PHYSICS
UNITS 3 & 4
2020

Name: MARKING GUIDE

Teacher: ____________________________

TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes
Working time for the paper: Three hours

MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

To be provided by the supervisor:
- This Question/Answer Booklet; Formula and Constants sheet

To be provided by the candidate:
- Standard items: pens, pencils, eraser or correction fluid, ruler, highlighter.
- Special items: Calculators satisfying the conditions set by the SCSA for this subject.

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.

MARKED

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	13	13	50	54	30
Section Two: Extended answer	7	7	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
			Total	180	100

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2019.* Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer Booklet.

3. When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

   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.

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

5. 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.
   - 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. Refer to the question(s) where you are continuing your work.

Section One: Short response **30% (54 Marks)**

This section has **thirteen (13)** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1 **(4 marks)**

Calculate both the maximum and minimum gravitational force that the Sun applies to Earth's moon.

$r_{min} = r_{Sun-Earth} - r_{Earth-Moon}$

$r_{min} = 1.50 \times 10^{11} - 3.84 \times 10^{8} = 1.496 \times 10^{11}\ m$ 1

$r_{max} = r_{Sun-Earth} - r_{Earth-Moon}$

$r_{max} = 1.504 \times 10^{11}\ m$ 1

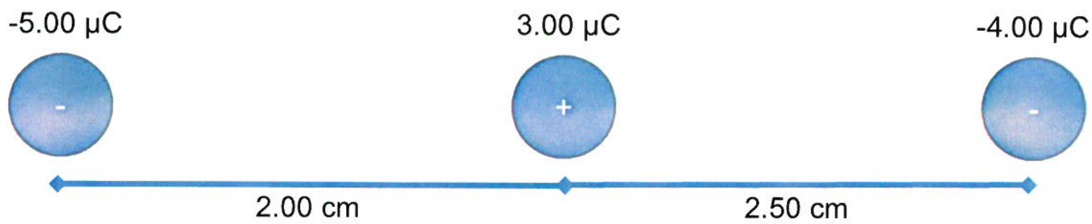
$F_g = \frac{GMm}{r^2}$

$F_{g,min} = \frac{6.67\times10^{-11}\times1.99\times10^{30}\times7.35\times10^{22}}{(1.504\times10^{11})^2} = 4.31 \times 10^{20}\ N$ 1

$F_{g,max} = \frac{6.67\times10^{-11}\times1.99\times10^{30}\times7.35\times10^{22}}{(1.496\times10^{11})^2} = 4.36 \times 10^{20}\ N$ 1

Question 2 **(4 marks)**

Find the net force acting on the 3.00 μC in the diagram below. Include a direction.



$F_{left} = -\frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{r^2} = \frac{1}{4\pi\times8.85\times10^{-12}} \times \frac{5.00\times10^{-6}\times3.00\times10^{-6}}{0.0200^2} = -337.2\ N$ 1

$F_{right} = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{r^2} = \frac{1}{4\pi\times8.85\times10^{-12}} \times \frac{4.00\times10^{-6}\times3.00\times10^{-6}}{0.0250^2} = 172.6\ N$ 1

$\sum F = -337.2 + 172.6 = -165\ N$ 1

Net force is 165 N <u>to the left.</u> 1

Question 3 **(4 marks)**

In relation to Young's double slit experiment using light and particles, state whether the following statements are **true** or **false**.

Statement	True or False
The results of a double slit experiment using a beam of light is supporting evidence that light travels in discrete packets of energy, called photons.	False
The results of a double slit experiment using a beam of electrons is supporting evidence that matter behaves as a wave.	True
An electron beam directed at the slits must have a high enough density of electrons to cause an interference pattern.	False
Using a detector at one or more of the slits to confirm the presence of any electrons will remove the interference pattern.	True

Question 4 **(5 marks)**

Explain how the detection of muons created in the upper atmosphere at ground level provides supporting evidence of time dilation as predicted by Einstein's special theory of relativity.

Muons created in the upper atmosphere move at high speeds, some towards the ground 1

The predicted half life of muons is short ($\approx 2\ \mu s$) 1

Therefore muons don't have the time to reach the ground before decaying on average 1

In practice, many more muons reach the ground than expected 1

This can be explained if the muon's half life is dilated as measured by Earth 1

Question 5 **(4 marks)**

Arrange the following list of matter in order of formation in the universe according to the Big Bang theory.

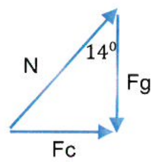
- Baryons, Nuclei, Light elements, Stars, Quarks and leptons, Heavy elements

Quarks and leptons
Baryons — 1 for quarks preceding baryons
Nuclei
Light elements — 1 for nuclei preceding light elements
Stars
Heavy elements — 1 for heavy elements occurring after stars

1 for all remaining items listed in correct order

Question 6 **(4 marks)**

A cyclist on a banked curve is moving at a steady speed and following a horizontal circular path with a 12.0 m radius. The banked curve has an incline of 14.0^0. Calculate the speed of the cyclist such that no frictional force is required to maintain the circular motion. Use a vector diagram to support your answer.



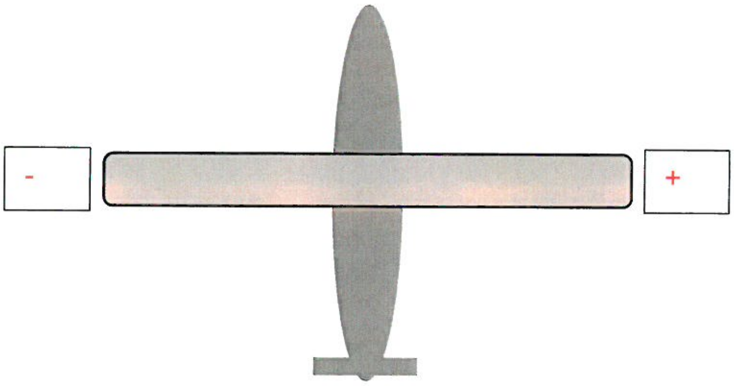
Labelled vector diagram 1-2

$tan\theta = \frac{F_c}{F_g} = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg}$ 1

$v = \sqrt{rgtan\theta} = \sqrt{12.0 \times 9.8 \times \tan(14.0)} = 5.41\ m\ s^{-1}$ 1

Question 7 **(5 marks)**

A plane's wingtips can generate an emf as the plane cuts magnetic flux lines of Earth's magnetic field. The diagram below shows the plane flying at 140 km h^{-1} up the page while the component of Earth's magnetic field directed out of the page is 45.0 μT. This generates a 7.88 mV potential.



