CHRIST CHURCH GRAMMAR SCHOOL

YEAR 12

PHYSICS Stage 3

END OF YEAR EXAMINATION 2011

SOLUTION

One		
Two		
Three		
Total		/ 180 = %

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/tape, ruler, and highlighters

Special items: non-programmable calculators satisfying the conditions set by the Curriculum Council for this course, drawing templates, drawing compass and a protractor.

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 Answer	14	14	50	54	30%
Section Two: Extended Answer	8	8	90	90	50%
Section Three: Comprehension and Data Analysis	2	2	45	36	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. Your answers should be written to 3 significant figures where appropriate.

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
END OF YEAR EXAMINATION 2011

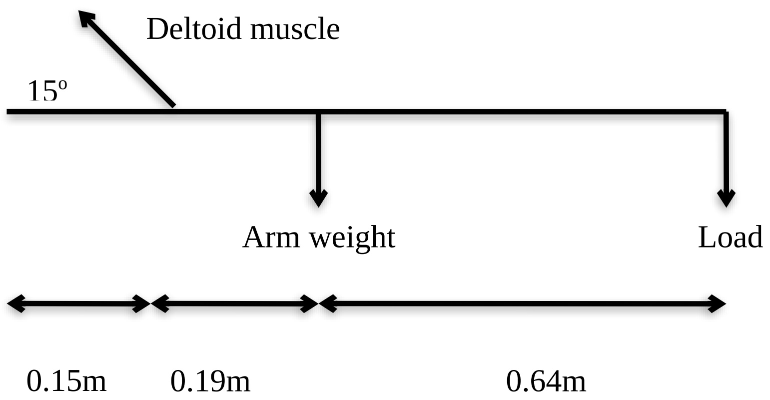
Section One: Short Answer

This section has **(14)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **50 minutes**.

Question 1 **(5 marks)**

The diagram below represents the human shoulder joint and the attached arm. The shoulder joint has the deltoid muscle connected to the humorous, a bone in the upper arm around 15 cm from the shoulder joint. The arm has a mass of 3.5 kg.



(a) If the arm and shoulder are in a state of static equilibrium what conditions must be met? (2 marks)

Σ F = 0 (√)

Σ M = 0 (√)

(b) Calculate the tension in the deltoid muscle when a 2.0 kg flowerpot is held in the hand with the arm outstretched (the load). (3 marks)

Take moments about shoulder joint

Σ ACW M = Σ CW M (√)

T (0.15 sin 15) = (0.34) (3.5 x 9.8) + (0.98) (2 x 9.8) (√)

T = 795 N (√)

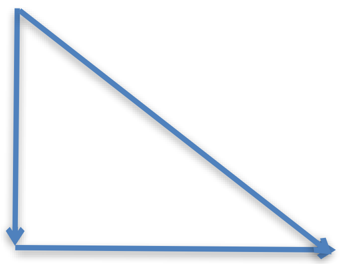
Question 2 **(4 marks)**

Various observations and scientific evidence have been used to put forward the 'Big Bang' theory, a model that describes the formation of the Universe. State and describe two pieces of scientific evidence that **supports** this theory.

Any of: Constantly expanding Universe
Abundance of hydrogen and helium in the Universe
Cosmic Background Radiation
Along with an explanation

Question 3 **(3 marks)**

A rubber bung breaks free in a physics experiment and is moving in a horizontal plane. It travels due west at 5.55 ms^{-1}, strikes the safety glasses of a student and then travels due south at 4.44 ms^{-1}. Calculate the change in velocity of the rubber bung.



Δ v = v-u (√)

Δ v = √($4.44^2 + 5.55^2$)

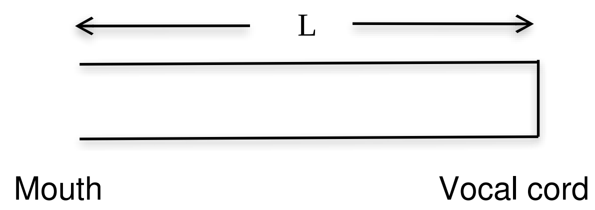
Δ v = 7.11 ms^{-1} (√)

Tan θ = 5.55/4.44 = 51.3°

7.11 ms^{-1} S 51.3° E (√)

Question 4 **(4 marks)**

A tube of length L as shown below can model the human vocal tract, which is open at one end and closed at the other. The fundamental frequency of this tube is 500 Hz.



(a) Calculate the length L of the tube. (2 marks)

Wavelength = Speed/ Frequency = 346 / 500 (1√2)

For fundamental mode of vibration, wavelength = 4 x length (1√2)

Length = (346 / 500) / 4 = 0.173 m (√)

(b) Kylie is rehearsing for a concert. She sings a pure note of a single frequency. The time between successive compressions of the sound wave arriving at her ears is 5 ms.

What is the frequency of the sound? (2 marks)

Period = 5 ms,
Frequency = 1/period (√)

= $1/(5 \times 10^{-3})$ = 200 Hz (√)

Question 5 **(4 marks)**

You need to construct a simple AC generator with an output of 12 V maximum when rotated at 60 Hz. A magnetic field of 0.050 T is available for use. If the area of the rotating coil is 100 cm^2, how many turns are required in your generator?

