Government of **Western Australia**
School Curriculum and Standards Authority

PHYSICS

ATAR course examination 2017

Marking Key

Marking keys are an explicit statement about what the examining panel expect of candidates when they respond to particular examination items. They help ensure a consistent interpretation of the criteria that guide the awarding of marks.

2017/68764

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

Question 1 **(2 marks)**

Although light exhibits many wave properties, representing it as a mechanical wave fails when considering light travelling from the Sun to Earth. Explain briefly what conclusion can be drawn.

Description	Marks
Cannot be modelled as a mechanical wave because it can travel through a vacuum (no propagation medium)	1
States its a particle **or** not a mechanical wave	1
Total	**2**

Question 2 **(2 marks)**

A deep-space probe moves away from the Earth with a speed of 0.55c. In this frame of reference an antenna on the probe rotates every 23.0 seconds. Calculate the time for **one** rotation when observed from Earth.

Description	Marks
$t = \frac{t_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}} = \frac{23.0}{\sqrt{\left(1 - \frac{(0.55c)^2}{c^2}\right)}}$	1
=27.5 s	1
Total	**2**

Question 3 **(4 marks)**

(a) Draw an arrow indicating the direction of the magnetic field at point P due to the magnet shown. (2 marks)

Description	Marks
Drawing of arrow shows	
Magnetic field: horizontal line	1
Direction: arrow head to the right	1
Total	**2**

(b) Describe the effect on a positively-charged particle travelling into the page at P. (2 marks)

Description	Marks
The particle would experience a force	1
It would be directed toward the bottom of the page (downward)	1
Total	**2**

Question 4 **(4 marks)**

(a) Draw an arrow indicating the direction of the magnetic field at point P due to the current-carrying wire Q as shown. (2 marks)

Description	Marks
Drawing of arrow shows	
Magnetic field: vertical line	1
Direction: arrow head upwards	1
Total	**2**

(b) Describe the effect on a positively-charged particle traveling into the page at P due to the current-carrying wire. (2 marks)

Description	Marks
The particle would experience a force	1
It would be towards the current carrying wire	1
Total	**2**

Question 5 **(4 marks)**

(a) If the intensity is the same for each colour, then the relative electrical energy consumption (U) for each colour is (1 mark)

A $U_{3000\ K} > U_{4000\ K} > U_{6000\ K}$.
B $U_{3000\ K} = U_{4000\ K} = U_{6000\ K}$.
C $U_{3000\ K} < U_{4000\ K} < U_{6000\ K}$.
D There is no correlation in terms of energy consumption.

(b) Which LED emits the greatest proportion of long wave length radiation? (1 mark)

A 3000 K (warm white)
B 4000 K (natural white)
C 6000 K (white)
D They are all the same.

(c) Which LED emits the greatest proportion of high frequency radiation? (1 mark)

A 3000 K (warm white)
B 4000 K (natural white)
C 6000 K (white)
D They are all the same.

(d) Which LED emits the greatest proportion of fast photons? (1 mark)

A 3000 K (warm white)
B 4000 K (natural white)
C 6000 K (white)
D They are all the same.

Description	Marks
(a) B	1
(b) A	1
(c) C	1
(d) D	1
Total	**4**

Question 6 **(3 marks)**

Determine the distance from the end of the beam at which the cat will make the system unstable.

Description	Marks
Picks appropriate points, eg: Unstable when $\Sigma\tau acw > \Sigma\tau cw$ at the point where the left fulcrum is	1
$8.0 \times 9.8 \times (1.00 - d) > 4.0 \times 9.8 \times 1.50$ $1.00 - d > 0.750$	1
$d < 0.250$ m	1
Total	**3**

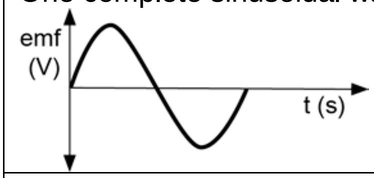
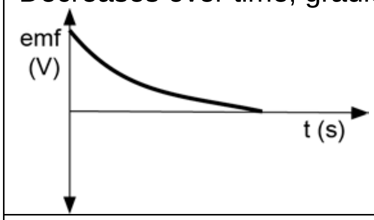
Question 7 **(2 marks)**

On which **two** postulates is the special theory of relativity based?

Description	Marks
The speed of light in a vacuum is an absolute constant	1
All inertial reference frames are equivalent **or** laws of physics are the same in all inertial reference frames	1
Total	**2**

Question 8 **(8 marks)**

Complete the table in terms of Motions A, B and C by sketching the emf induced in the loop and state whether the direction of emf is clockwise, anti-clockwise or not relevant.