(a) Label, on the diagram of the plane, the polarity of the induced emf in the wings. (1 mark)

(b) Calculate the length of the wings, from one tip to the other. (4 marks)

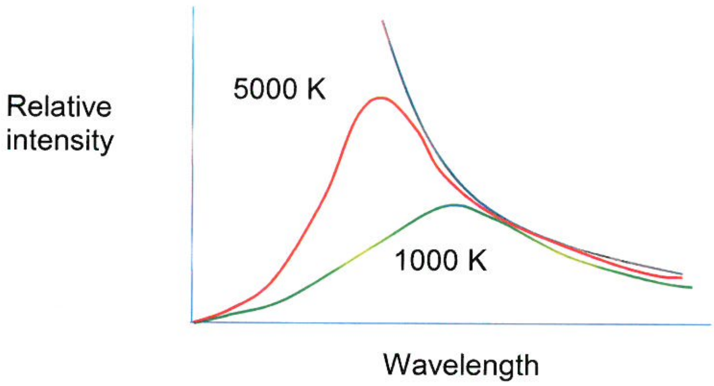
$v = 140\ km\ h^{-1} = \frac{140*1000}{3600}\ m\ s^{-1} = 38.89\ m\ s^{-1}$ 1

$\varepsilon = lvB$ 1

$l = \frac{\varepsilon}{vB} = \frac{7.88\times10^{-3}}{38.89\times45\times10^{-6}} = 4.50\ m$ 1-2

Question 8 **(4 marks)**

The curve below shows the expectated spectrum of a black body using classical physics.



New curves approach 0, 0

New curves follow classical values at large wavelength

5000K curve is taller and to peak is to the left of 1000 K curve

On the same set of axis, draw **two (2)** new curves representing a black body spectrum using a quantum model of light – one at 1000 K and one at 5000 K. Label each curve.

Question 9 **(4 marks)**

Consider a proton accelerated up to 2.89 × 10^8 m s^{-1}. Calculate the magnitude of its kinetic energy.

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$E = \frac{1.67\times10^{-27}\times(3.00\times10^8)^2}{\sqrt{1-\frac{(2.89\times10^8)^2}{(3.00\times10^8)^2}}} = 5.602\times10^{-10}\,J \qquad 1\text{-}2$$

$$E_k = E - rest\ energy$$

$$E_k = 5.602\times10^{-10} - 1.67\times10^{-27}\times(3.00\times10^8)^2 = 4.10\times10^{-10}\,J \qquad 1\text{-}2$$

Question 10 **(4 marks)**

Complete the table below concerning the forces within an atom as explained by the standard model.

Force within atom	Fundamental Force	Force-Carrying Gauge Boson
The repulsion of protons within a nucleus	Electromagnetic 1	Photon 1
The attraction of quarks in a nucleon	Strong/strong nuclear 1	Gluon 1

Question 11 **(4 marks)**

A golfer hits a ball at 10.4 m s^{-1}, inclined at 60.0^0. There is a hill in front of the golfer, such that the ball lands 2.00 m higher than where it started. Calculate the time the ball spends in the air.

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

$$2.00 = 10.4 sin60\, t - \frac{1}{2}\times 9.8\times t^2 \qquad 1\text{-}2$$

Uses quadratic to solve, $t = 1.58\,s\ (0.258\,s\ should\ be\ ignored)$ 1

Question 12 **(4 marks)**

An AC generator has an RMS output of 6.00 V. The generator's coil of 35 windings rotates at 630 rpm inside a 2.00×10^{-2} T field. Calculate the cross-sectional area of the coils.

$\varepsilon_{max} = \varepsilon_{rms} \times \sqrt{2}$
$\varepsilon_{max} = 6.00 \times \sqrt{2} = 8.485\ V$ 1

$f = \frac{630}{60} = 10.5\ Hz$ 1

$\varepsilon_{max} = 2\pi NBAf$
$A = \frac{\varepsilon_{max}}{2\pi NBf} = \frac{8.485}{2\pi \times 35 \times 0.02 \times 10.5} = 0.184\ m^2$ 1-2

Question 13 **(4 marks)**

A simplified diagram of a DC motor's coil within a magnetic field is shown below.

(a) State the direction of the current required in wire A such that the force felt by wire A is directed down the page. (1 mark)

Into the page 1

(b) The motor uses a split ring commutator. Explain the function of this component. (3 marks)

Every half spin of the coil, the split ring commutator reverses the direction of the current in the coil 1

This swaps the direction of the force applied to the sides of the coil 1

This keeps the direction of the torque constant, even after the coil spins 180 deg 1

End of Section One

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Section Two: Problem-solving **50% (90 Marks)**

This section has **seven (7)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 14 **(14 marks)**

Jill is based on Earth while Henry flies past in a spaceship at 0.750 c. Henry has a particle accelerator, capable of firing electrons at 0.600 c as measured from the frame of the particle accelerator. He uses the particle accelerator to fire an electron from the front of his spaceship to the back, which he observes take 5.60×10^{-8} s.

(a) Calculate the velocity of the electron as observed by Jill. Include a direction. (4 marks)

$u = \frac{v+u'}{1+\frac{vu'}{c^2}}$ 1

$u = \frac{0.750c-0.600c}{1+\frac{0.750c\times(-)0.600c}{c^2}} = 0.273\ c$ 1

$v = 0273\ c = 0.273 \times 3.00 \times 10^8 = 8.19 \times 10^7\ m\ s^{-1}$ 1

Velocity is $8.19 \times 10^7\ m\ s^{-1}$ **forward** 1

(b) Calculate the length of the spacecraft as measured by Jill on Earth. (3 marks)

Proper length as observed by Henry, calculated from motion of the electron
$l_0 = vt = 0.600c \times 5.60 \times 10^{-8} = 10.08\ m$ 1

Conversion to contracted length
$l = l_0\sqrt{1-\frac{v^2}{c^2}} = 10.08\sqrt{1-\frac{0.750^2c^2}{c^2}} = 6.67\ m$ 1-2

(c) Which observer, Henry or Jill, will observe the ~~longest~~ shortest time for the electron to complete its journey to the back of the spacecraft. No calculation is required, but you must justify your choice referring to principles of special relativity. (3 marks)

Jill observes the ~~longest~~ shortest time 1

Jill observes the electron moving at a slower speed compared to Henry 1

A smaller observed velocity decreases the time dilation effect, decreasing the observed time of the journey 1

Henry observes the ~~shortest~~ longest time.