V = 12V, f = 60Hz, B = 0.050T, A = 100cm^2 = 0.01 m^2 (√)

$\varepsilon = BAN2\pi f$ (√) so $N = \varepsilon/(BA2\pi f)$

$N = 12/(0.05 \times 0.01 \times 2\pi \times 60)$ (√)

N = 63.7 turns = 64 turns (√)

Question 6 **(5 marks)**

A binary system consists of two stars rotating about a point between them. Astronomers note that, for a particular binary system, two stars maintain a constant distance apart of 9.00×10^{11} m and complete one rotation about the point midway between them every 4.36 Earth years. If the stars masses are approximately equal, calculate the mass of each star.

$$F = \frac{G\, m_1 m_2}{(d)^2} = \frac{m_2 v^2}{r} \quad (\surd) \qquad v = s/t = (2\pi r/t)\ (\surd) \quad \text{(NOTE: } d = 2r$$

$$Gm_1 = \frac{4 \times 4\pi^2 r^3}{t^2}\ (\surd) \qquad \text{where } r = (9.00 \times 10^{11})/2$$

$$m_1 = \frac{16\,\pi^2\,(4.5 \times 10^{11})^3}{6.67 \times 10^{-11} \times (4.36 \times 365 \times 24 \times 3600)^2}\ (\surd)$$

$$= 1.14 \times 10^{31}\ \text{kg}\ (\surd)$$

Question 7 **(3 marks)**

A transformer is made up of a primary coil with 60 turns and a secondary coil with 2300 turns. The primary voltage of the transformer is measured at 110 V. Calculate the secondary voltage.

$$\frac{N_S}{N_P} = \frac{V_S}{N_P} \quad (\surd)$$

$2300/60 = V_S/110$

$V_S = (110 \times 2300)/60 \quad (\surd)$

$V_S = 4220$ V $(\surd)$

Question 8 **(3 marks)**

The signal from a microwave transmitter can be thought of as a beam of photons. The photons from a particular transmitter have a wavelength of 3.5×10^{-2} m. Calculate the approximate energy of each photon.

$E = (hc)/\lambda$ (√)

$E = ((6.63 \times 10^{-34}) \times (3 \times 10^{8}))/ (3.5 \times 10^{-2})$ (√)

$E = 5.68 \times 10^{-24}$ J (√)

Question 9 **(4 marks)**

A Boeing 767 airplane with a wingspan of 49.7 m flies horizontally at a location where the vertical component of the Earth's magnetic field is 6.0×10^{-5} T downwards.

(a) Calculate the magnitude of the induced emf between the tips of the wing when the speed of the airplane is 250 ms^{-1}. (3 marks)

$\varepsilon = Blv$ (√)

$\varepsilon = 6.0 \times 10^{-5} \times 49.7 \times 250$ (√)

$\varepsilon = 0.746$ V (√)

(b) If the plane was flying south, on which wing tip will there be a build up of electrons? (1 mark)

West wing

Question 10 **(4 marks)**

Greg has a toy car set that has a loop-the-loop, as shown in the diagram below. Estimate the minimum speed that a 200 g toy car should have at the top of the 50 cm loop to be able to complete the loop-the-loop without dropping off the track.

$F_c = F_N + mg$, $F_N = mv^2/r - mg$ (√)

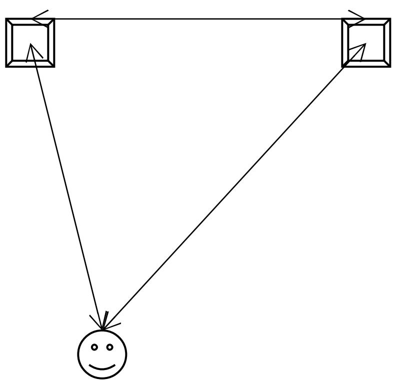
When $F_N = 0$ then $mv^2/r = mg$ (√)

$v^2 = gr$ so $v = \sqrt{(9.8 \times 0.25)}$ (√)

$v = 1.57\ ms^{-1}$ (√)

Question 11 **(4 marks)**

Two loudspeakers 2.50 m apart are connected to separate sounds source that send out identical sound waves 180˚ out of phase. A student stands 3.00 m from one speaker and 3.70 m from the other speaker.



Calculate the lowest frequency from the speakers that will produce a loud spot at this location.

PD = 3.70 - 3.0 m = 0.70 m (√)

Lowest frequency = largest wavelength.

If out of phase to get a loud spot the PD = $n\lambda/2$ so λ= 2 x PD = 2 x 0.7 = 1.40 m (√)

$f = v/\lambda$ (√)

f = 346/1.4

f = 247 Hz (√)

Question 12 **(3 marks)**

An X-ray tube uses a potential of 75kV between the cathode and the target anode to accelerate the thermionic electrons. What will be the kinetic energy (in Joules) of one thermionic electron just as it strikes the target anode?

V = 75kV, q = 1.60×10^{-19} C

W = qV (√)

W = $1.60 \times 10^{-19} \times 75 \times 10^{3}$ (√)

W = 1.20×10^{-14} J (√)

Question 13 **(4 marks)**

Some minerals such as fluorite; *fluoresce* under ultraviolet light. Using an energy level diagram explain what is meant by **fluorescence**.

