WESLEY COLLEGE

ATAR Physics Year 12

Semester Two Examination, 2016

Question/Answer Booklet

Student Name: Solutions

Time allowed for this paper

Reading time before commencing work: 10 minutes

Working time for paper: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer Booklet and the Formulae and Constants Sheet

To be provided by the candidate

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction tape/fluid, eraser, ruler, highlighters

Special items: non-programmable calculators approved for use in the WACE examinations, 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 unauthorised 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	**Marks Attained**
Section One: Short answers	13	13	54	54 (30%)	/54
Section Two: Problem-solving	7	7	90	90 (50%)	/90
Section Three: Comprehension	2	2	36	36 (20%)	/36
				180 (100%)	/180

Instructions to candidates

Write your answers in the spaces provided beneath each question. The value of each question (out of 150) is shown following each question.

The enclosed Physics: Formulae and Constants Sheet may be removed from the booklet and used as required.

Calculators satisfying conditions set by the Curriculum Council may be used to evaluate numerical answers.

Answers to questions involving calculations should be evaluated and given in decimal form. Give final answers to three significant figures and include appropriate units where applicable.

When calculating numerical answers, show your working or reasoning clearly. Despite an incorrect final answer, credit may be obtained for method and working, providing this is clearly and legibly set out.

Questions containing specific instructions to **show working** should be answered with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show working will not be awarded full marks.

Questions containing the instruction **estimate** may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of two significant figures and include appropriate units where applicable.

SECTION ONE: Short Response — 54 marks (30%)

This section has **15** questions. Answer **ALL** questions. Write your answers in the spaces provided.

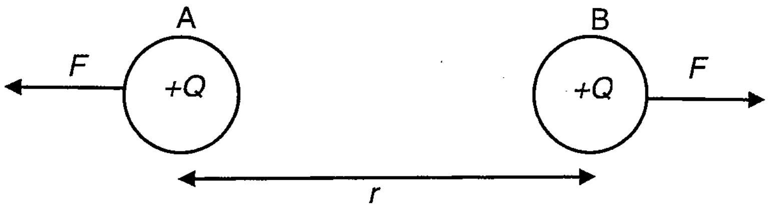
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

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

Question 1 **(3 marks)**

The two spheres A and B below are both given a charge *+Q*. They are separated by a distance *r*. The repulsive force between them is *F*.



When the charge on A is doubled the repulsive force between them is

doubled   halved   unchanged   (circle the correct response).   (1 mark)

When the charge on both spheres is doubled the repulsive force (compared to *F*) is

doubled   increased by a factor of four   increased by a factor of eight   (1 mark)

(circle the correct response)

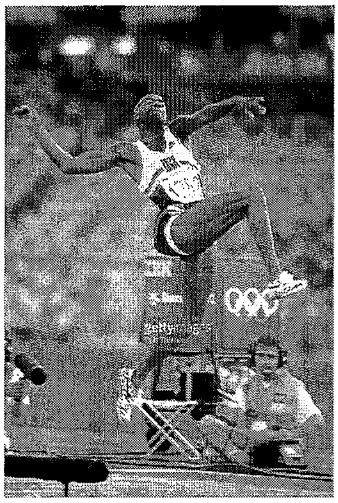
When the charge on both sphere is *+Q*, but the separation of the spheres is doubled to 2r, the repulsive force (compared to *F*) is

unchanged   decreased by a factor of two   decreased by a factor of four   (1 mark)

(circle the correct response)

Question 2 **(4 marks)**

A long jumper at the Rio Olympics launches himself into the air at a speed of 11.0 m/s and an angle of 22.5° to the horizontal in an attempt to beat the long distance world record of 8.95 metres. Show by calculation whether or not he is successful.



time to jump $\frac{2 \times 11 \sin 22.5^\circ}{9.8} = 0.86\text{s}$ (2)

distance travelled $11.00 \times \cos 22.5 \times 0.86$

$= 8.74\text{m}$ (2)

unsuccessful

Question 3 **(4 marks)**

The relatively nearby star Tau Ceti, lies 11.9 light-years from Earth. An interstellar spaceship from Earth is travelling to Tau Ceti at 90% of the speed of light.

(a) How far away is Tau Ceti (in light-years) to the astronauts on the spaceship? (2 marks)

length contraction

$L = 11.9 \times \sqrt{1 - \frac{v^2}{c^2}}$

$= 11.9 (1 - 0.9^2)^{\frac{1}{2}}$ (1)

(1)

Distance 5.19 light years

(b) How long will the spaceship take to reach Tau Ceti

(i) from the reference frame of the astronauts on the spaceship? (1 mark)

$\text{time} = \frac{\text{distance}}{\text{speed}} = \frac{5.19}{0.9}$

Time 5.76 years

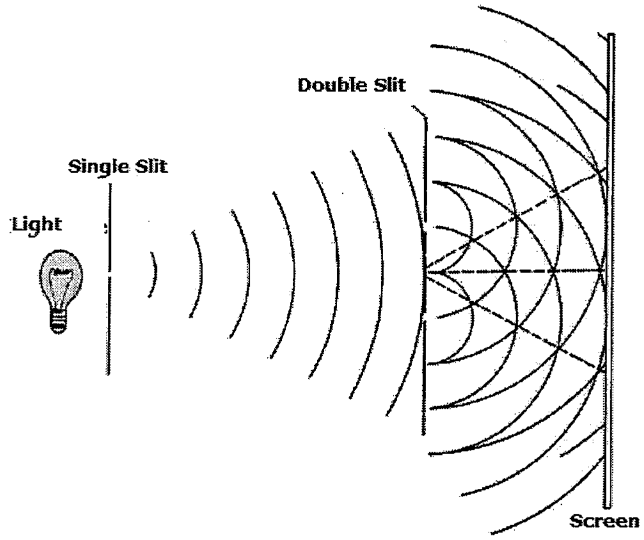
(ii) from the reference frame of observers on Earth? (1 mark)

$\frac{11.9}{0.9}$

Time 13.2 years

Question 4 **(3 marks)**

The diagram below illustrates Young's double-slit experiment. Briefly describe the experiment, what is observed on the screen, and what we can infer about the nature of light from the observations.



(1) light was diffracted through the single slits and then again through the double slit

(1) a series of dark and light bands is observed on the screen

(1) this is an example of interference

(1) light has wavelike properties

Question 5 **(5 marks)**

A satellite orbits the Earth in a circular orbit at an altitude of 4000 km. Calculate

(a) the centripetal acceleration experienced by the satellite. (3 marks)

$$a_c = g = \frac{GM}{r^2} = \frac{6.67\times10^{-11} \times 5.97\times10^{24}}{(6.37\times10^6 + 4\times10^6)^2} \quad (1)$$

(1)

Acceleration 3.70 m s^{-2}

(b) the orbital speed of the satellite. (2 marks)

$$a_c = \frac{v^2}{r} \qquad v = \sqrt{a_c r}$$

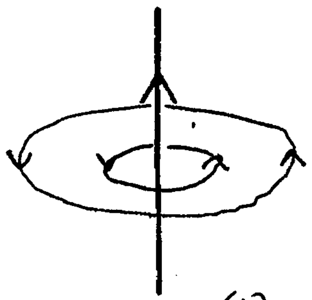
$$= \sqrt{3.7\times(6.37\times10^6 + 4\times10^6)}$$

Speed 6.2×10^3 m s^{-1}

Question 6 **(4 marks)**

The diagram below show a long straight vertical wire (diagram A) an arrow indicates the direction of the current through the wire.