(d) Knowing that the proper time it takes for the electron to reach the back of the spacecraft is observed from the rest frame of the electron, calculate the time Jill observes for the electron to reach the back of the spacecraft. (4 marks)

Find the proper time (converting from Henry's time)

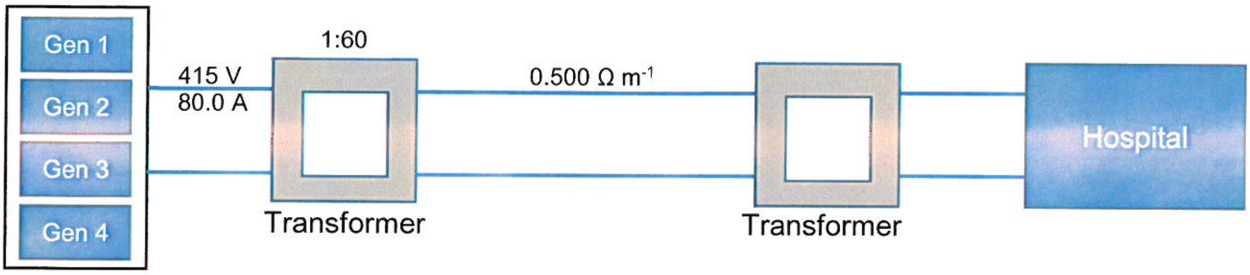
$t_0 = t\sqrt{1 - \frac{v^2}{c^2}} = 5.60 \times 10^{-8}\sqrt{1 - \frac{0.600^2c^2}{c^2}} = 4.48 \times 10^{-8}\ s$ 1-2

Find Earth time

$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{4.48\times10^{-8}}{\sqrt{1-\frac{0.273^2c^2}{c^2}}} = 4.65 \times 10^{-8}\ s$ 1-2

Question 15 **(14 marks)**

The emergency power supply of a hospital is shown below. Four diesel generators are connected in parallel which produces a combined voltage of 415 V and current of 80.0 A. The generators are attached to a step-up transformer which has a 1:60 turns ratio. The transformer transmits the electrical power through a transmission line to a second transformer, some distance away, which steps down the voltage for use in the hospital. The transmission line has a resistance of 0.500 Ω m^{-1}. A schematic of the power distribution system is given below.



(a) Explain the advantage of using a step-up transformer before transmitting electrical power over any significant distance. (3 marks)

Using a step up transformer will increase the voltage and decrease the current 1

Power loss due to the resistance of the transmission line is proportional to the square of the current through the line 1

Reducing the current significantly reduces the power loss 1

(b) Calculate the output voltage of the step-up transformer. (2 marks)

$V_s = V_p \times \frac{N_s}{N_p} = 415 \times \frac{60}{1} = 2.49 \times 10^4\ V$ 1-2

(c) Assume the transformers are 95.0% efficient and the only significant losses come from the transformers and the transmission line.

i. Calculate the power output from the step up transformer. (2 marks)

$P_{in} = VI = 415 \times 80 = 3.32 \times 10^4\ W$ 1

$P_{out} = P_{in} \times eff = 3.32 \times 10^{-4} \times 0.95 = 3.15 \times 10^4\ W$ 1

ii. The step down transformer receives 2.47×10^4 V. Calculate the power loss of the transmission line. (4 marks)

$R_{total} = 0.500 \times 45.0 = 22.5\ \Omega$ 1

$\Delta V = 2.49 \times 10^4 - 2.47 \times 10^4 = 2.00 \times 10^2\ V$ 1

$P_{loss} = \frac{V^2}{R} = \frac{2.00\times10^2}{22.5} = 1.78 \times 10^3\ W$ 1-2

(d) State one feature of a transformer that is designed to maximise the efficiency of the transformer. Describe how this feature achieves the increase in efficiency. (3 marks)

Laminations 1
These are layers of insulation in the soft iron core that minimises eddy currents, formed from unwanted electromagnetic induction in the core. Smaller eddy currents mean lower energy loss. 1-2

OR

Thick wires on larger current side 1
As current increases, losses due to resistive heating also increase. Thicker wires have lower resistance to minimise losses due to heat. 1-2

OR

Soft iron core 1
The soft iron core is ferromagnetic and helps strengthen and direct the magnetic field produced by the primary coils. This assists in ensuring the flux passes through the secondary coil to produce the electromagnetic induction effect. 1-2

Question 16 **(10 marks)**

A particle consisting of four quarks and one anti-quark is called a pentaquark. Pentaquarks were theorised as early as 1964 and the first evidence of their existence obtained in 2003. However, it wasn't until 2015 (and again in 2019) that enough data had been gathered to make a genuine claim that a particle had been discovered that matched the theoretical properties of a pentaquark.

(a) Show, via a calculation, that a pentaquark has a baryon number of +1. (2 marks)

Shows quarks have $+\frac{1}{3}$ baryon number and antiquarks have $-\frac{1}{3}$ in working 1

$4\ quarks + 1\ antiquark$

$4 \times \frac{1}{3} + -\frac{1}{3} = +1$ 1

(b) The equation below describes the formation of a pentaquark. A lambda baryon, $\Lambda_b^0\ (bud)$ decays via a W^- boson, forming a kaon minus, $K^-\ (s\bar{u})$ and the pentaquark, $P_c^+\ (u\bar{c}cud)$.

$$\Lambda_b^0 \rightarrow K^- + P_c^+$$

i. State which fundamental force is responsible for mediating this decay. Justify your choice. (2 marks)

Weak nuclear force 1

The W^- boson is a mediating particle of the weak nuclear force 1

ii. Mesons are a compsite particle consisting of a quark and an antiquark. State the names of the fundamental particles of the meson in the decay reaction. (2 marks)

Strange 1

Anti-up 1

iii. Show that electric charge is conserved during this decay. (2 marks)

$\Lambda_b^0 \rightarrow K^- + P_c^+$

$0 \rightarrow -1 + 1$ 1

$LHS = RHS$ (or some evidence conservation has been confirmed) 1

iv. Show that baryon number is conserved during this decay. (2 marks)