<table>
<tr><th colspan="2">Description</th><th>Marks</th></tr>
<tr><td rowspan="2">A</td><td>One complete sinusoidal wave, starts/finishes at 0 emf

</td><td>1–2</td></tr>
<tr><td>Direction – not relevant (accept clockwise)</td><td>1</td></tr>
<tr><td rowspan="2">B</td><td>No emf induced</td><td>1</td></tr>
<tr><td>Direction – not relevant</td><td>1</td></tr>
<tr><td rowspan="2">C</td><td>Decreases over time, gradient decreases over time

</td><td>1–2</td></tr>
<tr><td>Direction – clockwise</td><td>1</td></tr>
<tr><td colspan="2">Total</td><td>8</td></tr>
</table>

Question 9 **(5 marks)**

Calculate the tension in each rope in the above situation, given that the scaffold is in equilibrium.

Description	Marks
Picks appropriate pivot point with torques equal **or** uses a vector triangle	1
Calculates one tension $T_2 \times 3.00 \times \sin 75.0 = 65.0 \times 9.8 \times 0.800 + 15.0 \times 9.8 \times 1.50$ $T_2 = 252$ N **or** Given that the fact that the scaffold is not in equilibrium $\sum F_H = 0$ $T_1 \cos 75.0 = T_2 \cos 75.0$ $T_1 = T_2$	1–2
Calculates other tension $T_1 \sin 75.0 + T_2 \sin 75 = 65.0 \times 9.8 + 15.0 \times 9.8$ **or** $T_1 \times 3.00 \times \sin 75.0 = 15.0 \times 9.8 \times 1.50 + 65.0 \times 9.8 \times 2.20$ $T_1 = 560$ N **or** Given that the fact that the scaffold is not in equilibrium $\sum F_V = 0$ $T_1 \sin 75.0 + T_2 \sin 75.0 = mg = 80.0 \times 9.8 = 784$ N $2T_1 \sin 75.0 = 784$ $T_1 = 406$ N	1–2
Total	**5**

Question 10 **(4 marks)**

A radio antenna is able to convert electrical signals into radio signals, transmitting information to distant receivers. The antenna does this by oscillating a charge along its length. Describe the waves produced and how the signal is able to be picked up by the receiving antenna.

Description	Marks
Electromagnetic waves are transverse waves made up of mutually perpendicular, oscillating electric and magnetic fields	1–2
Oscillating charges produce electromagnetic waves of the same frequency as the oscillation; electromagnetic waves cause charges to oscillate at the frequency of the wave	1–2
Total	**4**

Question 11 **(4 marks)**

A truck transports a large 5.50 × 10^3 kg cylinder that has a radius of 2.00 m. The cylinder is fixed to the truck by four ropes, two on each side, on ring attachments as shown in the diagram below. If the maximum load on each of the ropes (T) is 5.50 kN, calculate the maximum allowable acceleration of the truck when it moves forward.

Description	Marks
$\theta = \tan^{-1}[2.10/2.00] = 46.3°$	1
The effect is on 2 ropes	1
$F_H = ma$ and $F_{TH} = 2$ (ropes) × T sin θ $F_H = F_{TH}$ ma = 2 (ropes) × T sin θ a = 2 × T sin θ / m = 11000 × sin 46.3 / 5500 a = 1.45 m s^{-2}	1-2
Total	**4**