- Fluorescence is a process that occurs when electrons in the ground state of an atom such as fluorite, absorbs photons of UV light promoting then to higher energy states e.g n = 1 to n = 5.

- The excited electrons then immediately decay back to the ground state by a series of steps (cascade decay) emitting photons of energy e.g. n = 5 to n = 4, n = 4 to n = 3 etc.

- The difference in energy between steps are usually small enough to emit visible photons of light

1 mark for suitable diagram

Question 14 **(4 marks)**

If you photograph the light of stars after it has been passed through a spectroscope, the real colour of the star's surface can be observed. When this technique is used some stars appear to emit more red frequencies, whereas others appear to emit more blue frequencies. Which stars would have the hottest surface temperature? Explain.

Colour is a measure of frequency where frequency is proportional to energy ($E = hf$). (√)

The colour of light is proportional to the temperature of the star's surface. (√)

Red light (700 nm) has a larger wavelength than blue (400 nm) and due to $c = f\lambda$, decreased wavelength means increased frequency. (√)

So blue will be a higher frequency than red so stars emitting blue light have more energy ($E= hf$) so are therefore hotter. (√)

End of Section One

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Section Two: Extended Answer

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

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

Name: ____________________________ Teacher: ____________________

Question 1 **(9 marks)**

On a day with no cross wind an SAS sniper fires a bullet that leaves the gun at 550 ms^{-1} horizontally and is aimed at the mid point of a target that is 150m away, which has a radius of 0.38m.

(a) Will the sniper hit the target? Justify your answer. (5 marks)

Horizontal
t= s/v (√)
= 150/550
= 0.273 s (√)

vertically
$s_v = ut + ½ at^2$ (√)
= 0 + (-0.49) $(0.273)^2$
= -0.364 m which is less than the size of the target of 0.38 m (√)
The bullet hits the target (√)

No marks given for stating 'Yes' if there is no justification of the answer.

(b) The metal bullet has a mass of 5.50 g and is shot West at the Swanbourne Barracks in a region where the Earth's magnetic field is 6.60 x 10^{-5} Tesla at 66° above the horizontal. As the bullet moves through the air, friction causes a charge build up of +2.27 x 10^{-11} C. Calculate the maximum force acting on the bullet due to the Earth's magnetic field. (3 marks)

F = q v B (√)

F = (2.27 x 10^{-11}) (550) (6.60 x 10^{-5} x sin 66) (√)

F = 7.53 x 10^{-13} N (√) 8.24 x 10^{-13} N without sin 66

(c) Which way will the bullet be deflected due to its interaction with the Earth's magnetic field? (1 mark)

North

Question 2 **(9 marks)**

In July 1969 the Apollo 11 Command Module with Michael Collins on board orbited the Moon waiting for the Ascent Module to return from the Moon's surface. The mass of the Command Module was 9.98×10^3 kg, its period was 119 minutes, and the radius of its orbit from the Moon's centre was 1.85×10^6 metres.

(a) Assuming the Command Module was in a circular orbit; **calculate** the magnitude of its orbital velocity. (3 marks)

$v = s/t = 2\pi r/T$ (√)

$v = (2\pi \times 1.85 \times 10^6)/(119 \times 60)$ (√)

$v = 1.628 \times 10^3\ ms^{-1} = 1.63 \times 10^3\ ms^{-1}$ (√)

Use of the mass of Moon from the Formulae and constants sheet is the incorrect method to solve this problem.

(b) Calculate the mass of the Moon. (3 marks)

$F_g = F_c$

$$\frac{GM_M m_{CM}}{R^2} = \frac{m_{CM} v^2}{R} \quad (\surd)$$

$$M_M = \frac{R\,v^2}{G} \qquad M_M = ((1.85 \times 10^6 \times (1.628 \times 10^3)^2)/(6.67 \times 10^{-11}) \quad (\surd)$$

$M_M = 7.37 \times 10^{22}$ kg (√)

No marks given if there is no calculation to determine answer

(c) When the Ascent Module docked with the Command Module there was an increase in the mass of the orbiting spacecraft. The 'docked' spacecraft remained at the same altitude. Docking made no difference to the orbital speed. Justify this statement. (3 marks)

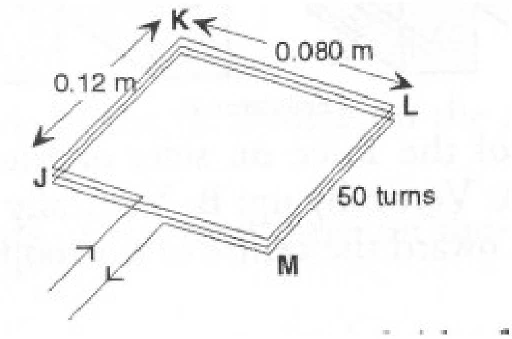
The orbital speed is due to the gravitational attraction of the command module to the mass of the moon (√)

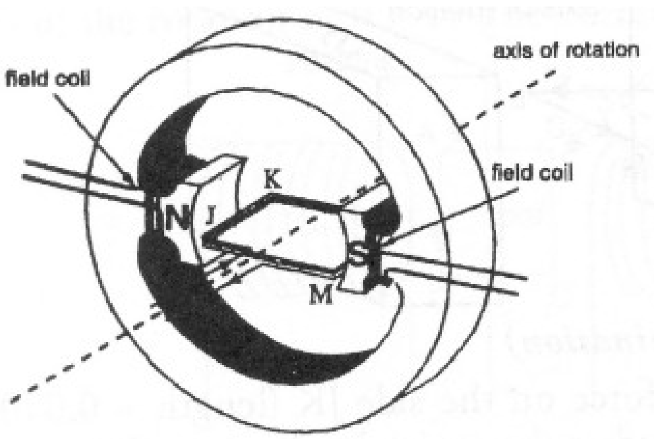
$(v = \sqrt{(GM_M/R)})$ (√)

Therefore the mass of the command module and the ascent module has no effect on the orbital speed. (√) or similar justification.