$\Lambda_b^0 \rightarrow K^- + P_c^+$

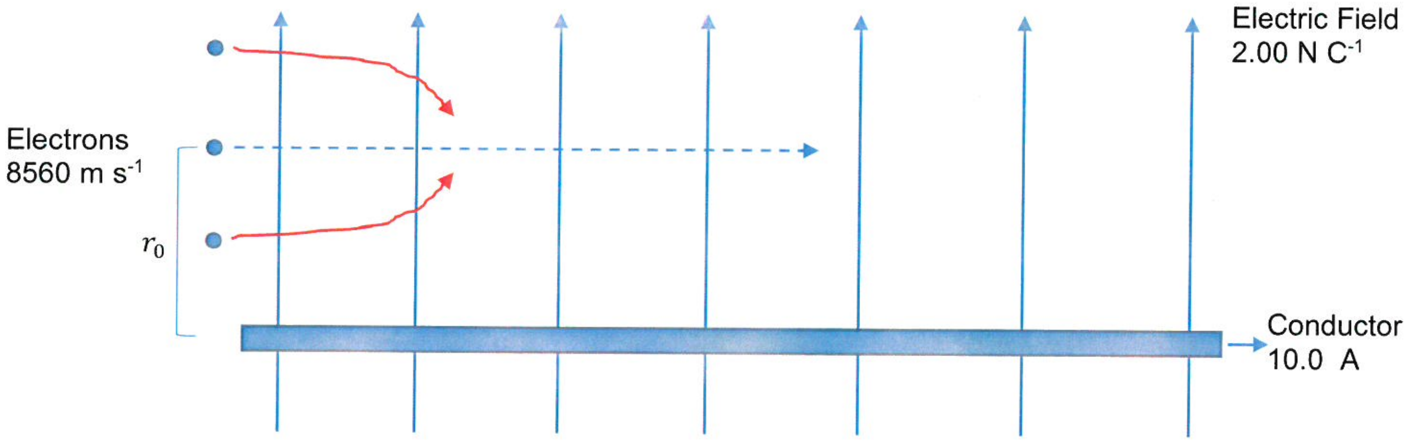
$+1 \rightarrow 0 + 1$ (may show individual quark baryon values, not required) 1

$LHS = RHS$ (or some evidence conservation has been confirmed) 1

Question 17 **(14 marks)**

A conductor carrying a current of 10.0 A to the right is placed in a uniform 2.00 N C^{-1} electric field acting upwards (as shown in the diagram). Electrons enter the electric field at different distances from the conductor and travel parallel to the conductor at a speed of 8560 m s^{-1}. A magnetic field is produced in the same region as the electric field by the current-carrying conductor. The electron at a perpendicular distance r_0 from the conductor (see the diagram) maintains a constant velocity while it is travelling through the two fields.

While completing this question, the effect that the charge on each electron has on other electrons can be ignored.



(a) State the direction of the magnetic field above the conductor. (1 mark)

Out of the page 1

(b) Calculate the force on the electrons due the electric field. Include a direction. (3 marks)

$F = Eq = 2.00 \times 1.60 \times 10^{-19} = 3.20 \times 10^{-19}\ N$ 1-2

down the page 1

(c) The path followed by the electron at a distance r_0 from the conductor is shown as a dashed line. For the remaining two electrons in the diagram (above and below the electron at r_0), sketch the paths they would take as the entered the region occupied by both the electric field and the magnetic field. (2 marks)

Top electron begins to curve towards conductor 1

Bottom electron begins to curve away from conductor 1

(d) Explain your choice for the electron path drawn for **one** of the electrons in part (c). (4 marks)

The electron closer to the conductor is in a larger magnetic flux density due to the conductor ($B = \frac{\mu_0}{2\pi} \times \frac{I}{r}$) 1

This causes an increase in magnetic force ($F = qvB$) 1

The magnetic force is stronger up the page than electric force down the page– causing it to deflect away from the conductor 1-2

Note: Similar marks for top electron curving towards conductor if chosen by student

(e) Calculate the distance r_0. (4 marks)

Forces in equilibrium

$F_E = F_B$ 1

$F_E = qvB$

$3.20 \times 10^{-19} = 1.60 \times 10^{-19} \times 8560 \times B$

$B = 2.336 \times 10^{-4}\ T$ 1

Distance from conductor

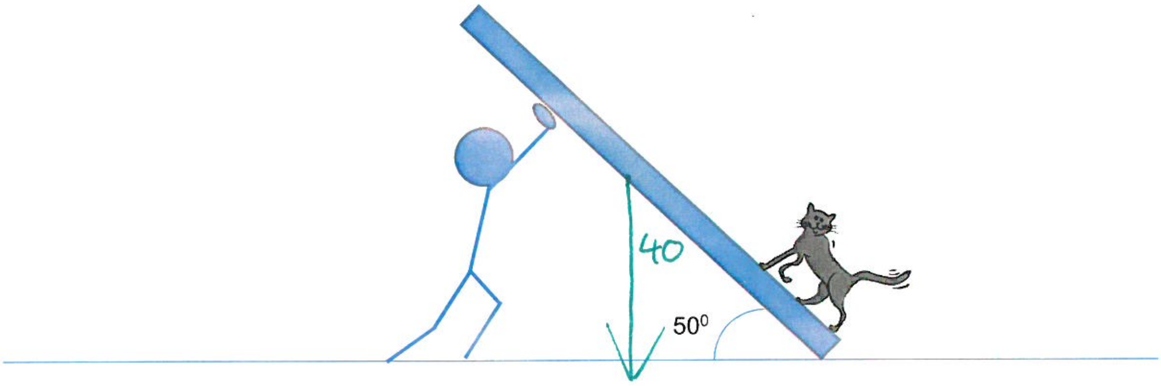
$B = \frac{\mu_0}{2\pi} \times \frac{I}{r_0}$

$2.336 \times 10^{-4} = \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{10.0}{r_0}$

$r_0 = 8.56 \times 10^{-3}\ m$ 1-2

Question 18 **(13 marks)**

A man moving a 35.0 kg bookshelf across carpet is startled by his cat, and the bookshelf becomes unbalanced, resulting in it being supported by the man from underneath. The 16.0 kg cat is above the bookshelf, as shown in the diagram below, and begins walking towards the top of the bookshelf. You can assume the man applies a force perpendicular to the face of the bookshelf falling on him.



(a) The bookshelf is 2.40 m tall with a uniformly distributed mass. The man is pushing with a maximum force of 270 N at a distance of 0.600 m from the top end of the bookshelf. Calculate how far up from the bottom end of the bookshelf the cat can walk before the man is unable to support it. (4 marks)

$\sum \tau_{cw} = \sum \tau_{acw}$
$F_{man} r_{man} = F_{shelf} r_{shelf} + F_{cat} r_{cat}$ 1

Distances:
$r_{man} = 2.40 - 0.60 = 1.80\ m$
$r_{shelf} = \frac{2.40}{2} cos50 = 0.771\ m$
$r_{cat} = Lcos50$ (L is length cat can walk) 1-2

$F_{man} r_{man} = F_{shelf} r_{shelf} + F_{cat} r_{cat}$ sin 40
$270 \times 1.80 = 35.0 \times 9.8 \times 0.771 + 16.0 \times 9.8 \times Lcos50$
$L = 2.20\ m$ 1 (1)

$\Sigma M_{cw} = \underset{(MAN)}{r \times F} = \Sigma M_{ACW} = \underset{(Book\ shelf)}{1.2 \times 35 \times 9.8 \times \sin 40^\circ}$ (1)

