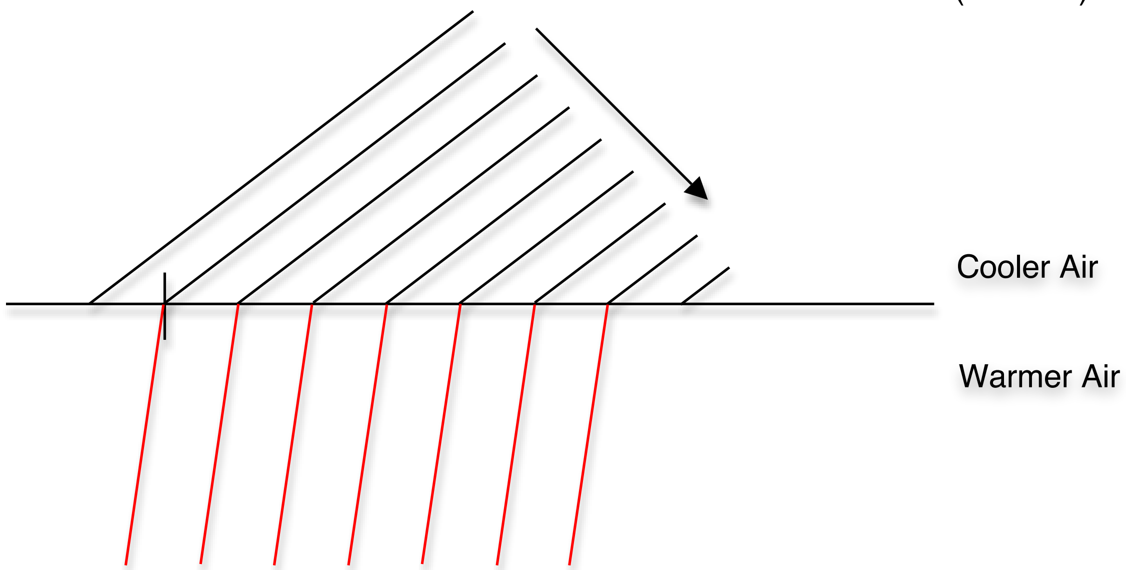
$$= 1.19 \times 10^9 W \quad (1)$$

Question 11 **(4 marks)**

Complete these diagrams:

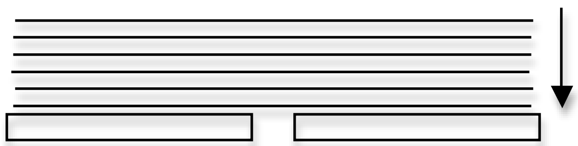
(a) Sound waves moving from air at 25.0°C to 50.0°C:

(2 marks)



(b) Light waves encountering a slit:

(2 marks)



Question 12 **(4 marks)**

A guitar is used to play a fundamental note of 65.4 Hz. The string used is 55.0 cm long and air temperature is 25.0°C. What is the speed of the wave on the string?

$$L = \frac{\lambda}{2}$$

$$\lambda = (2)(0.55)$$

$$= 1.10\ m$$

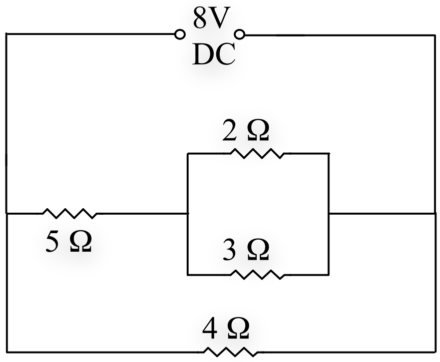
$$v = f\lambda$$

$$= (65.4)(1.10)$$

$$= 71.9\ ms^{-1}$$ (1)

Question 13 **(6 marks)**

The following questions refer to the circuit below:



(a) Determine the equivalent resistance of this circuit [3]

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$ 1

$$\frac{1}{R_T} = \frac{1}{5 + \frac{1}{(\frac{1}{2} + \frac{1}{3})}} + \frac{1}{4}$$ 1

$$R_T = 2.43\ \Omega$$ 1

(b) Determine the power dissipated through the 5.00 Ω resistor. [3]