Question 3 **(14 marks)**

Two students examine a DC motor from a toy car. They find it has an armature consisting of a rectangular coil with 50 turns as shown below. The armature is in the field of a two-pole magnet with a magnetic field of 0.2 T.





(a) If the motor draws 4.00 A at normal speed, what is the maximum torque experienced by the motor and its initial direction of rotation? (4 marks)

τ = BAIN (√)

τ = 0.2 x 4.0 x 0.12 x 0.08 x 50 (√)

τ = 0.384 Nm (√) in an anticlockwise direction (√)

(b) A split-ring commutator is an integral component in a DC motor. Explain the function and purpose of a split-ring commutator. (2 marks)

- The split ring commutator enables a change in the direction of the current every half cycle
- to ensure that torque continues to rotate the coil in the same direction

(c) The students notice that when the motor is put under load, the current in the motor increases. Explain this observation. (4 marks)

There is an emf induced in the coil as the motor turns, as the flux through the coil changes. According to Lenz's Law the emf acts in the direction opposite to the applied emf.

When the motor is put under load, the rate at which the flux is cut decreases as the motor is turning more slowly.

The back emf decreases as the speed decreases, increasing the effective emf

Using V = IR, with a constant resistance the current in the armature must increase as the emf (V) has increased.

(d) If the motor operates on 8.00 V and develops a 6.50 V back emf at normal speed, what current does it draw when starting? (4 marks)

$\varepsilon_{app} - \varepsilon_{back} = IR$ (√)

$8.0 - 6.50 \text{ V} = 4R$

$1.5/4 = R$, $R = 0.375\ \Omega$ (√)

When starting $\varepsilon_{back} = 0$ V (√)

$\varepsilon_{app} = IR$, $8.0 = I \times 0.375$

$I = 21.3$ A (√)

Question 4 **(14 marks)**

Rory is driving his car of mass 1.20 tonne with a constant speed of 36 kmh^{-1}. He encounters a bend that has a radius of 25.0 m along a flat piece of road.

(a) Calculate the force of friction between the tyres and the road. (3 marks)

velocity = 36 kmh^{-1} = 10.0 ms^{-1}

$F_F = ma = mv^2/r$ (√)

$= 1200 \times 10^2/25$ (√)

$F_F = 4.80 \times 10^3$ N (√)

(b) If the speed of the car is constant explain how the car 'accelerates' around the bend. (3 marks)

- Velocity is a vector and although the speed is constant the direction has changed therefore there is a change in velocity.
- Acceleration is the rate of change of velocity
- and since the velocity has changed the car is accelerating.

Or similar correct explanation

(c) Explain how the 'banking' of a bend can affect the speed at which the car can safely negotiate the bend, particularly if the car is travelling at high speed on a country road. (3 marks)

- When the road is horizontal the centripetal force is provided by friction alone
- When the road is banked the normal reaction of the road on the car has a component towards the centre of the bend contributing to the centripetal acceleration of the car,
- This reduces the reliance on the frictional force for centripetal force and hence decreases the probability of skidding making it safer to negotiate the bend.

Or similar correct explanation

(d) Calculate the angle of bank required for Rory's car to travel around a bend of 100 m radius when travelling at 100 kmh^{-1}. (5 marks)

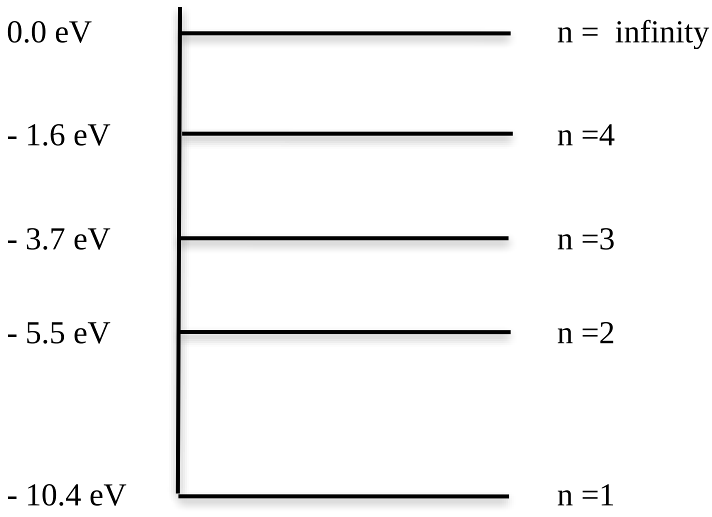
100 kmh^{-1} = 100/3.6 = 27.8 ms^{-1} (√)
$R\sin\theta = mv^2/r$ (1√2) $R\cos\theta = mg$ (1√2)

So $\tan\theta = v^2/rg$ (√)
[NOTE: using just this formulae to calculate the answer is not sufficient to get full marks]

$\tan\theta = (27.8)^2/(100 \times 9.8)$ (√) The angle of banking is $\theta = 38.2^\circ$ (√)

Question 5 **(13 marks)**

The diagram below shows the energy levels of a mercury atom.