A



(1) direction
(1) circular shape

(a) Sketch on the diagram the magnetic field produced by the current in the wire. (2 marks)

(b) The magnetic field strength is found to be 45 µT at a perpendicular distance of 1.75 cm from the long straight wire. Calculate the size of the current in the wire. (2 marks)

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$ $\quad \frac{B 2\pi r}{\mu_0} = I$ $\quad \frac{45\times10^{-6} \times 2\pi \times 0.0175}{4\pi \times 10^{-7}}$ (1)

Current 3.94 A
(1)

Question 7 **(4 marks)**

A proton is accelerated in the Large Hadron Collider at CERN in Geneva up to 99.995% of the speed of light. At this speed, calculate

(a) the momentum of the proton (2 marks)

$p_r = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1.67\times10^{-27} \times 3\times10^8 \times 0.99995}{\sqrt{1 - 0.99995^2}}$ (1)

(1)
Momentum 5.01×10^{-17} kg m s^{-1}

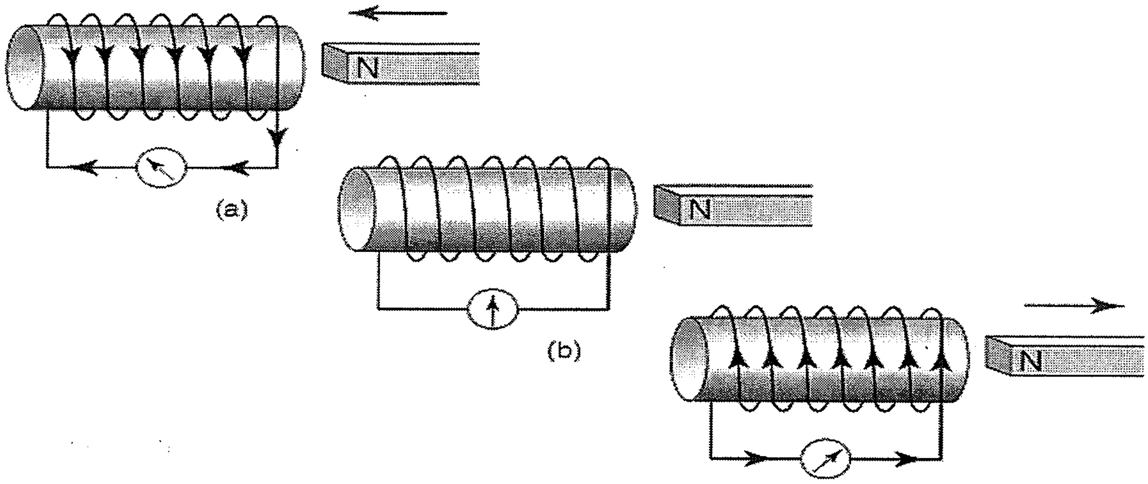
(b) the wavelength of the proton (2 marks)

$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{5.01\times10^{-17}}$ (1)

(1)
Wavelength 1.32×10^{-17} m

Question 8 **(4 marks)**

The diagrams below show the interaction between a bar magnet and a solenoid in three different situations. The needle of the galvanometer, shown below the solenoid, indicates any flow of current.



Briefly explain the following observations:

(a) No current flows (diagram b) when the magnet is held stationary near the solenoid. (1 mark)

- there is no change in flux

(b) The current flows in opposite directions in diagrams (a) and (c) when the magnet is pushed towards, then pulled away from the solenoid. (3 marks)

induced current always flows in a direction such that its magnetic field opposes the flux change that generated it (1)

when the magnet is pushed towards the magnet the change in flux is in the opposite direction to when it is pulled away (2)

so current must flow in opposite directions

Question 9 **(4 marks)**

A photoelectric cell contains an aluminium electrode that is illuminated with ultraviolet light of wavelength 284 nm. The work function of aluminium is 4.08 eV. Calculate the kinetic energy of the emitted photoelectrons.

energy of incident photon in eV $E = \frac{hc}{\lambda e} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{284\times10^{-9}\times1.6\times10^{-19}}$

$= 4.38\text{eV}$ (2)

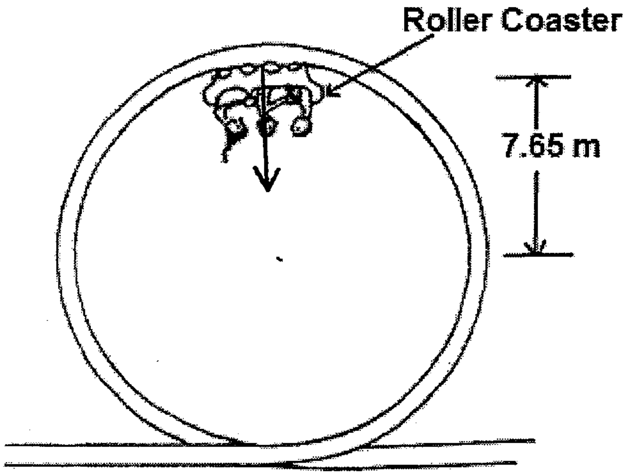
$E_k = E_{photon} - \text{workfunction} = 4.38 - 4.08 = 0.3\text{eV}$ (1)

$0.3\text{eV} \times 1.6\times10^{-19}$

Kinetic Energy 4.8×10^{-20} J

Question 10 **(6 marks)**

A roller coaster car with three passengers has a total mass of 9.73 x 10^2 kg. The participants experience being upside down at the top of the circular track of a "loop the loop" showground ride. The centre of mass of the car and passengers is 15.3 m from the bottom of the ride. It is travelling at a constant speed of 12.3 m s^{-1}.



a) On the diagram above **draw** an arrow to show the direction of the force of the rail acting on the car and passengers. (1 mark)

b) Calculate the magnitude of the force that the rails at the top of the ride exerts on the car and passengers. (5 marks)

$F_c = W + R$ (1)

$\frac{mv^2}{r} = mg + R$ (1)

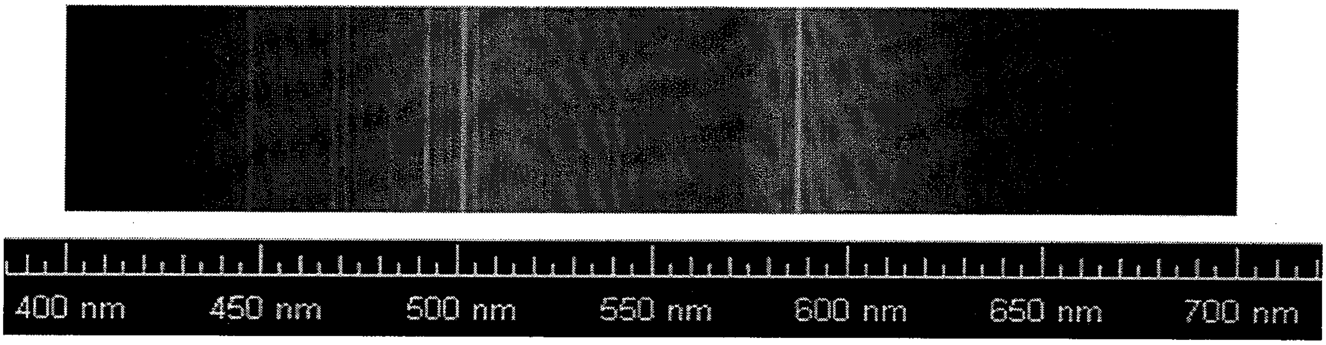
$\frac{mv^2}{r} - mg = R$ (1) (1) $\frac{9.73\times10^2\times12.3^2}{7.65} - 9.73\times10^2\times9.8$ (1)

$= 9707\text{N}$

Force 9710 N

Question 11 **(4 marks)**

Observations of the luminosity of a supernova in a distant galaxy indicate that it is 1.6×10^8 light years away from Earth. Analysis of the helium spectrum from the supernova shows that the yellow line that usually occurs at a wavelength of 587.6 nm was measured for this galaxy to be at 595.3 nm. This indicates that the supernova and galaxy are moving with a velocity of 1% of the speed of light.