$= 1.8 \times 270$ (1) $= + L \times 16 \times 9.8 \times \sin 40$ (1)

ie

$L = 2.20\text{m}$

(b) Calculate the magnitude of the reaction force the carpet applies to the bookshelf when the man must push with his full strength. (4 marks)

$\sum F_{up} = \sum F_{down}$
$F_{man,v} + R_v = F_{shelf} + F_{cat}$
$270 \times cos50 + R_v = 35.0 \times 9.8 + 16.0 \times 9.8$
$R_v = 326.2\ N$ 1-2

$\sum F_{right} = \sum F_{left}$
$F_{man,h} = R_h$
$R_h = 270sin50 = 206.8\ N$ 1

$R = \sqrt{326.2^2 + 206.8^2} = 386\ N$ 1

(c) Describe how the direction of the reaction force the carpet applies to the bookshelf changes as the cat walks up the bookshelf. Explain your reasoning (no calculations required). (5 marks)

As the cat walks, the counter clockwise torque produced by the cat's weight increases due to an increase distance from the pivot point (shelf and carpet contact) 1

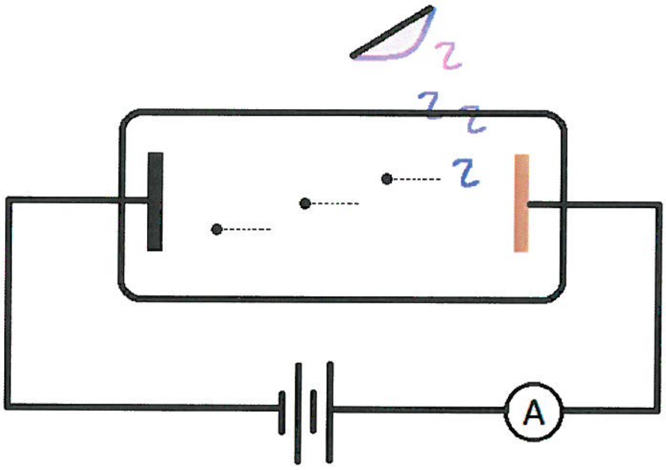
The man supplies more clockwise torque to maintain equilibrium, by pushing harder. 1

The vertical component of the reaction force is reduced due to the man taking some of the load. The horizontal component of the reaction force increases to balance the increased horizontal force applied by the man. 1-2

This results in the reaction force making a smaller angle with the ground 1

Question 19 **(14 marks)**

A photoelectric effect experiment using copper as the target anode is shown in the diagram below.



The required stopping voltage (V) to reduce the current reading in the ammeter to zero for a variety of light frequencies was recorded.

Frequency ($\times10^{15}$ Hz)	Stopping voltage (V)	Max Kinetic Energy of Photoelectrons ($\times10^{-19}$ J)
1.0 ± 0.2	-	-
1.5 ± 0.2	1.10	1.76
1.9 ± 0.2	2.76	4.42
2.3 ± 0.2	4.42	7.07
2.9 ± 0.2	6.90	

(a) The lowest incident frequency used did not have a stopping potential measurement. Suggest a reason why. (2 marks)

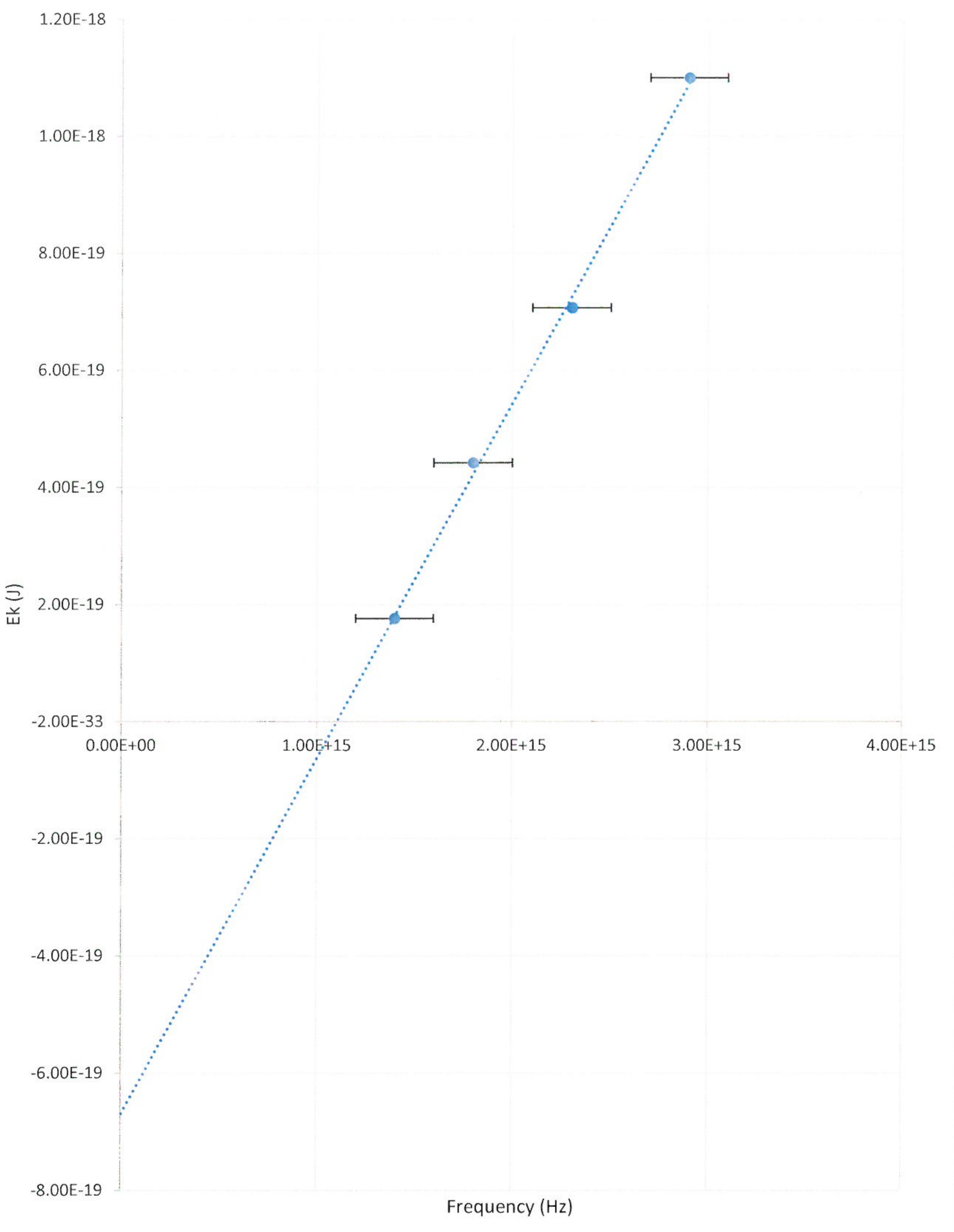
This frequency is below the threshold frequency and unable to provide enough energy for an electron to be removed from the anode. 1-2