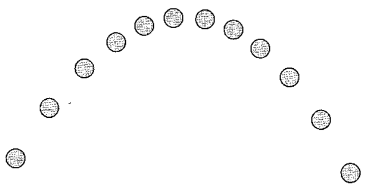
$$P = I^2R$$ 1

$$= (\frac{8}{2.43} - \frac{8}{4})^2(5)$$ 1

$$= 8.35\ W$$ 1

Question 14 **(1 mark)**

A ball thrown in the air traces a path as shown below:

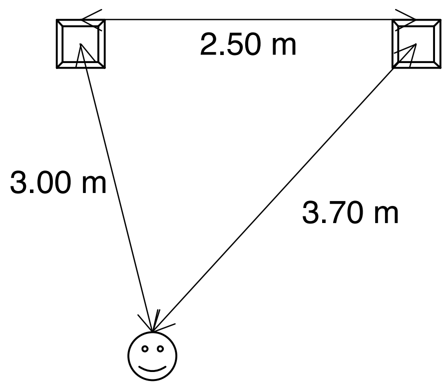


Which of the following statements is true (assuming no air resistance)?
Circle your chosen answer.

(A) The velocity of the ball keeps changing.
(B) The acceleration of the ball keeps changing.
(C) The velocity of the ball at the top of its motion is zero.
(D) The acceleration of the ball at the top of its motion is zero.

Question 15 **(4 marks)**

Two loudspeakers, 2.50 m apart, are connected to a single source and send out identical sound waves in phase. A student stands 3.00 m from one speaker and 3.70 m from the other speaker, as shown in the diagram below.



(a) Determine the lowest frequency from the speakers that will produce a quiet spot at this location on a 25.0°C day.

1st quiet spot:

$$PD = \frac{\lambda}{2}$$

$$3.70 - 3.00 = 0.70 = \frac{\lambda}{2} \quad (1)$$

$$\lambda = 1.40\ m \quad (1)$$

$$f = v\lambda \quad (1)$$

$$= (346)(1.40)$$

$$= 484\ Hz \quad (1)$$

End of Section One

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Section Two: Problem-Solving

This section has **eight (8)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **90 minutes**.

NAME:______________________________________

Question 1 **(14 marks)**

An American tourist takes his 25.0 W, 120 V shaver to Australia, finds an adapter plug (**without a transformer**) and plugs it into the 240 V socket.

(a) Determine the resistance of the shaver.

(3 marks)

$$P = \frac{V^2}{R}$$

$$25 = \frac{120^2}{R}$$

$$R = 576\ \Omega$$

(b) Assuming constant resistance in the electric shaver, what power does the shaver consume as it is ruined?

(3 marks)

$$P = \frac{V^2}{R} \quad (1)$$

$$= \frac{240^2}{576} \quad (1)$$

$$= 100\ W \quad (1)$$

(c) Realising his mistake, the tourist buys a transformer. If the transformer has 50 coils on the primary coil, how many coils are on the secondary?

(2 marks)

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

$$\frac{50}{N_S} = \frac{240}{120}$$

$$N_s = 25 \quad (1)$$

(d) If the transformer is only 80% efficient, what must be the power in the primary coil?

(3 marks)