Explain what has caused the yellow line to be recorded at a longer wavelength and how this provides evidence for the Big Bang Model for the origins of the Universe.

(1) the wavelength of the yellow line is bigger indicating that it has been red-shifted

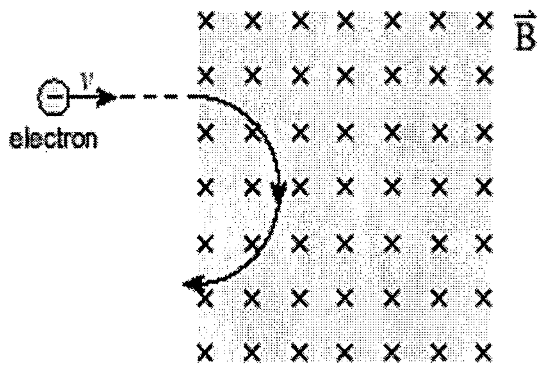
(1) red-shift indicates that the galaxy is moving away

(1) this provides evidence because it suggest that at some point in the past this galaxy was much closer

(1) it suggests the universe is expanding → Big Bang

Question 12 **(5 marks)**

An electron is fired into a uniform perpendicular magnetic field of strength 230 μT and follows a semi-circular path through the magnetic field of radius 350 mm, as illustrated at right.



(a) Calculate the speed of the electron in the magnetic field. (2 marks)

$r = \frac{mv}{qB}$ $v = \frac{rqB}{m} = \frac{350\times10^{-3}\times1.6\times10^{-19}\times230\times10^{-6}}{9.11\times10^{-31}}$ (1)

$= 1.41\times10^{7}\ ms^{-1}$ (1)

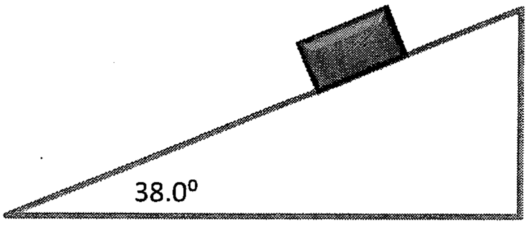
(b) Determine the potential difference through which the electron was accelerated from rest (before reaching the magnetic field) in order to have this speed. (3 marks)

$W = Vq = \Delta E_k = \frac{1}{2}mv^2$ (1)

~~$\frac{2Vq}{m}$~~ $V = \frac{mv^2}{2q} = \frac{9.11\times10^{-31}\times(1.41\times10^{7})^2}{2\times1.6\times10^{-19}}$ (1) $= 566\ V$ (1)

Question 13 **(4 marks)**

A block of mass 12.0 kg is sliding down a rough inclined plane. The angle of inclination is 38.0° and the force of friction acting on the block from the plane is 24.4 N.



Calculate the acceleration of the block down the inclined plane.

force down the plane due to gravity = $mg\sin\theta$ = 12×9.8×sin38° = 72.4 N (1)

net force down the plane = 72.4 − 24.4 = 48 N (1)

acceleration = $\frac{F}{m} = \frac{48}{12}$ = 4 (1)

Acceleration 4 (1) m s^{-2}

End of Section One

SECTION TWO: Problem-solving **90 marks (50%)**

This section has **7** questions. Answer **ALL** questions. Write your answers in the spaces provided.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

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

Question 14 **(13 marks)**

Kepler-186f is one of five planets found in an extrasolar system located about 490 light-years from Earth. The newly discovered exoplanet orbits about 52.4 million kilometres from its sun. It takes Kepler-186f about 130 days to orbit its red dwarf star. Kepler-186f is the first Earth-size alien planet found in the habitable zone of its star. That means the planet, which is about 10% larger in diameter than Earth, is in the part of its solar system where liquid water could exist on the planet's surface. An artist's impression of the planet's surface is shown at right.

(a) What is the orbital speed of Kepler-186f? (2 marks)

$v = \frac{2\pi r}{t} = \frac{2\pi \times 52.4 \times 10^9}{130 \times 24 \times 3600}$ (1)

$= 2.93 \times 10^4 \ ms^{-1}$

(1)

Speed 2.93×10^4 m s^{-1}

(b) Is Kepler-186f accelerating? Explain. (2 marks)

Yes (1)

it keeps changing direction so keeps changing velocity, a change in velocity is an acceleration.

(c) From the orbital data about Kepler-186f and your answer to part (a), calculate the mass of its red dwarf sun. (3 marks)

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2} \qquad M = \frac{r^3 4\pi^2}{G T^2} = \frac{(52.4\times10^9)^3 \times 4\pi^2}{6.67\times10^{-11}\times(130\times24\times3600)^2}$$

(1) (1)

(1)

Mass 6.75×10^{29} kg

(d) Kepler -186f has a diameter approximately 10% larger than Earth's. Assuming that Kepler-186f has a similar density to Earth, determine a value for its mass based upon the estimate of its size given above. Express your answer using appropriate significant figures.

(3 marks)

mass = density × volume = density × $\frac{4}{3}\pi r^3$

mass (186f) = mass (Earth) × 1.1^3

$= 6\times10^{24} \times 1.1^3$

1 or 2 sig figs (1)

Mass 8×10^{24} kg

(e) Calculate a value for the gravitational force between Kepler-186f and its sun. (3 marks)

$$F = \frac{G m_1 m_2}{r^2} = \frac{6.67\times10^{-11}\times 6.75\times10^{29} \times 8\times10^{24}}{(5.24\times10^{10})^2}$$

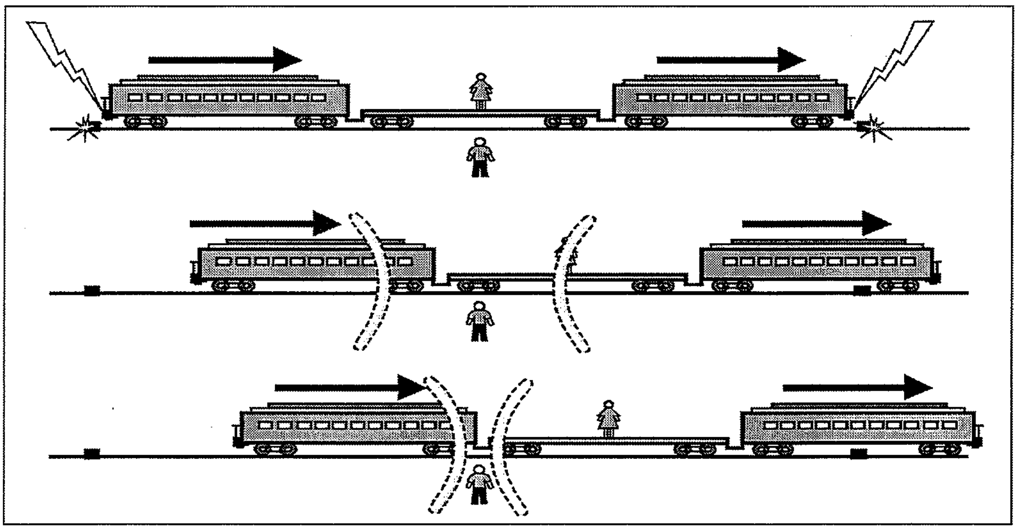
(2)

(1)

Force 1.3×10^{23} N

Question 15 **(8 marks)**

The series of diagrams below show a very fast train, with a woman standing on an open carriage, speeding at a relativistic velocity past a man standing on the ground next to the train tracks. Just as the train passes the man, two bolts of lightning strike the front and rear of the train. The woman observes that the lightning strike at the front of the train occurs before that on the rear.