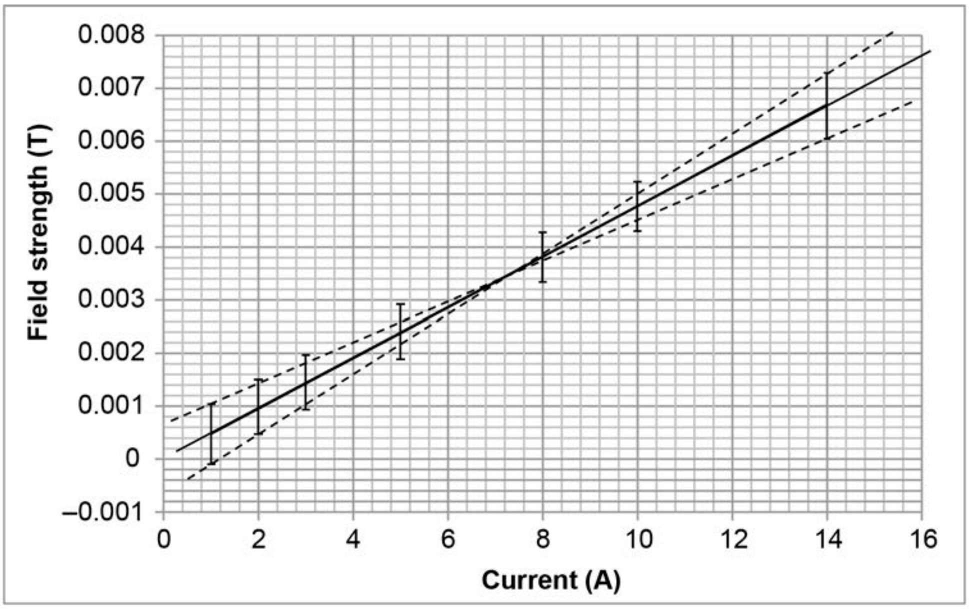
Question 12 **(5 marks)**

Describe the characteristics of a black body and use the black body radiation curves shown below to explain why the concept of light quanta was necessary.

Description	Marks
A black body is a theoretical body that absorbs and emits radiation perfectly but never reflects the incident radiation	1
As temperature increases, intensity increases overall and the peak intensity shifts to a shorter wavelength (or opposite for temperature decrease)	1–2
The ultraviolet catastrophe predicted classically (that there would be a high amount of UV light, but wasn't) gave rise to the idea of light being emitted in specific amounts	1–2
Total	**5**

Question 13 **(7 marks)**

The magnetic constant μ_0 is the magnetic permeability of a vacuum. An iron alloy would have a different permeability μ_a. To determine its permeability, a large block of the iron alloy had an insulated current-carrying wire pass through its middle. A measure of the magnetic field strength 1.00 m from the wire was made as the current was varied as shown on the graph below.



(a) Use $B = \frac{\mu}{2\pi}\frac{I}{r}$ to determine a gradient for the graph above and hence the magnetic constant μ (where $\mu = \mu_0\,\mu_a$). (3 marks)

Description	Marks
B = (μ/2πr) I (where r = 1 m) Gradient = B/ I = μ/2π(1)	1
Picks two appropriate points Gradient = ΔB/ ΔI = (0.0067-.0005)/(14-1) = 4.76×10^{-4} (accept 4.54×10^{-4} to 5.01×10^{-4})	1
μ = 2π × Gradient (Allow μ_a = 2π × Gradient) = 2.99×10^{-3} (accept 2.85×10^{-3} to 3.15×10^{-3}) Definition of μ_a and μ ambiguous so ignore any further manipulation of 2π × Gradient using the formula $\mu = \mu_0\,\mu_a$	1
Total	**3**

(b) Use the gradient and the vertical error bars in the graph on page 14 to comment on the uncertainty of your answer to part (a). Express your answer in the appropriate significant figures. (4 marks)

Description	Marks
Picks two other points to calculate max gradient Gradient = $\Delta B / \Delta I$ = (0.0073-(-0.0001))/(14-1) = 5.69×10^{-4}	1
Picks two other points to calculate min gradient Gradient = $\Delta B / \Delta I$ = (0.0061-0.01)/(14-1) = 3.92×10^{-4}	1
Gradient uncertainty is (5.69×10^{-4} - 3.92×10^{-4})/2) = $\pm 0.885 \times 10^{-4}$ $\pm\mu = 2\pi \times$ Gradient uncertainty = $2\pi \times \pm 0.885 \times 10^{-4}$ = $\pm 5.56 \times 10^{-4}$	1
= $3.0 \times 10^{-3} \pm 0.6 \times 10^{-3}$ (allow two significant figures to tolerance)	1
Total	**4**

End of Section One

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

Question 14 **(13 marks)**

(a) Calculate the magnitude of the initial velocity of the ball. (2 marks)

Description	Marks
$u_{Ball} = (u_v^2 + u_h^2)^{½}$ $= (12^2 + 10^2)^{½}$	1
$= 15.6$ m s^{-1}	1
Total	**2**

(b) (i) Show by calculation that the total time taken by the ball in the air to get from 1.00 m above the ground to 3.00 m above the ground could be either 0.180 s or 2.27 s. (3 marks)

Description	Marks
The net height is 3 m – 1 m s = 2 m	1
$s = u_v \times t + ½ \times g \times t^2 = 12\ t - 4.9\ t^2$ if $t_1 = 0.18$ s **or** $t_2 = 2.27$ s $s = 12 \times 0.18 - 4.9 \times 0.18^2$ $= 2.00$ m $s = 12 \times 2.27 - 4.9 \times 2.27^2$ $= 1.99$ m	1–2
Total	**3**

(ii) Which of these two calculated time values in part (b)(i) is more appropriate for the ball to travel to Quinn? State a reason why. (2 marks)