(b) Calculate the maximum kinetic energy of the photoelectrons produced from a 2.90×10^{15} Hz light source. Add this value to the table of results. (2 marks)

$E = Vq = 6.90 \times 1.6 \times 10^{-19} = 11.0 \times 10^{-19}\,J$ 1-2

(c) Draw a graph maximum kinetic energy (E_k) of the photoelectrons (in joules) vs frequency (f). Your vertical scale must allow for the vertical intercept to be shown. Add error bars for the frequency values. Include a line of best fit. (5 marks)

Suitable labels with units 1
Good scale 1
Accuracy of points 1
Suitable sized error bars 1
Line of best fit 1


1.20E-18
1.00E-18
8.00E-19
6.00E-19
4.00E-19
2.00E-19
-2.00E-33
-2.00E-19
-4.00E-19
-6.00E-19
-8.00E-19
Ek (J)
0.00E+00
1.00E+15
2.00E+15
3.00E+15
4.00E+15
Frequency (Hz)

(d) Using the graph, determine the work function (W) of copper. Justify your answer.
(2 marks)

Approx 6.7×10^{-19} J or 4.2 eV	1
Based on the vertical axis intercept	1
OR	
Approx 7.3×10^{-19} J	1
Using the cutoff f (horizontal intercept) and E=hf	1

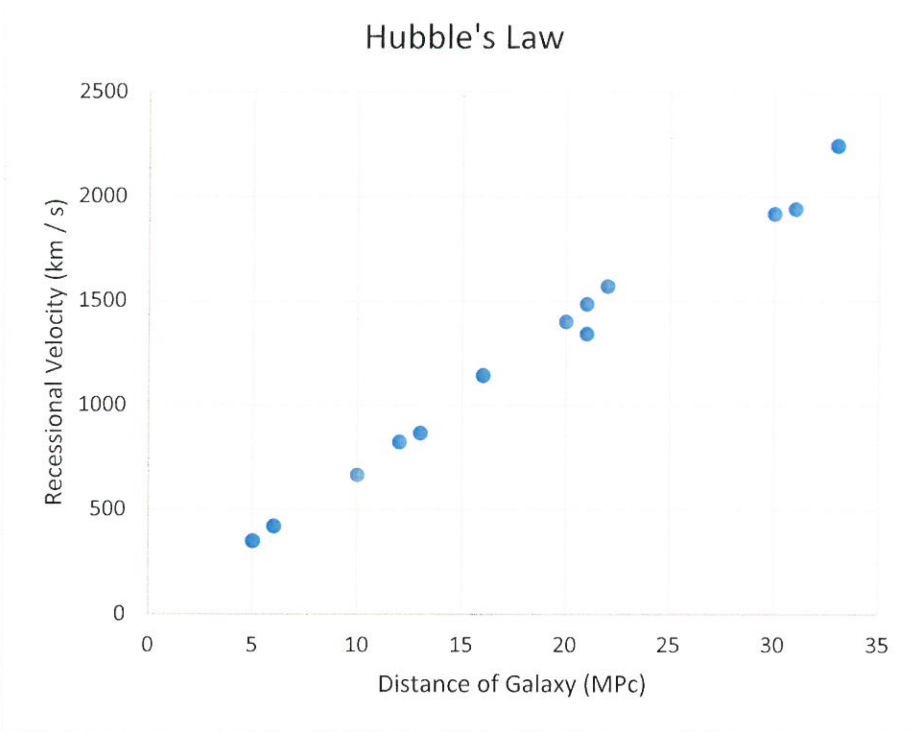
Note answers differ based on approach as gradient $\neq 6.63 \times 10^{-34}$

(e) Calculate the gradient of the graph and use this value to determine Planck's constant.
(3 marks)

Shows sufficient working for gradient calc	1
Uses graph values, not table	1
$h = gradient = 6.3 \times 10^{-34}\ J\ s$ (approx, based on line of best fit)	1

Question 20 **(11 marks)**

The graph below is representative of the findings of Edwin Hubble, who researched cosmological concepts that led to the Big Bang Theory.



(a) Describe the relationship that is observed within this graph. (2 marks)

As distance of a galaxy increases, recessional velocity increases proportionally
1-2

(b) The Steady State Theory preceded the Big Bang Theory. The Steady State Theory lost acceptance in the scientific community based on the work of Hubble. Explain how the relationship shown in the graph supports the Big Bang Theory and is in contradiction to the Steady State Theory. (3 marks)

Refers to assumptions of steady state theory
"The steady state theory stated the universe is static and always has been"
And/Or
"The steady state theory states the universe is infinitely old" 1

Describes inferences of graph details that support Big Bang/ contradict Steady State
"The graph reveals that if galaxies are all moving away, at some distant point in time, the galaxies were closer together/universe was denser/universe had a beginning" 1

Describes support of Big Bang theory
"This supports the Big Bang theory that states the universe started in a much hotter, denser state/ had a starting point in time" 1

(c) Hubble's law is described by the following equation:

$$v = H_0 D$$

Where v is the recessional velocity of a galaxy and D the distance of a galaxy.

i. Use the graph to calculate a value for Hubble's constant (H_0), which has units km s^{-1} Mpc^{-1}. You must add construction lines to the graph to show how your answer was obtained. (3 marks)

Adds a suitable line of best fit to graph 1

Performs a calculation to find gradient/Hubble's constant (accept 0,0 as a point if line of best fit passes through origin). E.g.:

$H_0 = \frac{v}{D} = \frac{680}{10} = 68\ km\ s^{-1}\ Mpc^{-1}$ 1-2

ii. At sufficiently large distances (D), the velocity of a galaxy (v) would be predicted to be larger than the speed of light. Comment on whether or not Hubble's Law can be applied at these large distances. (3 marks)

The recessional velocity observed is due to the expansion of space. 1

It is physically acceptable for a galaxy to be receding faster than speed of light due to the expansion of space. 1

Therefore Hubble's law can be applied, even at large distances 1

End of Section 2

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Section Three: Comprehension **20% (36 Marks)**