(a) What is the order in time of the two lightning strikes according to the man standing on the ground? (1 mark)

he sees them occuring at the same time - simultaneously

(b) Whose interpretation of events is correct, the man's or the woman's? Briefly explain. (2 marks)

both are equally correct (1)

each person is in an inertial reference frame & according to the postulates of special relativity no inertial reference frame (1) is preferred to any other

(c) How do you explain the woman's observations? (2 marks)

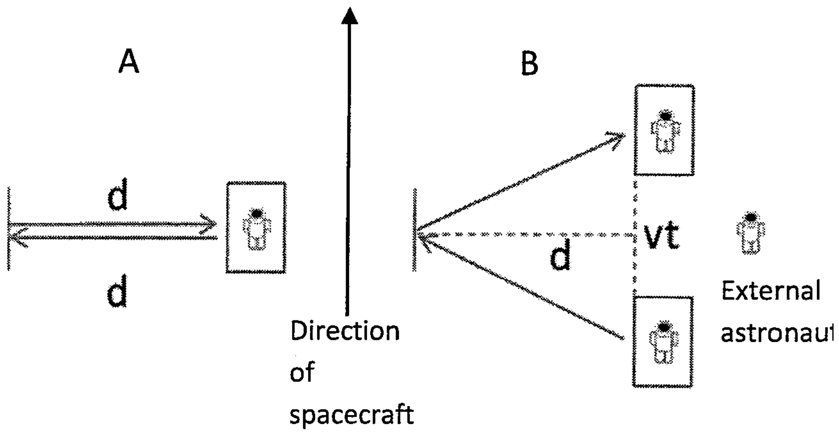
(1)

because the woman is moving to the right the wavefronts from the lightning bolt at the front of the train reach her before the wavefronts from the rear which have to travel further

(1)

In a futuristic scenario, an astronaut aboard a spacecraft travelling at a speed of close to the speed of light conducts a simple experiment (diagram A), by shining a beam of light onto a mirror that is a distance d away, and timing how long the reflection takes to return to her. Her value for the time taken by the light to travel to the mirror and back is

$$t_0 = {}^{2d}/_{c} \qquad \text{(equation 1)}$$



While she conducts this simple experiment, a second astronaut external to the spacecraft observes the experiment as the spacecraft speeds past at velocity v. He sees the beam of light follow the path shown in diagram B due to the motion of the spacecraft.

(c) Show that the time he measures for the light travelling to the mirror and back is given by the expression. You must show all the steps in your reasoning. (3 marks)

$$t = \frac{2\sqrt{d^2+\frac{1}{4}v^2t^2}}{c} \qquad \text{(equation 2)}$$

the light in B travels 2 lengths of a hypotenuse of a triangle which has sides d and $\frac{vt}{2}$

(1) so length of hypotenuse $= \left(d^2 + \left(\frac{vt}{2}\right)^2\right)^{\frac{1}{2}} = \left(d^2 + \frac{v^2t^2}{4}\right)^{\frac{1}{2}}$

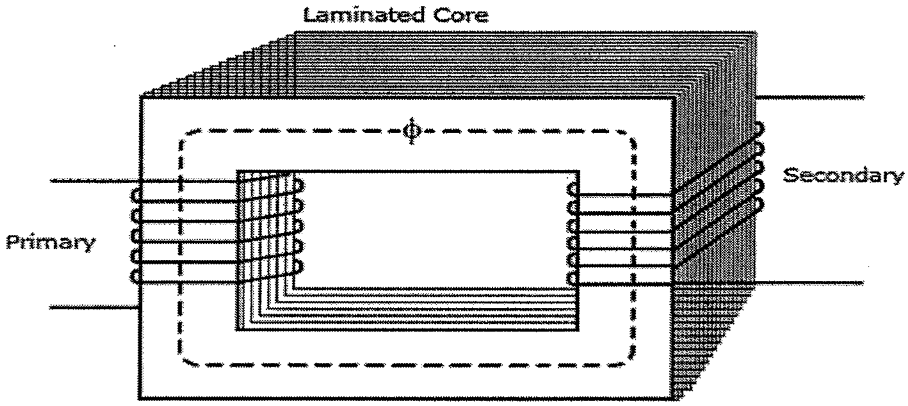
(1) but light travels 2 of them $2\left(d^2 + \frac{v^2t^2}{4}\right)^{\frac{1}{2}}$

(1)

time $= \frac{\text{distance}}{\text{speed}} = \frac{2\left(d^2 + \frac{v^2t^2}{4}\right)^{\frac{1}{2}}}{c}$

Question 16 **(12 marks)**

The diagram below shows an iron-cored transformer



(a) The primary coil is connected to an alternating current. Explain how energy is transferred from the primary coil to the secondary coil, with reference to *Faraday's Law of electromagnetic induction.* (4 marks)

(1) the alternating current in the coil produces magnetic flux that continually changes size and direction

(1) this ~~flu~~ changing flux causes changing magnetisation in the core

(1) due to faraday's law this changing flux ~~caus~~ induces a current in the secondary coil ~~becau~~

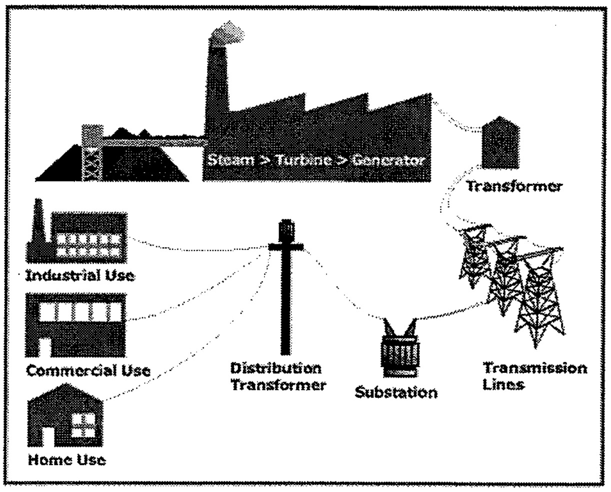
(1) this is a transfer of energy via changing flux

(b) What is a ***laminated*** core, and what is its purpose? (2 marks)

thin slices of iron glued with an ^slices of an^ electrical insulator

to reduce eddy currents so reduce energy loss

In order to transmit electric power more efficiently, an electricity company uses transformers and high voltage transmission lines to transmit power at 330 kV from the power station to the city 200 km away. The average output power of its generators is 600 MW. The high voltage transmission lines have a total resistance of 5.00 Ω over their 200 km length.



(c) Calculate the voltage at the end of the transmission lines (before the substation) after transmission along the high voltage lines? (4 marks)

current in lines $\frac{P}{V} = I$ $\frac{600\times10^6}{330\times10^3} = 1820A$ (1)

power loss $P = I^2R = 1820^2 \times 5 = 1.66\times10^7 W$ (1)

power at end $= 600\times10^6 - 1.66\times10^7 = 5.83\times10^8 W$ (1)

$\frac{5.83\times10^8}{1820}$ (1)

Voltage 321 kV

(d) Calculate the percentage power loss in the high voltage transmission lines. (2 marks)

$\frac{1.66\times10^7}{600\times10^6} \times 100 = 2.77\%$

(1)

(1)

% loss 2.77

Question 17 **(14 marks)**

Fermions are matter particles in the Standard Model. Leptons and Quarks are Fermions. Hadrons are made from quarks. A Baryon is made from 3 quarks and a Meson from 2 quarks. The anti-particle versions of Leptons each have a Lepton number of -1 and opposite charge. All Leptons have a Baryon number of zero.
Tables of some particles and their properties are shown below.