Description	Marks
2.27 s	1
This allows for the maximum distance to be achieved **or** 0.18 s is the time taken to get to 3 m while still going up.	1
Total	**2**

(c) Determine the horizontal distance (*s*) the ball will cover before Quinn catches it at point R. (2 marks)

Description	Marks
$s = u_H t = 10 \times 2.27$	1
$= 22.7$ m	1
Total	**2**

(d) Determine the average speed at which Quinn would need to travel from point Q to be able to catch the ball at point R. (3 marks)

Description	Marks
$d = (22.7^2 - 15^2)^{1/2} = 17.0$ m	1
$v_{avg} = 17 / 2.27$	1
$= 7.51$ m s^{-1}	1
Total	**3**

(e) Determine the ground angle (θ) at which Paul needs to kick the ball as shown on the initial diagram so that the ball travels to point R. (1 mark)

Description	Marks
$\theta = \tan^{-1}(17/15)$ $= 48.6°$	1
Total	**1**

Question 15 **(10 marks)**

(a) (i) Show that the lepton number is conserved in such an interaction. (3 marks)

Description	Marks
$hf + Z \rightarrow e^- + e^+ + Z$ **or** $\gamma \rightarrow e^- + e^+$	1
L for LHS = 0, L for RHS = 1 + -1 = 0	1
Therefore L is conserved (same on both sides)	1
Total	**3**

(ii) Given $E = mc^2$, determine the minimum frequency of a photon that could produce an electron-positron pair. (4 marks)

Description	Marks
$hf = mc^2$	1
$m = 9.11 \times 10^{-31} \times 2$ $= 1.82 \times 10^{-30}$ kg	1
$f = 1.82 \times 10^{-30} \times [3\times10^8]^2/6.63 \times 10^{-34}$	1
$f = 2.47 \times 10^{20}$ Hz	1
Total	**4**

Question 15 (continued)

(b) (i) Demonstrate that the baryon number is preserved in the way that the equation is written above but the lepton number is not. (2 marks)

Description	Marks
B = 1 LHS, B = 1 RHS – B is conserved	1
L = 0 LHS, L = 1 RHS – L is not conserved	1
Total	**2**

(ii) Identify the third particle in the decay to ensure that the lepton number is conserved. (1 mark)

Description	Marks
Electron antineutrino	1
Total	**1**

Question 16 **(9 marks)**

(a) Identify the elementary particle responsible for mediating each of the following phenomena and complete each sentence. (3 marks)

The elementary particle responsible for the weak force is the ________________.

The elementary particle responsible for the strong force is the ________________.

The elementary particle responsible for the electrostatic force is the ________________.

Description	Marks
W or Z boson	1
Gluon	1
Photon	1
Total	**3**

(b) (i) The relative strength of the gravitational force would **best** be described as (1 mark)

A 10^{12}.
B 10^{-4}.
C 10^{-12}.
D 10^{-38}.

Description	Marks
C **or** D	1
Total	**1**

(ii) Give an appropriate reason for your choice. (2 marks)

Description	Marks
Gravitational force does not contribute (too small) to subatomic interactions. Must be significantly lower strength than strong or weak force Note: Other explanations could compare EM force with gravitational force	1–2
Total	**2**

(c) The order of evolution of forces directly after the big bang is best thought of as (1 mark)

A gravitational first, then strong and weak last.
B weak first, then strong and gravitational last.
C strong first, then weak and gravitational last.
D simultaneous, i.e. that all forces were created at the same moment.

Description	Marks
A	1
Total	**1**

(d) A graviton is the proposed particle that mediates gravity but is as yet undiscovered. Suggest a characteristic for the graviton and give a reason why. (2 marks)

Description	Marks
0 mass – range of the force is infinite and force weakens with $1/r^2$ therefore must have 0 mass (could also explain that as force acts at an infinite distance the particle must travel at c, therefore mass=0) **or** 0 charge – would already have been detected as charged particles are identifiable through interaction with magnetic fields **or** could also provide (but is not part of the course) Spin = 2 – odd spin forces result in repulsive force between equal charges, gravity has no repulsive interaction so must have a non-odd spin i.e. 2.	1–2
Total	**2**

Question 17 **(13 marks)**

(a) Use appropriate formulae and calculations to show that the probe was able to move away from the Earth and not be captured in orbit around it. (6 marks)

Description	Marks
$F_c = F_g$ $m_1v^2/r = Gm_1m_2/r^2$	1
$v^2 = Gm_1/r$ **or** $r = Gm_1/v^2$	1
$r = 5.59 \times 10^5 + 6.37 \times 10^6 = 6.929 \times 10^6$ m	1
For orbit: $v = (6.67 \times 10^{-11} \times 5.97 \times 10^{24}/6.929 \times 10^6)^{½}$	1
$v = 7.58 \times 10^3$ m s^{-1}	1
v is much higher than this therefore can escape orbit	1
Total	**6**

Question 17 (continued)

(b) The Juno probe was launched from Earth on 5 August 2011 and entered Jupiter's orbit on 5 July 2016, a trip of 1796 days. It had an average velocity of 7.15×10^4 m s^{-1}. Assume there was no effect from gravitational fields.