(a) An electron in the ground state is struck by another electron that has 7.2 eV of kinetic energy.

(i) What maximum electron transition can occur in this instance? (1 mark)

Maximum transition would be n = 1 to n = 3

(ii) Calculate the remaining kinetic energy of this electron after the collision? (2 marks)

n = 1 to n = 3 10.4 - 3.7 = 6.7 eV (√)

7.2 - 6.7 = 0.5 eV (√)

(b) Calculate the minimum frequency of a photon that could ionise this atom from its ground state. (3 marks)

Ionising requires 10.4 eV = 10.4 x 1.60 x 10^{-19} = 1.664 x 10^{-18} J (√)

E = hf (√)
f = E/h f = (1.664 x 10^{-18})/(6.63 x 10^{-34})

f = 2.51 x 10^{15} Hz (√)

(c) How many lines will appear in the absorption spectra of this atom? (2 mark)

4 lines

(c) Determine the possible energy levels (in eV) of the photons emitted by the mercury atom as it returns from its ionised state. (5 marks)

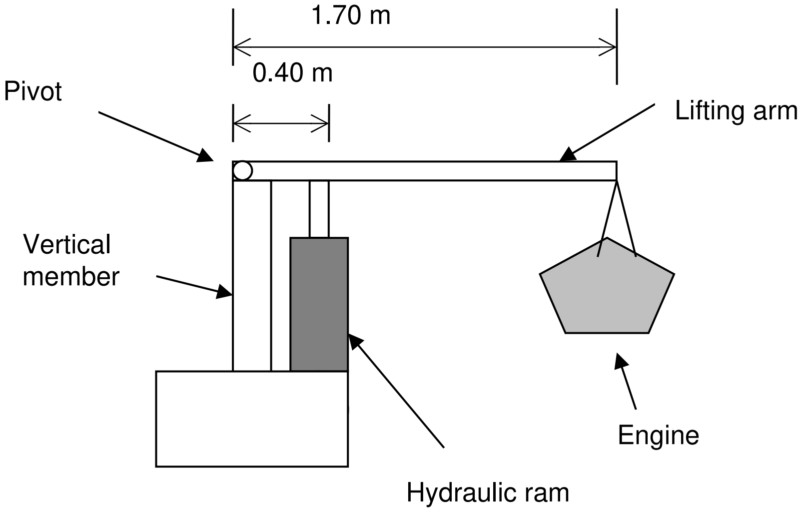
Possible energy levels are:

n = α to n = 1	10.4 eV
n = α to n = 2	5.5 eV
n = α to n = 3	3.7 eV
n = α to n = 4	1.6 eV
n = 4 to n = 1	8.8 eV
n = 4 to n = 2	3.9 eV
n = 4 to n = 3	2.1 eV
n = 3 to n = 1	6.7 eV
n = 3 to n = 2	1.8 eV
n = 2 to n = 1	4.9 eV

-1/2 mark for each missing or incorrect

Question 6 **(14 marks)**

A hoist is used to lift diesel engines from trucks. A hydraulic ram applies a force vertically upwards on a 10kg lifting arm, which lifts the engine from the truck body.



(a) Calculate the force exerted by the hydraulic ram when holding an engine of mass 1100 kg in the **horizontal** position shown. (5 marks)

$\Sigma \tau = 0$

$\Sigma \tau_{cw} = \Sigma \tau_{ccw} = 0$ (√)

$\Sigma \tau_{cw} = (10 \times 9.8 \times 0.85) + (1100 \times 9.8 \times 1.70)$ (√)

$\Sigma \tau_{cw} = 18409.3$ Nm (√)

$\Sigma \tau_{ccw} = 18409.3 = (F_{HR} \times 0.4)$ (√)

$F_{HR} = 18409.3/0.4 \quad = 4.60 \times 10^4$ N up (√)

-1/2 if no direction stated

(b) Is the vertical member in compression or tension? Briefly explain your answer. (3 marks)

- The hydraulic ram acts as the pivot with the engine and CoM of lifting arm providing a clockwise torque (√)
- This torque acts on the vertical member to pull it in a clockwise direction (as in a see saw) (√)
- So the vertical member must be under tension (√)

[NOTE: The base to which the vertical member is attached will provide a counter torque to stop the hoist from toppling.]