$$efficiency = \frac{P_{out}}{P_{in}} \quad (1)$$

$$0.80 = \frac{25}{P_{in}} \quad (1)$$

$$P_{in} = 31.3\ W \quad (1)$$

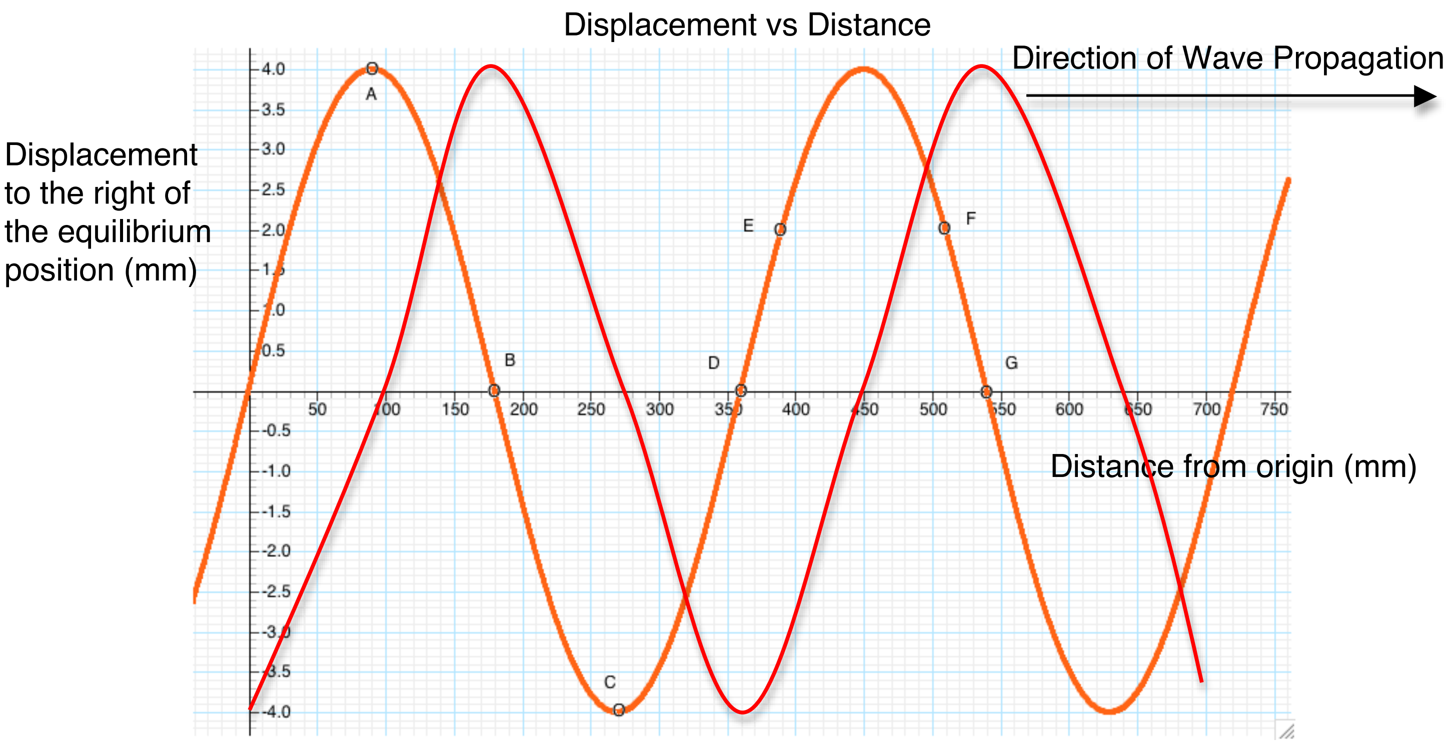
(e) To improve efficiency in a transformer a **laminated** soft iron core is utilised. How do the laminations improve efficiency?

(3 marks)

- By having a smaller area
- the magnitude of the eddy currents is restricted
- and this reduces energy loss due to resistive heating.

Question 2 **(12 marks)**

The graph below is a **displacement vs distance** graph for a sound wave progressing through air at one instant in time. Seven particles (A to G) are shown.



(a) From the graph determine the following:

(3 marks)

(i) Amplitude 4.0 mm

(ii) Wavelength 350 mm

(iii) Two particles that are in phase with each other B, G

(iv) Two particles that are stationary A, C

(v) A particle moving towards its equilibrium position E or D

(b) Determine the frequency of this sound wave.

(3 marks)

$v = f\lambda$ (1)

$346 = (f)(350 \times 10^{-3})$ (1)

$f = 989\ Hz$ (1)

(c) On the graph above sketch the shape of the sound wave after it has progressed forwards by a quarter of a period i.e. at time t = T/4

(2 marks)

(d) A boy strikes a tuning fork and records the sound on his iPod. When he plays back the recorded sound he notices that the tuning fork is making a sound, as well as the iPod.

(i) Name this phenomenon.