Lepton	Charge (q_e)	Lepton number	Baryon Number
Electron	-1	1	0
Electron-neutrino	0	1	0
Muon	-1	1	0
Muon-neutrino	0	1	0
Tau	-1	1	0
Tau-neutrino	0	1	0

Quark	Charge (q_e)	Baryon number
Up (u)	$+\frac{2}{3}$	$\frac{1}{3}$
Down (d)	$-\frac{1}{3}$	$\frac{1}{3}$
Top (t)	$+\frac{2}{3}$	$\frac{1}{3}$
Bottom (b)	$-\frac{1}{3}$	$\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$	$\frac{1}{3}$
Strange (s)	$-\frac{1}{3}$	$\frac{1}{3}$

Hadron	Quarks	Mass (MeV/c²)	Baryon Number	Lepton number
Proton	uud	938.3	+1	0
Neutron	udd	939.6		0
Pion-plus (π^+)	$u\bar{d}$	139.6	0	0
Sigma-plus	uus	1189.4	+1	0
Charmed Omega	ssc	1672.0	+1	0

a) List two ways that a lepton differs from a quark. (2 marks)

- low mass
- are fundamental particles (no substructure) any 2
- no interactions due to strong nuclear force

b) Determine the Baryon number of a neutron. Show your working. (1 mark)

B number $u = \frac{1}{3}$ $d = \frac{1}{3}$ $\frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1$

c) Determine the electric charge of a Charmed-Omega hadron. Show your working. (2 marks)

s s c

charge $-\frac{1}{3} - \frac{1}{3} + \frac{2}{3} = 0$

(1) (1)

d) Consider the proposed reactions below –

A proton decays to a positron and a pion-plus meson $p \rightarrow e^{+} + \pi^{+}$

A neutron decays to a proton, an electron and an anti-neutrino. $n \rightarrow p + e^{+} + \bar{v}$

Using your knowledge of conservation laws in the Standard Model determine whether the reactions can occur or not. Show all your reasoning. (6 marks)

$p \rightarrow e^{+} + \pi^{+}$

charge $p = +1$
$e^{+} = +1$ (1)
$\pi^{+} = +1$

charge is not conserved (1)
so reaction does not occur (1)

[similar argument with baryon number $p = 1$ $e^{+} = 0$ $\pi^{+} = 0$]

$n \rightarrow p + e^{+} + \bar{v}$

charge $n = 0$
$p = 1$
(1) $e^{+} = 1$
$\bar{v} = 0$

(1) charge is not conserved so reaction does not occur (1)

[Baryon number is conserved
Lepton number is not conserved]

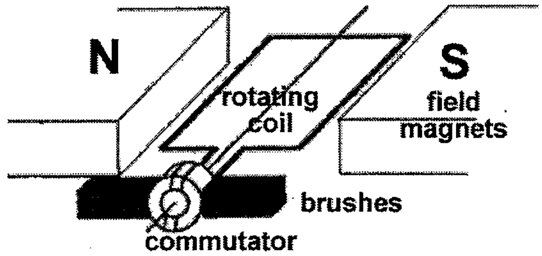
e) Determine the mass of a Charmed-omega hadron in kilograms using scientific notation to 3 significant figures. (3 marks)

mass $= 1672 \frac{MeV}{c^2}$

Mass ____________________ kg

Question 18 **(17 marks)**

A typical DC electric motor is shown at right. The coil contains 250 turns and has dimensions of 8.00 cm in length by 5.00 cm in width. The field magnets produce a uniform magnetic field of strength 0.0240 T in which the coil rotates.



(a) Explain the purpose of the commutator and brushes. (2 marks)

(1) – the brushes provide a sliding electrical contact to the commutator

(1) – the commutator reverses the current direction every ½ turn

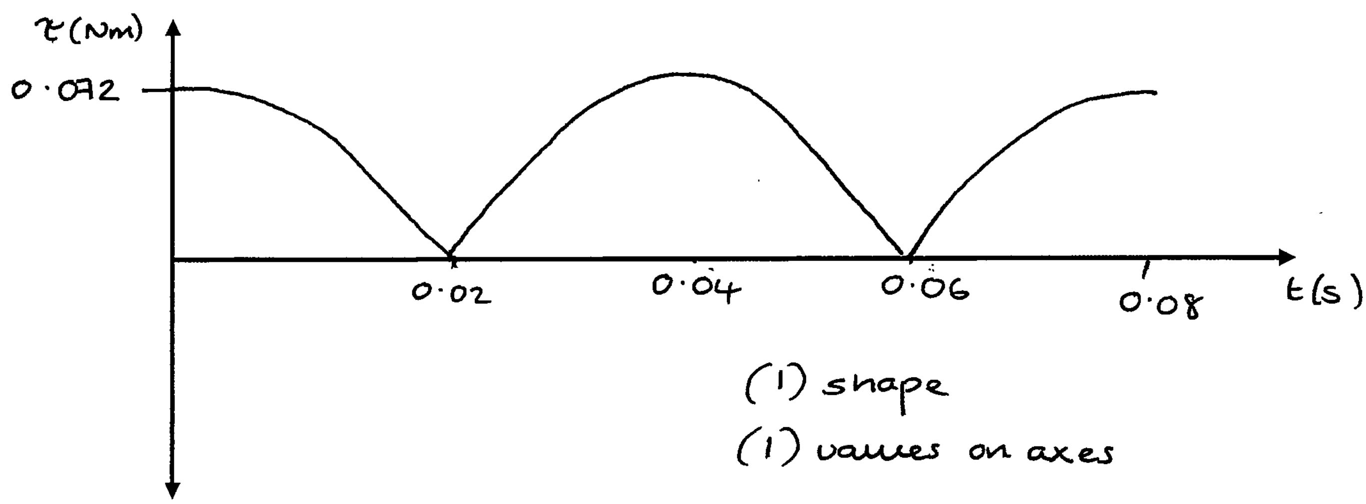
(b) Describe two ways that an *actual* electric motor would differ from the one shown in the diagram above. (2 marks)

Any 2
- curved magnetic poles
- electromagnets for poles rather than permanent magnets
- multiple armatures ~~tr~~ rather than single coil
- segmented comutator rather than split ring

(c) When in operation under load, the motor rotates at a steady rate of 750 rpm (revolutions per minute) and draws a current of 3.00 A. On the axes below, sketch the torque produced by the motor over a full rotation of the coil, starting from the position shown in the diagram above. Include appropriate scales on both axes. (6 marks)

$f = 750\text{ rpm} = \frac{750}{60} = 12.5\text{ Hz}$ $T = \frac{1}{12.5} = 0.08\text{ s}$ (1)

max torque $\tau = NIAB = 250 \times 3 \times (0.08 \times 0.05) \times 0.024 = 0.072\text{ Nm}$ (2)



(1) shape

(1) values on axes

(d) Even when under no load at all, the motor has a maximum rotational speed that it can reach. Explain why this is so, with reference to Faraday's Law and Lenz's Law. (4 marks)

as the motor gains speed due to the torque produced by the interactio
(1) between the current and the magnetic field, the coil cuts magnetic flux

(1) according to Faraday's Law, the changing magnetic flux through the coil will induce an emf in the coil

(1) this induced emf will act so as to oppose the external emf that is driving the motor (Lenz's Law)

(1) as the motor speeds up the induced emf (back emf) will increase until it balance the external emf at which point the motor has reached its maximum rotational speed

(e) Determine the maximum rotational speed of the motor (in rpm) when connected to a 6.00 V battery and operating under no load. (3 marks)

maximum speed occurs when back emf = 6.00V (1)

$$\mathcal{E}_{rms} = \frac{2\pi NBAf}{\sqrt{2}}$$

$$f = \frac{\sqrt{2}\,\mathcal{E}_{rms}}{2\pi NBA} = \frac{\sqrt{2} \times 6.00}{2\pi \times 250 \times 0.024 \times (0.08 \times 0.05)} \quad (1)$$

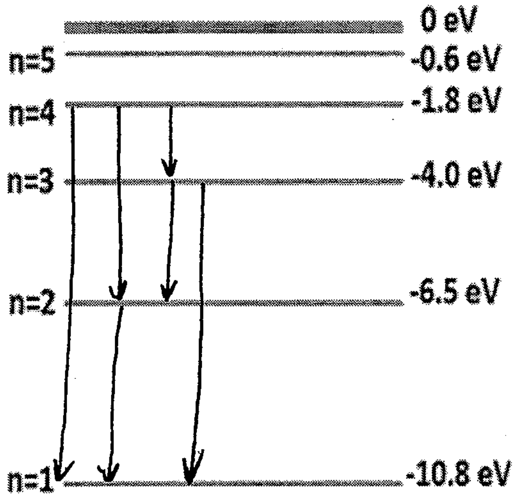
$$f = 56.3\,Hz = 3380\,rpm$$

(1)

Rotational speed 3380 rpm

Question 19 **(12 marks)**

The figure at right illustrates some of the valence electron energy levels in a gaseous atom of a particular element. The energies of the levels are given in electron volts (eV).