(i) Compared to a clock on Earth, would a clock on the Juno probe be reading faster or slower? (1 mark)

A faster
B slower

Description	Marks
B	1
Total	**1**

(ii) Calculate the time difference between the two clocks. (4 marks)

Description	Marks
Converts to seconds $1796 \times 24 \times 60 \times 60 = 1.551744 \times 10^8$ s = t_0	1
$t = 1.551744 \times 10^8/[1 - (7.15 \times 10^4/3 \times 10^8)^2]^{½}$	1
t = 155174404.4 s	1
Difference = $t - t_0$ = 4.41 s	1
Total	**4**

(iii) Apart from gravitational effects, what **two** assumptions did you make in your calculations? (2 marks)

Description	Marks
Velocity is constant during the flight (not accelerating)	1
Velocity is relative to a stationary Earth **or** equipment accuracy	1
Total	**2**

Question 18 **(20 marks)**

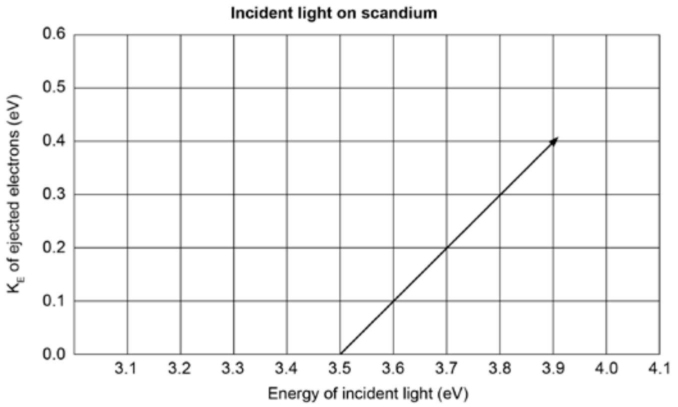
(a) Explain what is meant by the term 'work function' as it relates to the photoelectric effect. (2 marks)

Description	Marks
The minimum energy required to remove an electron from the surface of a material **or** The minimum energy of an incident photon which will eject an electron from the surface of a material	1–2
Total	**2**

(b) (i) Calculate the maximum kinetic energy, in electron volts of an ejected photoelectron when ultraviolet light is used on a scandium surface. (4 marks)

Description	Marks
h = 6.63 × 10^{-34} J s / 1.6 × 10^{-19} J per eV = 4.144 × 10^{-15} eV	1
E_{Photon} = hc/λ = (4.144 × 10^{-15} × 3 × 10^8) / (3.38 × 10^{-7}) = 3.678 eV	1
E_k = E_{Photon} - W = (4.144 × 10^{-15} × 3 × 10^8) / (3.38 × 10^{-7}) eV – 3.50 eV = 3.678 – 3.50	1
= 0.178 **or** 0.18 eV	1
Total	**4**

(ii) Sketch a graph of the kinetic energies of photoelectrons versus the energy of light incident on a scandium surface. (2 marks)

Description		Marks
	Intercepts x axis at 3.50 Line passes through (3.68, 0.18)	1–2
	Total	**2**

(c) When the violet light is used on an unknown material, a stopping potential difference of 0.350 V reduces the photocurrent to zero.

(i) Calculate the work function of this material. (4 marks)

Description	Marks
E_{Photon} = hc/λ = (4.144 × 10^{-15} × 3 × 10^8) / (3.86 × 10^{-7}) = 3.22 eV	1–2
E_k = E_{Photon} - W Work function = E_{Photon} - stopping potential = (4.144 × 10^{-15} × 3 × 10^8) / (3.86 × 10^{-7}) eV – 0.350 eV = 3.22 – 0.350 = 2.87 eV	1–2
Total	**4**

(ii) From the table on page 26, determine the possible element in the material. (1 mark)

Description	Marks
Calcium	1
Total	**1**

Question 18 (continued)

(iii) Explain what happens when the yellow (585 nm) light is incident on the unknown surface. Include a calculation to support your answer. (4 marks)