(1 mark)

Resonance

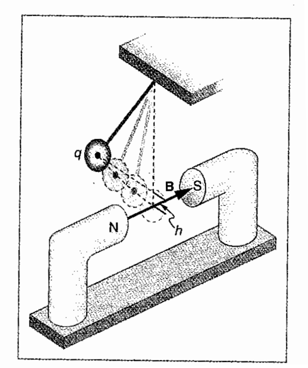
(ii) Explain why this phenomenon occurs.

(3 marks)

- The Ipod sends out pressure waves which push against the tuning fork causing it to vibrate.
- Because the frequency of the pressure waves is equal (or close to) the natural frequency of the tuning fork (ie the driving frequency is equal or close to the natural frequency)
- (energy transfer is the most efficient) and large amplitude oscillations occur.

Question 3 **(10 marks)**

A pendulum is set up so that it swings between the poles of a permanent magnet as shown in the figure below. The bob has a charge of + 0.250 μC and is released from a height 30.0 cm above its lowest point. The magnetic field strength is 1.50 T and at the lowest point of its path, the bob is completely within the poles of the magnet.



(a) Determine the speed of the bob at its lowest point. (3 marks)

$$E_p = E_k$$

$$(mgh) = (\frac{1}{2}mv^2)$$ (1)

$$(9.8)(0.30) = \frac{1}{2}(v^2)$$ (1)

$$v = 2.42\ ms^{-1}$$ (1)

(b) What is the magnetic force on the positively charged particles in the bob at the lowest point in its path? (4 marks)

$$F = qvB$$ (1)

$$= (0.25 \times 10^{-6})(2.42)(1.50)$$ (1)

$$= 9.08 \times 10^{-7} N \quad UP$$ (1) (1)

(c) Would there be eddy currents at the lowest point in the bob's path? Explain your reasoning. (3 marks)

- At the lowest point in the bob's path, the bob will be entirely within the confines of the magnetic field.
- There will be not net change in magnetic flux through the bob.
- So no induced emf and hence enddy currents will be induced.

Question 4 **(11 marks)**

Acoustic microscopes can be used to provide detailed images of very small objects using reflection of sound waves. The sound waves in one such microscope have a frequency of 4.20 GHz.

(a) If the specimen is immersed in liquid helium, what is the wavelength of these ultrahigh-frequency waves?
(speed of sound in helium = 240 ms^{-1})

[3]

$$v = f\lambda \quad (1)$$
$$240 = (4.20 \times 10^9)(\lambda) \quad (1)$$
$$\lambda = 5.71 \times 10^{-8}\,m \quad (1)$$

(b) If the specimen is around 2 μm wide – how many wavelengths fit into this?

[2]

$$\frac{2 \times 10^{-6}}{5.71 \times 10^{-8}} = 35.0 \quad (1)$$

(1)

(c) Why are ultrahigh frequencies necessary to resolve specimens of this magnitude?

[3]

- For reflection to occur the wavelength must be smaller than the object.
- If the wavelength is larger, diffraction around the object will occur.
- Very high frequencies have very short wavelengths and thus can be used to resolve very small objects.

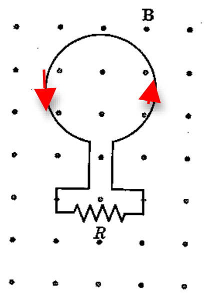
(d) Visible light has frequencies ranging from approximately 4.00 x 10^{14} Hz to 7.14 x 10^{14} Hz. What lower limit does this place on the size of objects which can be observed with a light microscope.

[3]

$$v = f\lambda \quad (1)$$
$$3 \times 10^8 = (7.14 \times 10^{14})(\lambda) \quad (1)$$
$$\lambda = 4.20 \times 10^{-7}\ m \quad (1)$$

Question 5 **(10 marks)**

A loop antenna (as shown in the diagram below) of area 200 cm^2 and resistance 15.0 Ω lies perpendicular to a uniform magnetic field of 3.00 mT.



If the field drops linearly to zero in a time interval of 50.0 ms,

(a) Show on the diagram the direction of induced current.

(1 mark)

(b) Explain why the current is induced in this direction.

(3 marks)

- As the magnetic field decreases in strength, the induced emf (and hence current) will be in such a direction as to oppose this change.
- An anticlockwise current will have a magnetic field directed out of the page
- According to the right hand grip rule.