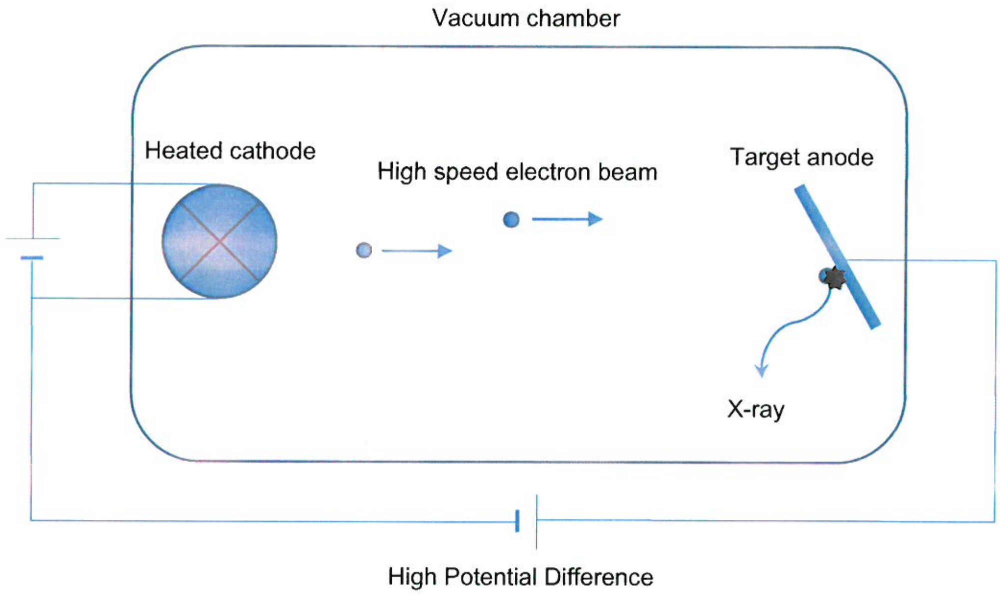
This section contains **two (2)** questions. You must answer both questions. Write your answers in the spaces provided. Suggested working time for this section is 40 minutes.

Question 21 **(18 marks)**

X-Rays

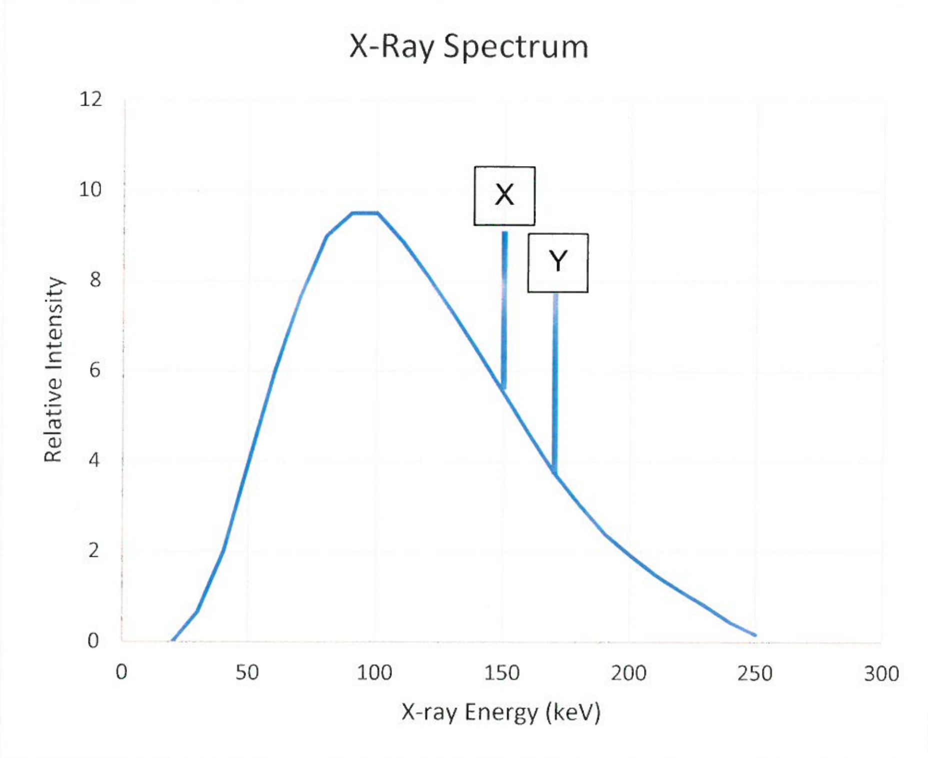
X-rays are used in medicine and dentistry as a diagnostic tool – to take images of suspected broken bones and checking teeth alignment. X-rays are electromagnetic waves that have a very short wavelength, varying from 1.00 pm to 10.0 nm. This allows them to penetrate through the body. As they do so, the body absorbs some of the X-rays, reducing the intensity of the X-ray beam. Denser material like bone absorbs more X-rays. This allows for an image to be taken which reveals some internal structures of the body based on differing densities – like bones and teeth against skin and muscle.

X-rays are produced for medical use by sending high-speed electrons to collide with a metal target. The setup of an X-ray tube is shown below.



A filament is heated to eject electrons. A very high potential difference is created between the filament (the cathode) and the target metal (the anode) – as much as 250 000 V. The electron beam hits the anode and the rapid deceleration of the electrons creates an X-ray. This process is quite inefficient, with only 1.00 % of the electron's energy being converted into an X-ray on average. The remaining energy is lost as thermal heating of the anode – thus metals with high melting points are used. The amount of deceleration of the electrons has a broad distribution, thus the energies of the X-rays produced also has a broad distribution, with most X-rays forming at lower energies. This type of X-ray is called "bremsstrahlung", which is German for "braking radiation".

Another mechanism works simultaneously to produce X-rays in the X-ray tube. The high speed electrons can knock out electrons from the inner energy levels of the atoms in the target anode. When an electron is removed from the n = 1 or n = 2 level, it leaves a space for a free electron to fill. As the free electron falls from the ionisation energy level to the inner energy level, it emits a high energy photon – an X-ray. The wavelengths of these X-rays are unique to the material that makes up the target anode and are thus are called "characteristic X-rays". Compared to bremsstrahlung radiation, the wavelengths of characteristic X-rays are well defined, and so occur at a greater intensity at these wavelengths, forming peaks in the X-ray spectrum. An X-ray spectrum containing both bremsstrahlung and characteristic X-rays is shown below.