(a) The valence electron of the atom is in the lowest energy level shown. What is the ionisation energy of the atom in joules? (2 marks)

ionisation energy = 10·8eV (1)

$10 \cdot 8 \times 1 \cdot 6 \times 10^{-19}$

Ionisation energy $1 \cdot 73 \times 10^{-18}$ J (1)

(b) State two physical processes by which an electron in the ground state can move to a higher energy level. (2 marks)

Any two
- absorption of a photon of energy exactly equal to the energy level difference
- bombardment by an electron with sufficient K.E. to excite the atom
- thermal excitation whereby if the sample of gas is hot enough then atomic collisions may be energetic enough to excite atoms

A cold gaseous sample of the element is bombarded by electrons of energy 9.5 eV and observed to emit electromagnetic radiation.

(c) Show on the diagram above the energy level transitions that cause this emission of electromagnetic radiation. (2 marks)

(d) Calculate the longest wavelength of the emitted electromagnetic radiation. (3 marks)

Longest wavelength of radiation = smallest energy = 2·2eV (1)

$$\lambda = \frac{hc}{E} = \frac{6 \cdot 63 \times 10^{-34} \times 3 \times 10^{8}}{2 \cdot 2 \times 1 \cdot 6 \times 10^{-19}} \quad (1)$$

(1)

Wavelength $5 \cdot 65 \times 10^{-7}$ m

Invisible ultraviolet light of photon energy 6.8 eV is shone through a cold gaseous sample of the element, which then fluoresces and is observed to glow with a turquoise-blue light.

(e) Calculate the frequency of the turquoise-blue light. (3 marks)

6.8 eV excites atoms to level $n=3$

$n=3$ to $n=2$ releases photon with 2.5 eV – visible light (1)

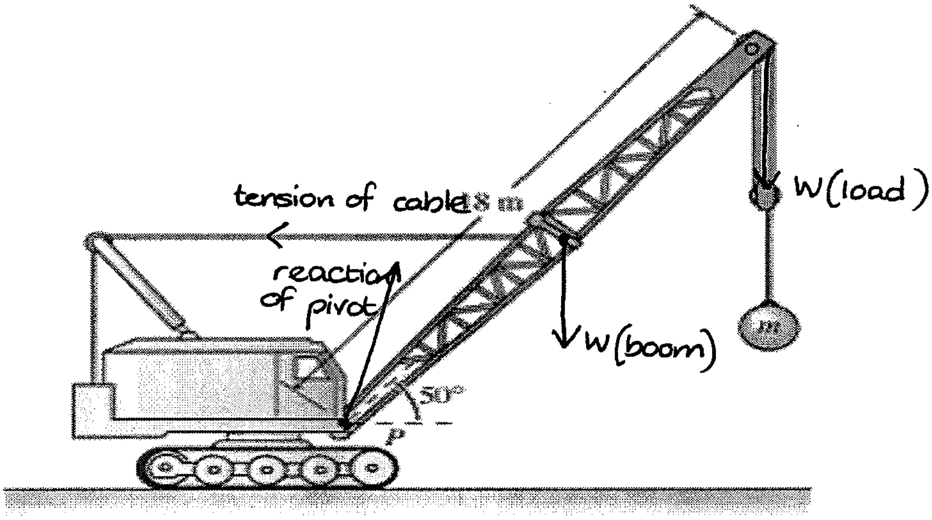
$$f = \frac{E}{h} = \frac{2.5 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$$ (1)

(1)

Frequency 6.03×10^{14} Hz

Question 20 **(14 marks)**

A mobile crane is used to lift a load m of mass 1600 kg, as shown in the diagram below. The 18 m long boom (crane arm) has a mass of 850 kg, centred halfway along its length, and can pivot about point P at its base.



(a) Clearly show all forces acting on the boom as labelled arrows on the diagram. (2marks)

½ mark each

(b) A horizontal steel cable connects to the boom 8.00 m from the pivot P. Show that the tension in the cable needed to hold the boom stationary is 37 500 N. (4 marks)

take moments about the pivot at point P $\sum \tau_{cw} = \sum \tau_{acw}$ (1)

$(850 \times 9.8) \times 9\sin 40° + (1600 \times 9.8) \times 18\sin 40° = F_T \, 8\sin 50°$

(1) (1)

$F_T = 37\ 500$ N

(c) Determine the magnitude and direction of the reaction force provided by the pivot P on the boom. (4 marks)

horizontal $R_H = F_T = 37500 N$ (1)

vertical $R_v = w_{load} + w_{boom} = 15680 N + 8330 N = 24000 N$ (1)

$R = (R_H^2 + R_v^2)^{\frac{1}{2}} = (37500^2 + 24000^2)^{\frac{1}{2}} = 44500 N$

$\tan\theta = \frac{R_v}{R_H} = \frac{24000}{37500}$ $\theta = 32.7°$

(1)

Magnitude 44 500 N

(1)

Direction 32.7 °

(d) The boom is lifted to a more vertical position.

i) At the instant the boom is first moved upwards, the tension in the cable (compared to the value in part (a))

(Increases) Decreases Stays the same (circle the correct answer) (1)

Explain your answer. (2 marks)

need a greater torque to accelerate the combined mass of the boom + load from their stationary positions (1)

(ii) when the boom is held stationary again in a new more vertical position, the tension in the cable (compared to the value in part (a))

Increases (Decreases) Stays the same (circle the correct answer) (1)

Explain your answer. (2 marks)

the clockwise torque due to the weight forces of the boom and load decrease because their perpendicular distances to the pivot have decreased (1)

End of Section Two

SECTION THREE: Comprehension and data analysis **36 marks (20%)**

This section has 2 questions. You must answer both questions. Write your answers in the spaces provided.

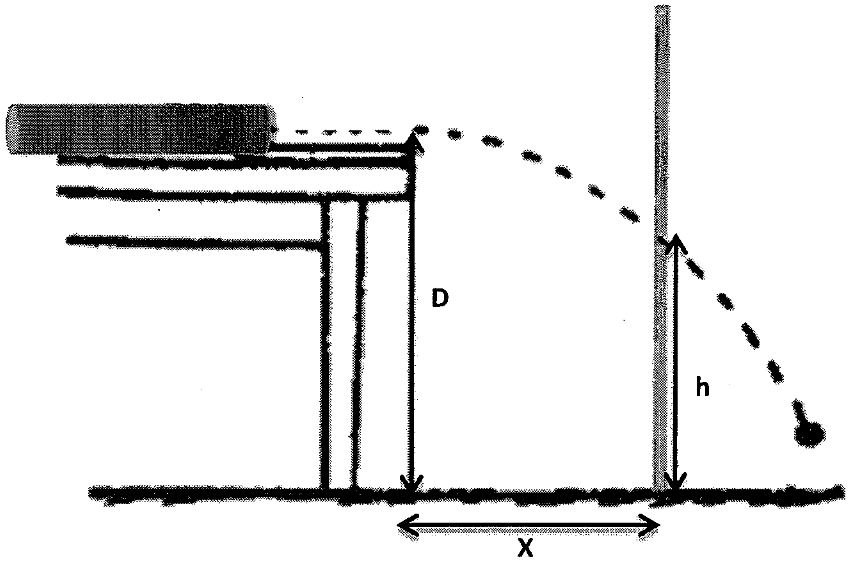
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time: **40 minutes.**

Question 21 **PROJECTILE LAUNCHER EXPERIMENT** **21 marks**

A group of students conducted an investigation into projectile motion where they used a projectile launcher to shoot a ball bearing off the edge of a table of height **D**, at a variety of different speeds **u**. For each trial they measured its height **h** above the floor, after it had travelled a fixed distance **X** horizontally from the edge of the table, by videoing the ball bearing as it passed a meter ruler set up as shown below.