(c) Determine the magnitude of the induced emf.

(3 marks)

$$\varepsilon = -\frac{\Delta\phi}{\Delta t} \quad (1)$$

$$= -\frac{(0-(3.00\times10^{-3})(200\times10^{-4}))}{50.0\times10^{-3}} \quad (1)$$

$$= 1.20 \text{ mV} \quad (1)$$

(d) Determine the power dissipated in the loop over the time the field is dropping to zero.

(3 marks)

$$P = \frac{V^2}{R} \quad (1)$$

$$= \frac{(1.20\times10^{-3})^2}{15.0} \quad (1)$$

$$= 9.60\times10^{-8} \text{ W} \quad (1)$$

Question 6 **(12 marks)**

An osprey is carrying a fish to the chicks in its nest. It is 4.00 m west and 12.00 m above the centre of its 30.0 cm diameter nest and flying east at 3.50 ms^{-1} at an angle 30.0° below the horizontal when the fish wriggles free.

(a) Determine the horizontal and vertical components of the initial **velocity** of the fish.

(4 marks)

$$v_h = 3.50\cos 30 = 3.03\ ms^{-1} \quad East$$

$$v_v = 3.50\sin 30 = 1.75\ ms^{-1} \quad Down$$

(b) How long does it take the fish to travel the vertical distance to the osprey's nest?

(4 marks)

$$s = ut + \frac{1}{2}at^2$$

$$-12 = (-1.75)(t) + \frac{1}{2}(-9.8)(t^2)$$

$$4.9t^2 + 1.75t - 12 = 0$$

$$t = \frac{-1.75 \pm \sqrt{(1.75)^2 - (4)(4.9)(-12)}}{(2)(4.9)}$$

$$= 1.40\ s$$

(c) Does the fish land in the osprey's nest? Justify your answer with appropriate calculation/s.

(4 marks)

$s_h = tv_h$ (1)

$= (1.40)(3.03)$

$= 4.24$ m (1)

no (1) $4.24 > 4.15$ (1)

Question 7 **(9 marks)**

A clarinet is a wind instrument that can only produce **odd multiple** harmonics of the fundamental frequency.

(a) This is an air column that is (circle your response):

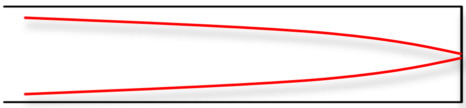
(1 mark)

open at both ends closed at both ends open at one end

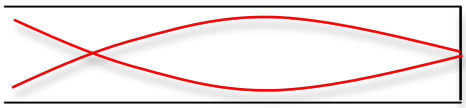
(b) Sketch the **particle displacement** wave envelopes (modes of vibration) for the fundamental frequency and 1st overtone of the clarinet [Hint: you may choose to alter the given diagrams].

(2 marks)

Fundamental



1st Overtone



(c) If the effective length of the clarinet is 37.0 cm, calculate the frequency of the 2nd overtone produced on a 25.0°C day.

(3 marks)

$$f_n = \frac{nv}{4L}$$ (1)

$$f_n = \frac{(5)(346)}{(4)(0.37)}$$ (1)

$$f_n = 1170\ Hz$$ (1)

(d) On a colder day, explain how will the fundamental frequency be altered.

(3 marks)

- The fundamental frequency will decrease.
- The fundamental wavelength will not change (no change in pipe length).
- Wave speed is proportional to temperature and as v=fλ, if v decreases then f must also decrease.

Question 8 **(12 marks)**

A simple motor consists of a 200 turn, square loop of side 20.0 cm. The current through the loop, when the motor is first started, is 25.0 A and the magnetic flux density is 1.50 T. The motor operates with a 20.0 V power supply.

(a) What is the magnitude of the torque on the coil?

(3 marks)

$\tau = \text{BANI}$ (1)

$= (1.50)(0.2^2)(200)(25)$ (1)

$= 300 \text{ Nm}$ (1)

(b) What is the resistance of the coils?

(2 marks)

$\text{V} = \text{IR}$ (1)

$20 = (25)(\text{R})$

$= 0.800\ \Omega$ (1)

When the motor is turning at full speed the current drawn drops to 12.0 A.