(a) Explain why the X-ray spectrum is continuous when X-rays are produced using an X-ray tube. (3 marks)

X-rays are produced by deceleration of electrons hitting an anode target 1

The range of deceleration has a broad, continuous distribution 1

Thus the energy of the X-rays also has a broad, continuous distribution 1

(b) Of the two peaks, labelled X and Y in the spectrum in the article, which is caused by the removal of an n = 1 electron? Justify your choice. (3 marks)

Peak Y 1

This peak occurs at a higher X-ray energy than peak X 1

A free electron falling into n=1 will produce a higher energy X-ray than an electron falling into n=2. 1

(c) Calculate the wavelength of the X-rays produced at the peak labelled X in the spectrum. (4 marks)

$E_{joules} = 150 \times 10^3 \times 1.6 \times 10^{-9} = 2.40 \times 10^{-14}\, J$ 1-2

$E = hf \text{ and } c = \lambda f$

$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{2.40 \times 10^{-14}} = 8.29 \times 10^{-12}\, m$ 1-2

(d) Suggest two (2) reasons why the X-ray tube needs to be a vacuum. (2 marks)

To ensure the electrons hit the metal anode at a high speed/don't lose E due to collisions 1

Electrons are not deflected prior to reaching the metal anode 1

(e) Using the classical formula for kinetic energy, calculate the speed of the electrons as they collide with the target anode. (3 marks)

$E = Vq = 250\ 000 \times 1.60 \times 10^{-19} = 4.00 \times 10^{-14}\ J$ 1

$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 4.00 \times 10^{-14}}{9.11 \times 10^{-31}}} = 2.96 \times 10^{8}\ m\ s^{-1}$ 1-2

(f) With reference to your answer to part (e), explain whether this result is accurate. If you could not obtain an answer to part (e), you may assume the speed of the electrons is approximately 2.50×10^{8} m s^{-1}. (3 marks)

The speed of the electrons is a high percentage of the speed of light. 1

The classical formula for kinetic energy is not suitable when approaching the speed of light. 1

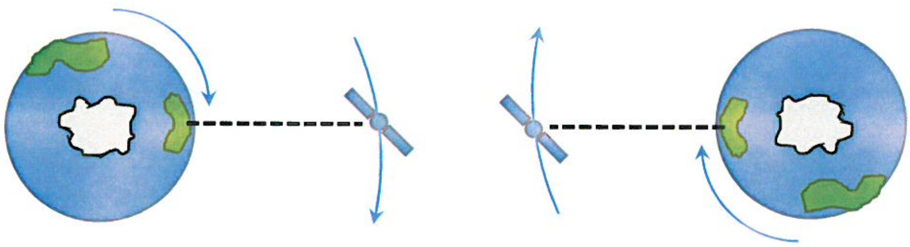
This answer is not accurate. 1

Question 22 **(18 marks)**

Geosynchronous Orbit

Satellite orbits around Earth are classified according to altitude. At one extreme is the low Earth orbit (LEO) which skims the upper atmosphere. The International Space Station orbits here, a measly 410 km above the Earth's surface. This is so close to Earth that without constant corrections, the thin amount of atmosphere at this height would drag the station 2 km towards Earth in a month. Satellites in this orbit have very short viewing windows from a single location on the Earth but will often return to the same portion of sky quickly, particularly if the orbit is very equatorial. The advantage of this orbit is that electronic equipment is protected from harsh solar winds which are high speed charged particles ejected from the Sun.

At the other extreme of satellite orbits is the high Earth orbit (HEO). Out in HEO there is no protection against solar winds. The HEO sits above the medium Earth orbit (MEO). The boundary between the two occurs at the geosynchronous orbit (GSO). The GSO is the exact altitude at which a satellite's orbital period matches the rotation of the Earth about its axis; these satellites take 24 hours to complete an orbit. Because GSO satellites take the exact same time to orbit as the Earth takes to rotate, it is possible they may maintain their position above the same patch of ground – they are in sync with the Earth. This is shown in the diagram below. After half an orbital period, the same land mass is below the satellite.



GSO are great to ensure that communication with the satellite is never interrupted. A ground station cannot communicate with a satellite that is in space above the far side of the planet – just as mobile phone reception does not work in an underground car park – too much solid matter blocks the signal. GSO is quite an altitude to reach though, as it is an order of magnitude higher than LEO, thus it takes significantly more energy (fuel) to reach this orbit. That said, it such a useful orbit that over 400 satellites currently reside here. When these satellites are decommissioned they are sent to a graveyard orbit that is even higher in HEO so as to keep the GSO clear for future use.

(a) Suggest why satellites are protected from solar winds in LEO. (1 mark)

The Earth has a magnetic field which extends out into LEO. This field protects equipment against moving charged particles/ solar winds. 1

(b) Explain why the International Space Station uses frequent thruster boosts. (5 marks)

The ISS is in a low Earth orbit which still has a thin amount of atmosphere 1

Atmospheric drag reduces the velocity of the ISS 1

The gravitational force will exceed the centripetal force when the velocity drops ($\frac{GMm}{r^2} > \frac{mv^2}{r}$). 1

This will cause the station to start to fall towards the Earth 1

Frequent boosts are required to maintain the velocity, overcoming atmospheric drag, to sustain its circular orbit. 1

(c) Show, using suitable calculations, that the International Space Station would not be visible from a single location on Earth for very long. (4 marks)

$r = 410 \times 10^3 + 6.37 \times 10^6 = 6.78 \times 10^6\ m$ 1

$T^2 = \frac{4\pi^2}{GM} r^3 = \frac{4\pi^2}{6.67\times10^{-11}\times5.97\times10^{24}} \times (6.78 \times 10^6)^3 = 3.0899 \times 10^7\ s^2$
$T = 5.559 \times 10^3 s\ \ (\approx 93\ min)$ 1-2

As the ISS revolves around the Earth every 93 min, and is very close to Earth, it won't be visible from any one place on Earth for very long. 1

(d) Australia wants to launch a satellite that can constantly monitor cloud coverage of the continent. Suggest an orbit to place the satellite in and justify your choice. (2 marks)

Geosynchronous/GSO 1

To have an orbital period that can maintain a constant observation of Australia 1

(e) State two (2) disadvantages of a HEO. (2 marks)

No protection from solar wind 1

Takes more fuel/energy/money to reach this orbit 1

(f) Calculate the altitude of the boundary between MEO and HEO. (4 marks)

$T = 24\ hours = 86400\ s$ 1

$r^3 = \frac{GM}{4\pi^2}T^2 = \frac{6.67\times10^{-11}\times5.97\times10^{24}}{4\pi^2} \times 86400^2 = 7.529 \times 10^{22}\ m^3$

$r = \sqrt[3]{7.529 \times 10^{22}} = 4.223 \times 10^7\ m$ 1-2

$altitude\ = 4.223 \times 10^7 - 6.37 \times 10^6 = 3.59 \times 10^7\ m$ 1

End of Questions

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Additional working space

Spare grid for graph

End of examination

Acknowledgements

Question 16
Feynmann diagram of pentaquark creation
CERN on behalf of the LHCb collaboration
https://commons.wikimedia.org/wiki/File:Pentaquark-Feynman.svg
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Question 17
Cat Drawing by Unknown Author is licensed under CC BY-NC-ND