The table below shows the data they gathered over several trials, where they used successively larger launch speeds **u** and measured the height **h** at which the ball bearing passed by the ruler.

Launch speed **u** (m s^{-1})	Height (m)	$1/u^2$ (m^{-2} s^{-2})
1.6	0.11	0.39
2.0	0.40	0.25
2.4	0.56	0.17
2.8	0.66	0.13
3.2	0.72	0.10
3.6	0.76	0.08

The general relationship between vertical displacement Y, horizontal displacement X and speed u for an object launched at angle θ to the horizontal is given by

$$Y = (tan\theta)X + \frac{gX^2}{2u^2(cos\theta)^2}(equation\ 1)$$

The relationship the students deduced linking speed u and height h for their experiment was

$$h = \frac{-4.9X^2}{u^2} + D(equation\ 2)$$

(a) Show how the students deduced their modified relationship, equation 2, for a launch angle of 0° from equation1. You must show all the steps in your reasoning. (3 marks)

$Y = (\tan\theta)X + \frac{gX^2}{2u^2(\cos\theta)^2}$ when $\theta = 0°$ $\tan\theta = 0$ so $(\tan\theta)X = 0$

$\cos\theta = 1$

$Y = \frac{gX^2}{2u^2}$ $\frac{9.8}{2} = 4.9$ $Y = D - h$

$D - h = \frac{gX^2}{2u^2}$ $D - h = \frac{4.9X^2}{u^2}$ $h = D - \frac{4.9X^2}{u^2}$ → equation 2

(b) Complete the third row of the column. Use an appropriate number of significant figures. (2 marks)

1 for values

1 for 2 sig figs

(c) Draw a graph of h on the y-axis and $1/u^2$ on the x-axis. (an additional copy of the graph paper is available at the back of this paper if needed). Draw a line of best fit.

mark scheme for graph with graph (4 marks)

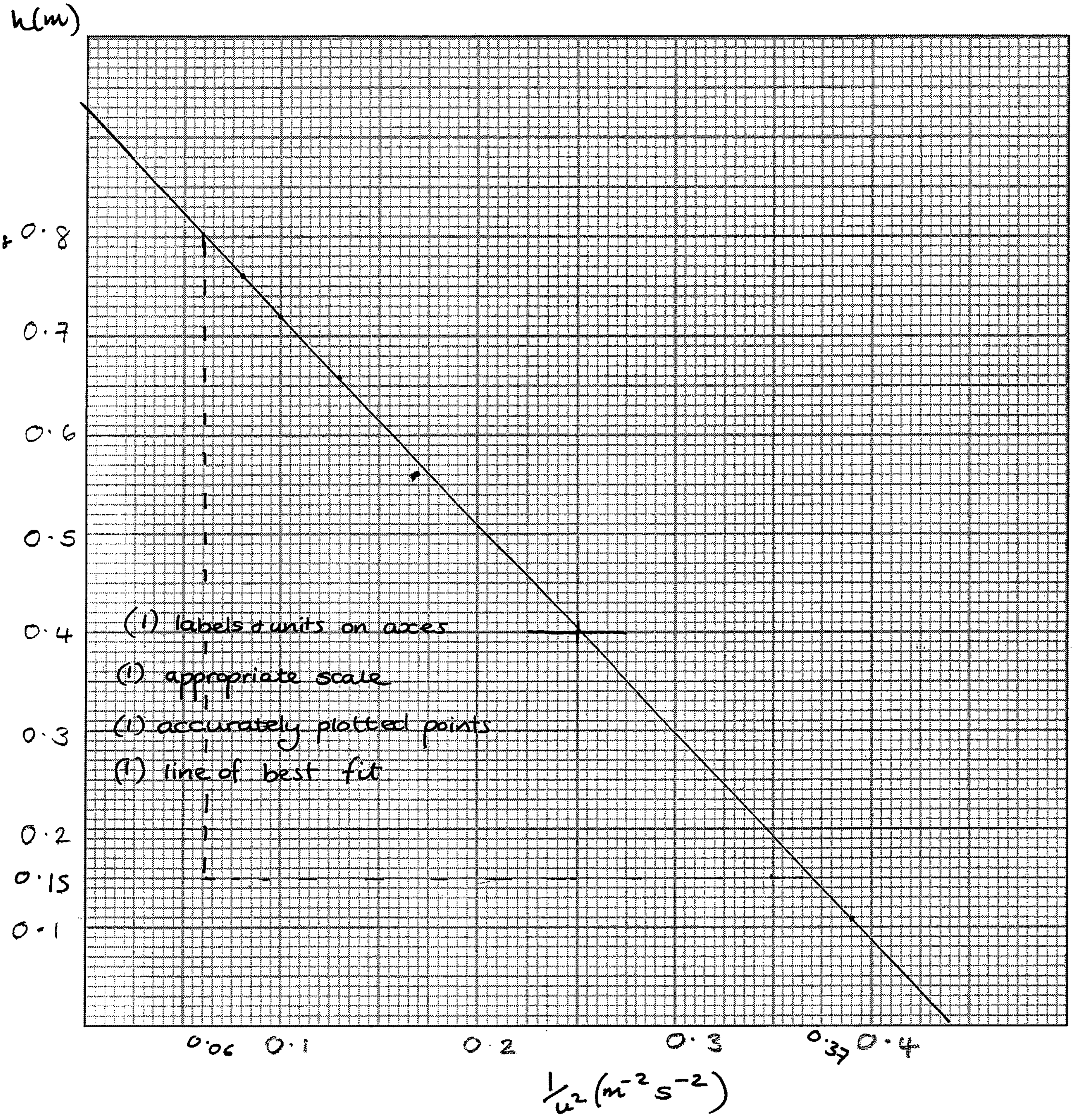
(d) The students estimated that their values for height h were accurate to ± 1 cm while the launch speed u was accurate to ± 0.1 m/s. Using these estimates calculate the **uncertainty** in both the vertical and horizontal variables and **plot** error bars on the graph, for the point where height h = 40 cm **only**. (3 marks)

h = 40cm = 0.4 m ± 0.01m

% error of u $= \frac{0.1}{2}$ 5% so % error in u^2 = 10%

$u^2 = 0.25 \pm 0.025$ } (2)

plotted on graph (1)



(e) Determine the gradient of the graph. You must show on your graph how you have determined the gradient and include the unit for the gradient. Use an appropriate number of significant figures. (4 marks)

(1) indication of values used from graph ← allow a range

$$\frac{0 \cdot 15 - 0 \cdot 8}{0 \cdot 37 - 0 \cdot 06} = \frac{-0 \cdot 65}{0 \cdot 31} = -2 \cdot 1 \ m^3 s^{-2}$$

(1) (1)

sig figs no more than 2 (1)