(b) What is the back emf generated at full speed?

(3 marks)

$\text{V}_{\text{net}} = \varepsilon - \text{V}_{\text{back}}$ (1)

$(12)(0.8) = 20 - \text{V}_{\text{back}}$ (1)

$\text{V}_{\text{back}} = 10.4 \text{ V}$ (1)

(d) If the motor is now being used to lift a piece of heavy machinery (i.e. the motor is under load), what will happen to the magnitude of the back emf. Explain your reasoning.

(4 marks)

- As the motor lifts the heavy piece of machinery, it will turn more slowly.
- As the motor is cutting the field lines an emf will be induced (Faraday's Law)
- The induced emf is proportional to the rate of cutting field lines.
- The magnitude of the back emf will increase

End of Section Two

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Section Three: Comprehension

This section has **two (2)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **45 minutes**.

NAME:_______________________________________

Question 1 **(17 marks)**

Inductance

Induction is the process in which an emf is induced by changing magnetic flux. There are many devices which make use of this process, some are more effective than others. Transformers, for example, are designed to be particularly effective at inducing a desired voltage and current with very little energy loss to other forms.

Is there a useful physical quantity related to how 'effective' a given device is? The answer is yes, and that physical quantity is called **inductance**. The units of inductance are called the **henry (H)**.

Self-Inductance, is the effect of faraday's law of inductance of a device on itself. Self-Inductance is given the symbol **L**. A device that exhibits significant self-inductance is called an **inductor**. The larger the self-inductance of a device, the greater its opposition to any change in current through it.

A common example of an inductor is a solenoid.

The self-inductance of a solenoid of cross-sectional area A, N turns and length ℓ is given by the formula:

$$L = \frac{\mu_0 N^2 A}{\ell}$$

Where μ_0 is the permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ TmA^{-1}

Given below is data for the inductance of a series of solenoids increasing in cross-sectional area. Each solenoid has 100 turns and a fixed length ℓ .

Self-Inductance (μH)	Diameter (cm)	Area (m^2)
6.60	1	7.85×10^{-5}
26.4	2	3.14×10^{-4}
106	4	1.26×10^{-3}
238	6	2.83×10^{-3}
422	8	5.03×10^{-3}

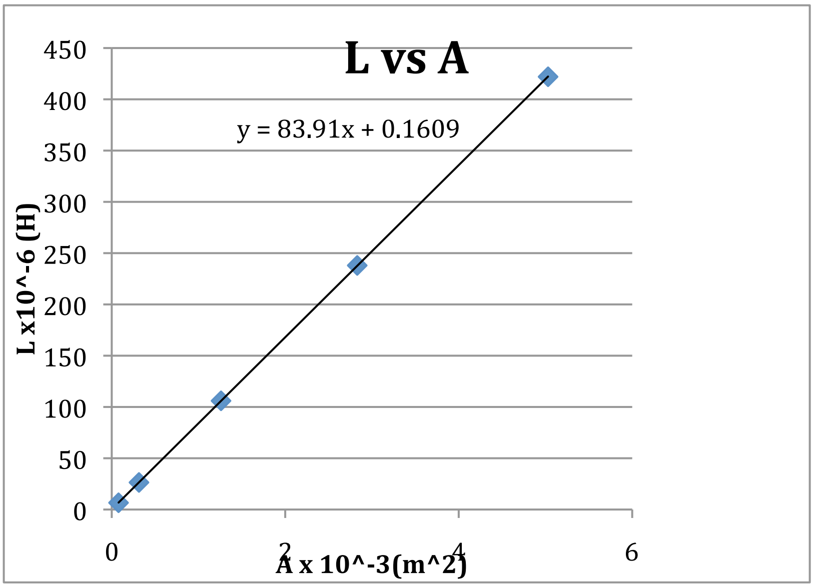
(a) Process the given data so that you will be able to plot a graph of

L vs A

(2 marks)

(b) Plot a graph of L vs A on the graph paper on the next page.

(5 marks)



1	Title
1	Axis Labels and Units
1	Correct Points Plotted
1	Linear Scale
1	Line of Best Fit
-2	Incorrect Graph

(c) Determine the gradient of your graph.