Description	Marks
No current occurs or no electrons are ejected.	1
E_{Yellow} $= (4.144 \times 10^{-15} \times 3 \times 10^{8}) / (5.85 \times 10^{-7})$ $= 2.12$ eV	1–2
This is less than W for the surface	1
Total	**4**

(d) Explain how the photoelectric effect demonstrates one of the properties of light. (3 marks)

Description	Marks
Photoelectric effect demonstrates that light is a particle.	1
Energy of the individual particle of light incident on the material must be higher than the work function of the material for electrons to be ejected.	1
If light was a wave, intensity of the light would be sufficient for electrons to be ejected.	1
Total	**3**

Question 19 **(12 marks)**

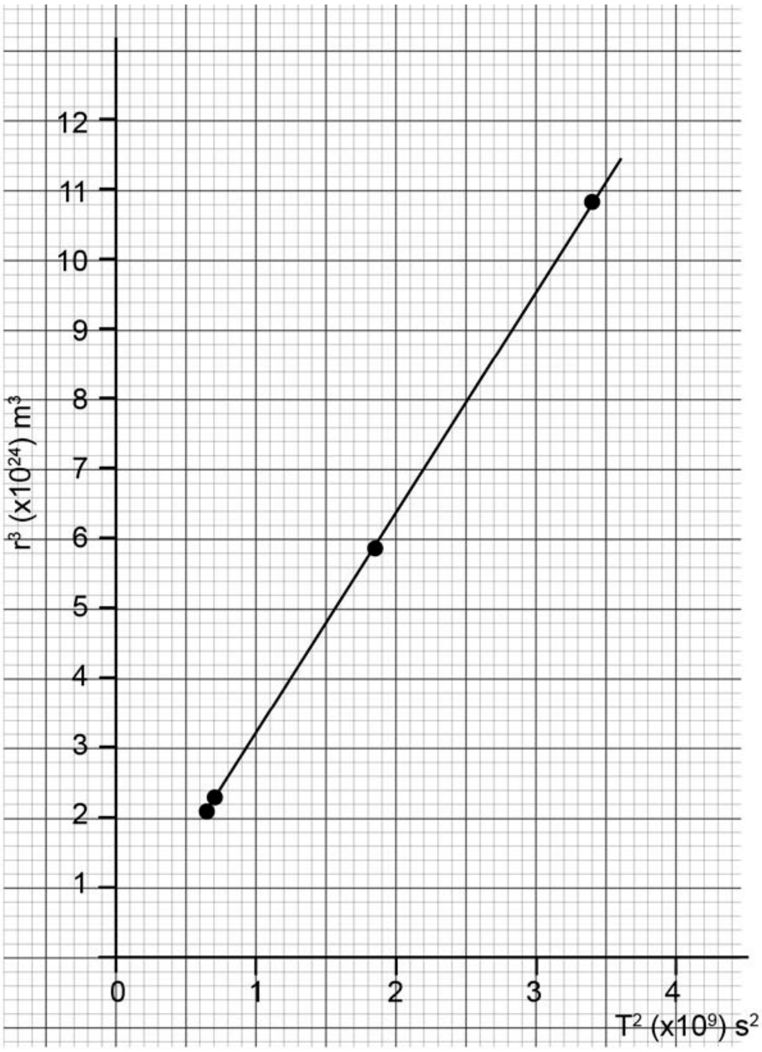
(a) Complete the following table, using the data provided for the moons. (2 marks)

Moon	**Orbital radius (r) ($\times 10^{6}$ m)**	**Orbital period (T) ($\times 10^{3}$ s)**	**r^3 ($\times 10^{24}$)**	**T^2 ($\times 10^{9}$)**
Metis	128	25.5	2.10	0.65
Adrastea	129	25.8	2.15	0.67
Amalthea	181	43.0	5.93	1.85
Thebe	222	58.3	**10.94**	**3.40**

Description	Marks
10.94 **or** 10.9	1
3.40	1
Total	**2**

(b) Plot the data from the table above onto the grid on page 31, demonstrating the relationship described by Kepler's laws of planetary motion. Draw the line of best fit.