(c) If the lifting arm is raised to make an angle of 30˚ above the horizontal position shown, calculate the reaction force the pivot exerts on the lifting arm. (6 marks)

$\Sigma\tau = 0$ so $\Sigma\tau_{CW} = \Sigma\tau_{CCW}$ and $\Sigma F = 0$ then ΣF_H and $\Sigma F_V = 0$

$\Sigma\ \tau_{cw} = (10 \text{ x } 9.8 \text{ x } 0.85 \text{ x } \cos 30) + (1100 \text{ x } 9.8 \text{ x } 1.70 \text{ x } \cos 30)$ (√)
$\Sigma\ \tau_{cw} = 15942.9$ Nm (√)

$\Sigma\ \tau_{ccw} = 15942.9 = (F_{HR} \text{ x } 0.4 \cos 30)$ (√)

$F_{HR} = 15942.9/(0.4 \text{ x } \cos 30) = 4.60 \text{ x } 10^4$ Nm up (√)

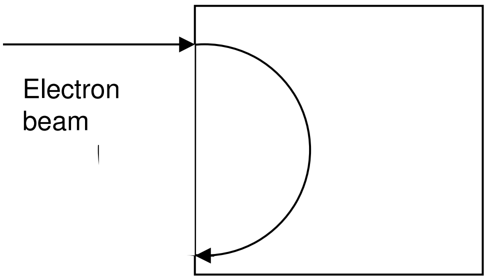
$\Sigma F_V = (1100 \text{ x } 9.8) + (10 \text{ x } 9.8) - 46023 + F_{RV} = 0$
$F_{RV} = 35145$ N down (√)

$\Sigma F_H = 0$ as there are no horizontal components acting

Therefore the reaction force on pivot is $3.5 \text{ x } 10^4$ N (√)

Question 7 **(10 marks)**

A beam of electrons is fired into an evacuated chamber with a velocity of 1.33×10^8 ms^{-1}, as shown in the diagram below. A magnetic force field of flux density 5.15×10^{-3} T makes the electrons move in a semicircle and hit the chamber wall at point P?



(a) What is the direction of the magnetic field needed to make the electrons move in this path? (1 mark)

Into the page

(b) Calculate the magnitude of the force that acts on each electron. (3 marks)

F = qvB (√)
$F = 1.6 \times 10^{-19} \times 1.33 \times 10^8 \times 5.15 \times 10^{-3}$ (√)
$F = 1.10 \times 10^{-13}$ N (√)

(c) Describe the path an electron would take if it entered the evacuation chamber at a higher velocity. Justify your description with an explanation. (2 marks)

The magnetic field exerts a centripetal force on the electron such that $mv^2/r = qvB$.
Rearranging r = mv/qB (√)

As v increases r must also increase as r is proportional to v (√)

(d) Describe the changes that would need to be made in order to make a proton fired into the chamber at a similar velocity of 1.33×10^8 ms^{-1}, arrive at point P. Justify you answer with an explanation. (4 marks)

• A proton would require the magnetic field to be reversed (√) as it has the opposite charge to an electron, i.e. out of the page (√)
• A proton has greater mass (approx. 2000 times heavier) than an electron (√) and as r = mv/qB, for a constant r, v and magnitude of q, the magnetic field B must be approximately 2000 times greater. (√)

Question 8 **(7 marks)**

Two physics students set up an air column in a 1.20 m pipe. Using a 440 Hz tuning fork they measure the sound intensity levels at different points inside the pipe. Starting at one end of the pipe they found:

(i) maximum intensities at 0.00 m, 0.40 m, and 0.80 m
(ii) minimum intensities at 0.20 m and 0.60 m

(a) Using **only** the information provided above determine the wavelength of the sound. (2 marks)

The internodal distance is $\lambda/2$ (√)

$0.4 = \lambda/2$ so $\lambda = 2 \times 0.4 = 0.8$ m (√)

(b) Determine the speed of sound in this experiment. (2 marks)

$v = f\lambda$ (√)

$v = 440 \times 0.8 = 352 \text{ ms}^{-1}$ (√)

(c) Explain whether the students were using an open or closed pipe. (3 marks)

- A maximum intensity will also occur at 1.20 m, the length of the pipe
- This means maximum intensities (displacement antinodes) occur at both ends of the pipe
- Therefore the pipe must be open as if it were closed there should be a single maximum intensity (displacement antinode) at one end of the pipe only.

Or similar suitable justification that shows that displacement antinodes occur at either end of an open pipe.

End of Section Two

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Section Three: Comprehension and Data Analysis

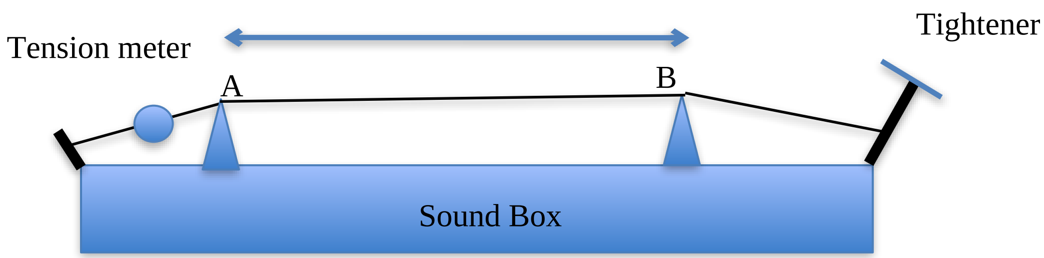
This section has **(2)** questions. Answer **both** questions. Write your answers in the space provided.

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

Name: ____________________________ Teacher: ____________________

Question 1 **(17 marks)**

The device shown below is used for studying sound produced by a wire that has been stretched and under tension.



The wire is stretched between 2 points A and B, a distance of 'x' meters apart. On the left end near A is a tension meter. On the right past B, the wire is attached to a tightener, a handle that can be used to tighten the wire. The wire can be set vibrating and its frequency is then measured. In an experiment using this apparatus students collected the following measurements.