(3 marks)

- Triangle and working
- Gradient = $(83.9)(1 \times 10^{-6} / 1 \times 10^{-3}) = 83.9 \times 10^{-3}$
- Units = Hm^{-2}

(d) Use the gradient you determined in (c) to calculate the length of the solenoids.

(2 marks)

$$\frac{\mu_0 N^2}{\ell} = \text{gradient}$$

$$\frac{(4\pi \times 10^{-7})(100^2)}{\ell} = 83.9 \times 10^{-3}$$

$$\ell = 1.50 \times 10^{-1} \text{m}$$

(f) As the solenoids became larger in diameter, their self-inductance increased. Explain why this is so.

(3 marks)

- Self inductance is a measure of the opposition to change in a device.
- As the diameter increases, the change in magnetic flux will increase (for the same change in B)
- This means a larger emf will be induced.

(e) A precision laboratory resistor is made of a coil of wire 1.50 cm in diameter and 4.00 cm long, and it has 500 turns. What is its self-inductance?

(2 marks)

$$L = \frac{\mu_0 N^2 A}{\ell}$$

$$= \frac{(4\pi \times 10^{-7})(500^2)(\pi)(\frac{0.015}{2})^2}{0.04}$$

$$L = 1.39 \text{ mH}$$

Question 2 **(18 marks)**

<u>The Doppler Effect</u>

You probably have at some time observed the *Doppler Effect* perhaps without even realising it! An ambulance sounding its siren as it passes by is an example of this phenomenon. The pitch of the siren drops significantly, sometimes as much as two whole notes on the musical scale, as the ambulance goes past. The *Doppler Effect* can also be observed when listening to the engine of a Formula One racing car as it approaches and recedes (goes away) from spectators at a racetrack. The pitch of the motor seems to be extremely high as the car approaches, but drops dramatically as the car passes the spectators and speeds away.

The relative motions of the sound source and the observer are responsible for the change in pitch of the sounds in the examples cited above. To explain the *Doppler Effect*, consider the following example. When a horn on a **stationery sound source** (a car) is sounded, it emits longitudinal pressure waves that travel out in all directions. These spherical wavefronts move with the same speed and have a constant frequency. To all **stationary observers**, no matter where they are located, the pitch heard is based on the actual frequency of the horn. This occurs because the sound waves reaching the ears of any stationary observer listening to the sound arrive with the same frequency as the emissions from the source.

Figure 1 (below) shows the effect a **moving sound source** has on the sound waves being produced by the horn on a car when observed at stationery points A and B. The horn is actually moving toward the waves travelling forward and away from the waves travelling to the rear of the car. The speed of sound propagated is the same in both directions as detected by observers at A and B. However the wavefronts travelling forward are bunched closer together whilst those wavefronts leaving the back of the car are more spaced apart. As the horn continues to produce sound waves, a stationery observer at A will hear more waves per second than an observer at B.

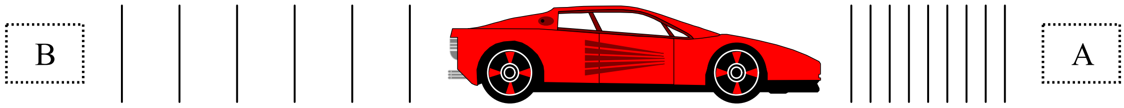


Figure 1 – car moving towards A

When an observer is moving towards or away from a **stationary sound source** the situation is quite different. The distance between successive wavefronts as measured by observers is unchanged but the **velocity** of the passing wavefronts relative to the observer is altered depending on whether the observer is moving towards or away from the source.

The general relationship between velocity and frequency for the *Doppler Effect* is given by the following single equation:

$$\frac{f_o}{V - v_o} = \frac{f_s}{V - v_s}$$

Where:
f_s = the frequency of the source
f_o = the frequency heard by the observer
V = the velocity of sound
v_s = the velocity of the source
v_o = the velocity of the observer

Since velocity is a vector quantity, consideration must be given to the direction of the waves. If the velocity of sound, V, is assigned a positive value and then the following rules apply.