(4 marks)

Description	Marks
Axes labelled with suitable scale	1
Correct units shown	1
Data points correctly drawn	1
Line of best fit drawn correctly	1
	
Total	**4**

Question 19 (continued)

(c) Using your graph, determine Kepler's constant (the ratio of r^3 to T^2). Express your answer in the appropriate significant figures. (3 marks)

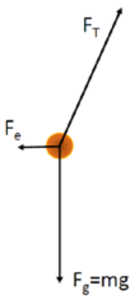
Description	Marks
Uses gradient and not data points	1
$r^3/T^2 = 3.2(\pm0.1) \times 10^{15}$	1
2-3 significant figures	1
Total	**3**

(d) Use your graph to determine the mass of Jupiter. (3 marks)

Description	Marks
$r^3/T^2 = GM_J/4\pi^2$ $M_J = 4\pi^2(r^3/T^2)/G$	1
$M_J = 4\pi^2 \times 3.2 \times 10^{15}/6.67 \times 10^{-11}$	1
$M_J = 1.9 \times 10^{27}$ kg	1
Total	**3**

Question 20 **(13 marks)**

(a) On the ball below complete a labelled, free body diagram of the force(s) acting on one of the balls. (3 marks)

Description	Marks
 Draws in the three forces shown At least two labelled appropriately Does not include any extra forces	1–3
Total	**3**

(b) Show by calculation that the magnitude of the velocity of each ball is 2.76 m s^{-1}. (1 mark)

Description	Marks
$v = 2\pi r/t$ = 2 × 3.14 × 1.10 / 2.50 = 2.76 m s^{-1}	1
Total	**1**

(c) Determine the angle (θ) and the tension (F_T) of the cord. (6 marks)

Description	Marks
Horizontally $F_T \times \sin\theta - F_e = F_c$ $F_T \times \sin\theta = mv^2/r + k_0(Q_1 \times Q_2)/d^2$ $F_T \times \sin\theta = (0.2 \times 2.76 \times 2.76) / 1.10 +$ $(8.99 \times 10^9 \times 7.0 \times 10^{-6} \times 7.0 \times 10^{-6}) / (2.2)^2$ $F_T \times \sin\theta = 1.385 + 0.0913 = 1.476$ N	1–3
Vertically $F_T \times \cos\theta = mg$ $F_T \times \cos\theta = 0.2 \times 9.8 = 1.96$ N	1
$\theta = \tan^{-1}(1.476/1.96) = 37.0°$	1
$F_T = 1.476 / \sin\theta$ $= 1.476 / \sin 37.0° = 2.45$ N **or** uses Pythagoras	1
Total	**6**

(d) In completing the calculations for part (c), why it is reasonable to consider the gravitational attraction between the two spheres to be negligible? Use a formula to support your answer. (3 marks)

Description	Marks
There is a gravitational force that exists between the spheres	1
The force is very small and would not affect the answer's magnitude when calculated to 3 significant figures	1
Quantifies magnitude somehow e.g. $F_g = Gm_1m_2/r^2$ $= 6.67 \times 10^{-11} \times 0.2 \times 0.2/2.2^2$ $= 5.51 \times 10^{-13}$ N (which is small indeed)	1
Total	**3**

End of Section Two

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

Question 21 **(22 marks)**

(a) An electron is accelerated to 0.189c by the SEM.

(i) Ignoring relativistic effects, calculate the accelerating potential needed to achieve this velocity. (4 marks)

Description	Marks
$v = 0.189c = 5.67 \times 10^7$ m s^{-1}	1
$V q = ½ m_e v^2$ $V = ½ m_e v^2 /q$ $V = ½\ 9.11 \times 10^{-31}(5.67 \times 10^7)^2/1.6 \times 10^{-19}$	1–2
$= 9.15 \times 10^3$ V	1
Total	**4**

(ii) Ignoring relativistic effects, calculate the wavelength of this electron. (3 marks)

Description	Marks
$\lambda = h/p = h/mv$	1
$\lambda = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 5.67 \times 10^7)$	1
$= 1.28 \times 10^{-11}$ m	1
Total	**3**

(b) Infer what information the detectors are able to measure to allow researchers to determine the composition of the material. (3 marks)

Description	Marks
Lists two or more physical process with two measurements **or** uses one physical process with measurement and description of use	3
Lists two or more physical process with one measurement only e.g. frequencies of x-rays or values of current flow	2
Lists two or more physical processes only	1
Total	**3**

(c) The H-3000 used an acceleration voltage of 2000 kV to accelerate an electron from rest.