Frequency 'f' (Hz)	Tension 'T' (N)	f^2
100	110	1.00×10^4
150	260	2.25×10^4
200	450	4.00×10^4
250	700	6.25×10^4
300	1020	9.00×10^4
350	1380	1.23×10^5
400	Wire broke	1.60×10^5

The relationship between tension (T) and frequency (f) is given by

$$T = l^2 \mu f^2$$

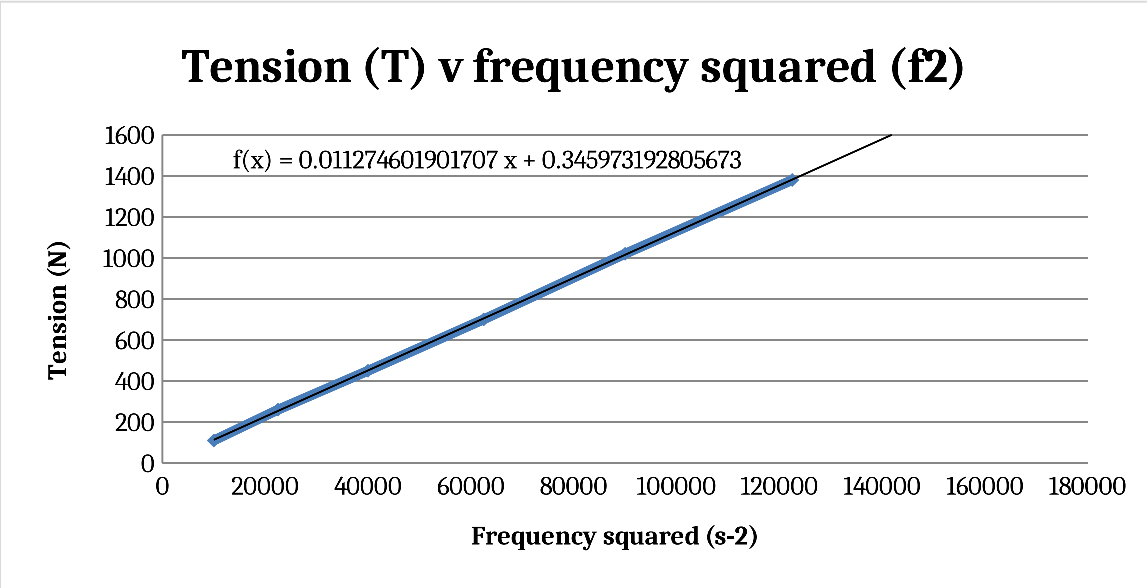
Where 'l' is the length of the wire and 'μ' is the linear density of the wire.

(a) Complete the table. (3 marks)

1 mark unit (s^{-2}), -1/2 mark each error

(b) Construct a graph of 'T' versus 'f^2' on the graph paper provided. (5 marks)

Title – 1 mark, Axes labels and units – 1 mark, Correct Points Plotted – 1 mark
Line of Best Fit - 1 mark Linear Scale - 1 mark



(c) Determine the gradient of the graph. (3 marks)

Triangle – 1 mark Value – 1 mark (approx. 1.13×10^{-2})
Units – 1 mark (Ns^2)

(d) Using the equation, to what is the gradient equivalent. (1 mark)

The gradient is equivalent to $l^2\mu$

(e) Given that l is 0.750 m, calculate μ, the linear density of the wire for this particular experiment. (5 marks)

Gradient = $l^2\mu$ (√)

$1.13 \times 10^{-2} = l^2\mu$ (√)

$\mu = 1.13 \times 10^{-2}/(0.75^2)$ (√)

$\mu = 0.020$ kg m^{-1} (√ value, √ unit)

Question 2 **(19 marks)**

The Helium – Neon Laser. Modified from http://repairfaq.cis.upenn.edu/Misc/laserhen.htm

The term laser stands for "Light Amplification by Stimulated Emission of Radiation". However, lasers as most of us know them, are actually sources of light - oscillators rather than amplifiers.

All materials exhibit what is known as bright line spectra when excited in some way. In the case of gases, this can be an electric current or (RF) radio frequency field. In the case of solids like ruby, a bright pulse of light from a xenon flash lamp can be used. The spectral lines are the result of spontaneous transitions of electrons in the material's atoms from higher to lower energy levels. A similar set of dark lines result in broadband light that is passed through the material due to the absorption of energy at specific wavelengths. Only a discrete set of energy levels and thus a discrete set of transitions are permitted based on quantum mechanical principles. The entire science of spectroscopy is based on the fact that every material has a unique spectral signature.

The HeNe laser depends on energy level transitions in the neon gas. In the case of neon, there are dozens if not hundreds of possible wavelength lines of light in this spectrum. Some of the stronger ones are near the 632.8 nm line of the common red HeNe laser - but this is not the strongest:

The strongest red line is 640.2 nm. There is one almost as strong at 633.4 nm. That's right, 633.4 nm and not 632.8 nm. The 632.8 nm one is quite weak in an ordinary neon spectrum, due to the high energy levels in the neon atom used to produce this line. There are also many infra-red lines and some in the orange, yellow, and green regions of the spectrum as well.