(f) Calculate the fixed distance X that the ball bearing travelled horizontally from the edge of the table. (2 marks)

$$h = \frac{-4\cdot 9X^2}{u^2} + D$$

$$\text{gradient} = -4\cdot 9X^2$$

$$-2\cdot 1 = -4\cdot 9X^2 \quad (1)$$

$$X = \sqrt{\frac{2\cdot 1}{4\cdot 9}} = 0\cdot 65\text{cm} \ (1)$$

(g) From your graph, find

(i) the height D of the table (1 mark)

vertical intercept 0·93m (1)

(ii) the minimum launch speed needed for the ball bearing to reach the metre ruler while still in the air (before hitting the floor) (2 marks)

minimum launch speed $h = 0$ (1)

~~[illegible]~~ so $D = \frac{4\cdot 9X^2}{u^2}$

$$u = \sqrt{\frac{4\cdot 9X^2}{D}} = \sqrt{\frac{4\cdot 9\times 0\cdot 65^2}{0\cdot 93}} = 1\cdot 5\text{ms}^{-1}$$

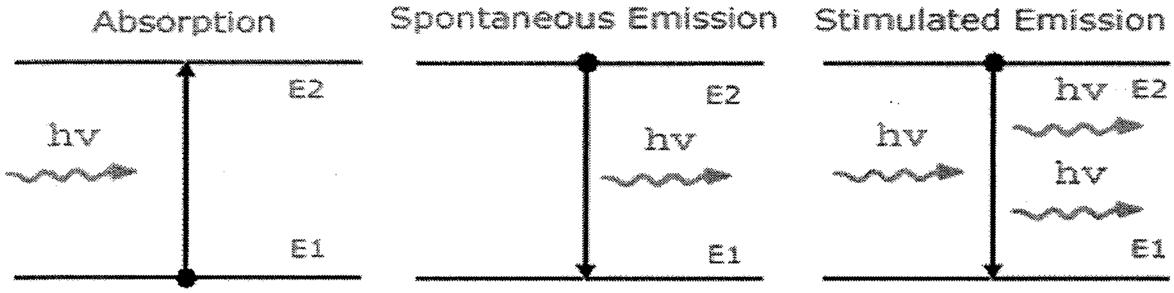
(1)

Question 22 **LASERS** **(15 marks)**

The word 'laser' stands for 'Light Amplification by Stimulated Emission of Radiation'. A laser is an instrument made of a certain material that can be stimulated, by an external energy source, to emit light. Light from everyday sources, such as a light bulb, is produced in a haphazard process called spontaneous emission that gives an incoherent source of light (the photons have a random phase difference), which is then emitted in all directions.

In the Bohr atomic model, electrons orbit the nucleus with a definite energy, which increases with distance from the centre of the atom. Most atoms are in the ground state with electrons in the lowest energy level - this distribution is called a normal population. If energy is supplied to the atoms then electrons can be forced to higher energy levels (Figure 1) and the atoms are said to be in an excited state. For most substances the absorbed energy is emitted 'spontaneously' (Figure 2) in a very short time, typically less than 10^{-8} s, as a photon of energy hv.

Figure 1 **Figure 2** **Figure 3**



E1: Lower Energy State, E2: Higher Energy State

A laser on the other hand requires a substance that has a metastable state (an energy level in which an electron will remain for a time of the order of 10^{-3} s or longer) and atoms that are in an inverted population (more atoms are in the excited state than in the ground state).
These two conditions are necessary so that the process of stimulated emission can cause a coherent beam of light.

The stimulated emission process is shown above in Figure 3. When a photon of light of the same energy as the difference between the ground state and excited state hits an excited atom it causes the electron to fall back down to the ground state, emitting light of the same frequency that is in phase with the first photon and travels in the same direction. These photons strike other excited atoms causing an avalanche of photons with the same wavelength and in phase. A monochromatic laser beam is formed by having a resonating tube that has mirrors at each end, one fully reflecting, the other partially reflecting, which allows a small percentage of the photons to pass through.

The excitation of the atoms in a laser can be done in several ways to produce the necessary inverted population. In a ruby laser, the lasing material is a ruby rod consisting of Al_2O_3 with a small percentage of aluminium (Al) atoms replaced by chromium (Cr) atoms. The Cr atoms are the ones involved in lasing. The Cr atoms are excited by strong flashes of light of wavelength 540 nm, which correspond to a photon energy of 2.3 eV. As shown in Figure 4 below, the atoms are excited from the ground state to the second excited state. This process is called optical pumping. The atoms quickly decay either back to the ground state or to the intermediate first excited state, which is metastable with a lifetime of about 3×10^{-3} s. With strong pumping action an inverted population can be formed. As soon as a few atoms in the metastable state jump down to the ground state they emit photons that produce stimulated emission and the lasing action begins. A ruby laser thus emits a beam whose photons have energy 1.79 eV and a wavelength of 694.5 nm (or "ruby-red" light).

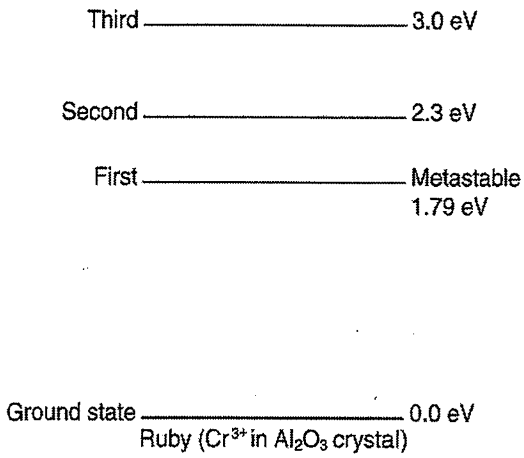


Figure 4: Energy levels of chromium in a ruby laser.

(a) What are the main differences between an everyday light source and a laser? (2 marks)

an everyday light source produces incoherent light (1)
where photons have a random phase difference (1)
or which emitted is emitted in all directions (1)

(laser is coherent, all same λ & in phase)

(b) Describe the difference between a normal population of atoms and an inverted population of atoms. (2 marks)

(1) a normal population of atoms is one where most atoms are in the ground state (electrons are in lowest energy configuration)

(1) an inverted population of atoms is where more atoms are in an excited state than in the ground state

(c) Briefly describe the two conditions that are necessary for stimulated emission to take place. (3 marks)

- a substance that has a metastable state (1)
- i.e. an excited energy level in which an electron will remain for a time longer than a millisecond (1)
- atoms that are in an inverted population (1) (more atoms in excited state than ground state)

(d) How does the stimulated emission process produce a coherent beam of light? (3 marks)

when ~~an~~ a photon of energy 1·79eV hits an excited ~~electron~~ atom with its electron in the metastable state it causes the electron to drop to the ground state & emit a photon of the same energy & frequency (1)

these two photons are in phase with each & travel in the same direction, striking other excited atoms & stimulating further release of photons of the same wavelength and in phase (1)

the laser is a tube containing the lasing material with mirrors at each end, one fully reflecting & the other only partially reflecting so that some of the photons pass through the partially reflecting mirror & emerge as a coherent laser beam (1)

(e) To what part of the electromagnetic spectrum does the transition from the second excited state to the intermediate first metastable excited state in the ruby laser (Figure 4) correspond? What implication does this have on the operation of the laser?

(3 marks)

$E = 2.3 - 1.79 = 0.51 eV = 8.16 \times 10^{-20} J$

$f = \frac{E}{h} = \frac{8.16 \times 10^{-20}}{6.63 \times 10^{-34}} = 1.23 \times 10^{14} Hz < 4 \times 10^{14} Hz$ (1)

infrared radiation (1)

I.R. causes heating of the laser (1)

(f) What is the theoretical maximum efficiency of the ruby laser? (2 marks)

$\text{efficiency} = \frac{\text{useful output energy}}{\text{total input energy}} \times 100\%$ (1)

$= \frac{1.79}{2.3} \times 100 = 77.8\%$ (1)

End of Section Three - End of Questions

Additional Working Space