(i) Calculate the speed of the electron according to the classic model of energy conservation. (3 marks)

Description	Marks
$V q = ½ m_e v^2$ $v^2 = 2 V q / m_e$	1
$v^2 = 2 \times 2000 \times 10^3 \times 1.6 \times 10^{-19} / 9.11 \times 10^{-31} = 7.03 \times 10^{17}$	1
$v = 8.38 \times 10^8$ m s^{-1}	1
Total	**3**

(ii) Explain the behaviour of the electron, taking relativistic effects into account. (3 marks)

Description	Marks
The speed of an electron cannot go greater than the speed of light because of the relativistic effects on the mass (energy or momentum) of the electron	1
When the speed approaches the speed of light, the electron's mass increases **or** When the speed approaches the speed of light, the electron's momentum approaches infinity, despite little change to its speed $p = m v [1/(1-v^2/c^2)^{1/2}]$ **or** According to mass-energy equivalence $E = m c^2 [1/(1-v^2/c^2)^{1/2}]$, the kinetic energy of the electron approaches infinity as the electrons velocity approaches the speed of light despite little change to its speed	1-2
Total	**3**

(d) Estimate the maximum cross-sectional diameter of the electron beam. For simplicity, assume circular motion of electrons due to the magnetic field. Express your answer in the appropriate significant figures. (5 marks)

Description	Marks
$F_m = v q B$ and $F_c = mv^2/r$ $F_m = F_c$ $r = m v / q B$	1
$v = 0.01 \times 6.3 \times 10^7 = 6.3 \times 10^5$	1
$r = 9.11 \times 10^{-31} \times 6.3 \times 10^5 / 1.6 \times 10^{-19} \times 3.5 \times 10^{-3}$ $r = 1.02 \times 10^{-3}$ m	1
Estimated e-beam size (diameter D) = 2 r = $2 \times 1.02 \times 10^{-3}$ $D = 2.0 \times 10^{-3}$ m	1
One or two significant figures	1
Total	**5**

(e) Estimate the expected magnification of the H-3000. (1 mark)

Description	Marks
Micrometre was 1 200 Nanometre was 1 000 000 Picometre could be expected to be another 1000× so 1 000 000 000	1
Total	**1**

Question 22 **(14 marks)**

(a) The Swarm satellite system allows scientists to look past the magnetic fields generated by the ionosphere (a layer of the atmosphere containing particles ionised by radiation). Infer how the ionosphere would generate magnetic fields. (2 marks)

Description	Marks
Ionosphere is composed of charged particles (States this only, one mark). Moving charged particles (current) generate magnetic fields	1-2
Total	**2**

(b) Estimate the strength of the magnetic field detected by a satellite at a height of 460 km above the Earth's surface, if the Earth's magnetic field measures 5×10^{-5} T at the surface. Express your answer in the appropriate significant figures. (4 marks)

Description	Marks
Estimate that B generated at a depth of 3000 km (accept up to 6400 km)	1
Assuming cylindrical expansion: $Br = (\mu_0/2\pi) \times I =$ constant $B_h r_h = B_s r_s$ $B_h = 5 \times 10^{-5} \times 3000/3460$ $B_h = 4.3 \times 10^{-5}$ T (answer may range between this and 4.7×10^{-5} T) **or** spherical expansion: 3460^2 B = $5 \times 10^{-5} \times 3000^2$ (B α $1/r^2$) B = 3.8×10^{-5} T (answer may range between this and 4.4×10^{-5} T) **or** B α $1/r^3$ (If candidate has knowledge of dipole fields)	1–2
One or two significant figures	1
Total	**4**

(c) The Earth's magnetic field is thought to be generated by convection currents in the iron/nickel molten outer core. Explain how a magnetic field could be generated by a convection current of molten iron/nickel. (2 marks)

Description	Marks
Fe/Ni are ferromagnetic materials. The moving metal (ions/electrons) generate electrical currents which have a corresponding magnetic field.	1–2
Total	**2**

(d) The jet is detected by changes in the Earth's magnetic field due to the presence of 'flux lobes'. Explain how the flux lobes are produced. (3 marks)

Description	Marks
Produced by the movement of molten iron	1-2
Jet/stream of molten iron creates a magnetic flux which moves out and distorts the field	1
Total	**3**

(e) In the article, one professor thought the 'acceleration of the jet was due to push-back from magnetic fields'. Elaborate, using appropriate physics principles. (3 marks)

Description	Marks
Magnetic material, in this case the iron/nickel, creates currents. This experiences a force in a magnetic field when they cut flux lines and this accelerates the jet. If only uses the provided text: 'The flow of iron generates the magnetic field, but, he says, the magnetic field may then be affecting the flow of the iron.' (one mark)	1–3
Total	**3**

End of questions

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Question 22 Quotes from adaptation of: Coghlan, A. (2016, December 19). Molten iron river discovered speeding beneath Russia and Canada. *New Scientist Daily News*. Retrieved December, 2016, from www.newscientist.com/article/2116536-molten-iron-river-discovered-speeding-beneath-russia-and-canada/

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