The helium does not participate in the lasing (light emitting) process but is used to couple energy from the discharge to the neon through collisions with the neon atoms. This pumps up the neon to a higher energy state resulting in a population inversion meaning that more atoms in the higher energy state than the ground or equilibrium state.

It turns out that the upper level of the transition that produces the 632.8 nm line has an energy level that almost exactly matches the energy level of helium's lowest excited state. The vibrational coupling between these two states is highly efficient.

You need the gas mixture to be mostly helium, so that helium atoms can be excited. The excited helium atoms collide with neon atoms, exciting some of them to the state that radiates 632.8 nm. Without helium, the neon atoms would be excited mostly to lower excited states responsible for non-laser lines.

The most common and least expensive HeNe laser by far is the one called 'red' at 632.8 nm. However, all the others with named 'colours' are readily available with green probably being second in popularity due to its increased visibility (near the peak of the of the human eye's response curve (555 nm). And, with some HeNe lasers with insufficiently narrow-

band mirrors, you may see 640 nm red as a weak output along with the normal 632.8 nm red because of its relatively high gain. There are even tunable HeNe lasers capable of outputting any one of up to 5 or more wavelengths by turning a knob.
When the HeNe gas mixture is excited, all possible transitions occur at a steady rate due to spontaneous emission. However, most of the photons are emitted with a random direction and phase, and only light at one of these wavelengths is usually desired in the laser beam. At this point, we have basically the glow of a neon sign with some helium mixed in!
To turn spontaneous emission into the stimulated emission of a laser, a way of selectively amplifying one of these wavelengths is needed and providing feedback so that a sustained oscillation can be maintained. This may be accomplished by locating the discharge between a pair of mirrors forming what is known as a Fabry-Perot resonator or cavity. One mirror is totally reflective and the other is partially reflective to allow the beam to escape.

These mirrors are normally made to have peak reflectivity at the desired laser wavelength. When a spontaneously emitted photon resulting from the transition corresponding to this peak happens to be emitted in a direction nearly parallel to the long axis of the tube, it stimulates additional transitions in excited atoms. These atoms then emit photons at the same wavelength and with the same direction and phase. The photons bounce back and forth in the resonant cavity stimulating additional photon emission. Each pass through the discharge results in amplification - gain - of the light. If the gain due to stimulated emission exceeds the losses due to imperfect mirrors and other factors, the intensity builds up and a coherent beam of laser light emerges via the partially reflecting mirror at one end. With the proper discharge power, the excitation and emission exactly balance and a maximum strength continuous stable output beam is produced.

Spontaneously emitted photons that are not parallel to the axis of the tube will miss the mirrors entirely or will result in stimulated photons that are reflected only a couple of times before they are lost out the sides of the tube. Those that occur at the wrong wavelength will be reflected poorly if at all by the mirrors and any light at these wavelengths will die out as well.

(a) Explain what is meant by “The entire science of spectroscopy is based on the fact that every material has a unique spectral signature”. (3 Marks)

• The science of spectroscopy is based on the idea that atoms emit or absorb photons of light when electrons are excited to higher energy levels or when the excited electrons return from higher to lower energy levels.
• There are only a discrete set of energy level transitions possible based on quantum mechanical principles.
• This means that every element or compound has its own distinctive emission or absorption spectra that acts like a fingerprint for the material.

(b) Compare the process of producing spontaneously emitted photons and the process of producing stimulated emitted photons. (4 marks)

• Spontaneously emitted photons occurs by electrons absorbing photons of energy and becoming excited then emitting light as the electron decays back to a lower energy level from the higher excited state.
• This is a random process.
• Stimulated emitted photons occur when specific energy emissions are selectively amplified to maintain a sustained oscillation.
• Under specific conditions this emission stimulates other excited atoms to emit photons of the specific energy emission, which is not a random process.

(c) If Helium gas is not used in the lasing process, what is its role in the production of laser light? (4 marks)

• The helium atoms are used to couple energy from the discharge to the neon atoms
• through collisions with the neon atoms.
•This increases the neon to higher energy state where more atoms of the higher energy state exist rather than the lower equilibrium state.
• Without the helium the neon atoms would mostly be excited to a lower state than would result in non-laser lines.

(d) Explain the significance of the wavelength 632.8 nm. (3 marks)

• The wavelength 632.8 nm is the one required to achieve a red HeNe laser
• The upper level of the transition that produces the 632.8 line in neon atoms has an energy level that almost exactly matches the energy level of helium's lowest excited state.
• The vibrational coupling between these two states is highly efficient.

(e) What is the corresponding gap in energy levels of the atom, for the wavelength 632.8 nm? State your answer in electron Volts. (2 marks)

$E = hc/\lambda$

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}} \ (\surd)$$

$E = (3.14 \times 10^{-19})/(1.60 \times 10^{-19})$ $= 1.96$ eV ($\surd$)

(f) How do the Mirrors enable laser light to form for a particular wavelength? (3 marks)

- The mirrors are designed so that they can have peak reflectivity for the laser wavelength desired.
- The mirror reflects the selected wavelength backwards and forwards in the resonating cavity
- stimulating additional emissions that are moving in the same direction and in phase, thus producing a coherent and amplified beam of laser light of maximum energy output

END OF SECTION THREE

END OF EXAMINATION