Rule 1: If the source approaches an observer:
v_s is positive (+ve) – the observer is in front of the source.
If the source moves away from an observer:
v_s is negative (-ve) – the observer is behind the source.

Rule 2: If an observer approaches the source, v_o is negative (-ve),
If an observer moves away from the source v_o is positive (+ve).

Rule 3 If the source and observer are moving in the same direction,
i) v_s and v_o are both +ve if the observer leads the source.
ii) v_s and v_o are both –ve if the source leads the observer.

It is significant to note that if the observer is at rest and the source is approaching at a velocity v_s which is greater than V, then the value of the frequency heard by the observer, f_o is negative. This would indicate that if v_s = +2V, someone shouting from a supersonic craft moving towards a stationery observer would be heard in reverse!

(a) The passage refers to the 'pitch' of a particular sound. What sound wave measurement is related to pitch?

(1 mark)

- Pitch is equivalent to frequency

(b) For a stationery observer, explain why the pitch of an approaching car seems higher than the pitch of a stationary car, which in turn is higher than the pitch of a car moving away?

(4 marks)

- Any object making a sound of constant frequency creates three dimensional wavefronts that travel at the speed of sound within the medium separating the source and the observer,
- • that arrive at the frequency of the originating sound.
- • If a car is moving towards an observer the distance between successive wavefronts gets smaller so there are more wavefronts arriving at the observer in the same unit of time increasing frequency.
- • Similarly, if the car is moving away from the observer the distance between successive wavefronts increases so fewer wavefronts arrive in the same unit of time, decreasing frequency.

(c) An observer moving towards a **stationery sound source** hears a different pitch of sound compared to when they were both stationery relative to each other.

(i) Why is this?

(2 marks)

• The distance between successive wavefronts as measured by the observer is the same

• but the velocity of the passing wavefronts relative to the observer is increased or decreased depending on whether the observer is moving towards or away from the sound source.

(ii) Explain whether the pitch heard by the moving observer would be higher or lower.

(2 marks)

• When moving towards the sound source frequency increases

• When moving away the frequency decreases

(d) A Grand Prix motorcyclist racing at Phillip Island, Victoria passes the grandstand at a speed of 2.00×10^2 kmh^{-1}. If the exhaust pipe makes a sound of frequency 650 Hz, calculate the frequencies that a microphone placed in front of the grandstand would pick up as the motorcycle approaches and recedes? Assume the speed of sound is 340 ms^{-1} on this day and that the microphone is fixed directly in line with the motion of the motorcycle.

(4 marks)

$$\frac{f_o}{V - v_o} = \frac{f_s}{V - v_S}$$

moving towards microphone

$f_0 = (650x\ 340)/(340 - 55.6)$
$= 777$ Hz

moving away from microphone $f_0 = (650x\ 340)/(340 + 55.6)$
$= 559$ Hz

(e) The motorcyclist in (d) celebrates victory by doing a burnout in a stationery position? A TV crew in a parked vehicle some distance away, records the motorcycle's exhaust pipe emitting a frequency of 650 Hz once again. The TV crew drives towards the motorcycle at 2.00×10^2 kmh^{-1}. What frequency of sound are they detecting at this approach speed?

(2 marks)

$$\frac{f_o}{V - v_o} = \frac{f_s}{V - v_S}$$

moving towards microphone

$f_0 = (650x\ 340)/(340 - 55.6)$
$= 777$ Hz

moving away from microphone $f_0 = (650x\ 340)/(340 + 55.6)$
$= 559$ Hz

(f) Sonic Booms (sound shock waves) are heard by stationary observers on the ground when aircraft reach speeds of Mach 1 (the speed of sound). State what you can infer from using the formula about why this happens.

(3 marks)

$$\frac{f_o}{V - v_o} = \frac{f_s}{V - v_S}$$

In this instance the plane is travelling at 340 ms-1, the speed of sound and the observer is stationary so $f_0 /340 = f_s/(340 - 340) = 0$ Hz.
Just below the speed of sound the observed frequency would be very high (approaching 340 x f_s) and just above the speed of sound the observed frequency would be negative (approaching -340 x f_s). A rapid change in observed frequency is experienced