ACADEMIC ASSOCIATES
Make Success a Reality

PHYSICS

UNIT 3 Semester One 2019

Marking Key

Marking keys outline the expectations of examination responses. They help to ensure a consistent interpretation of the criteria that guide the awarding of marks.

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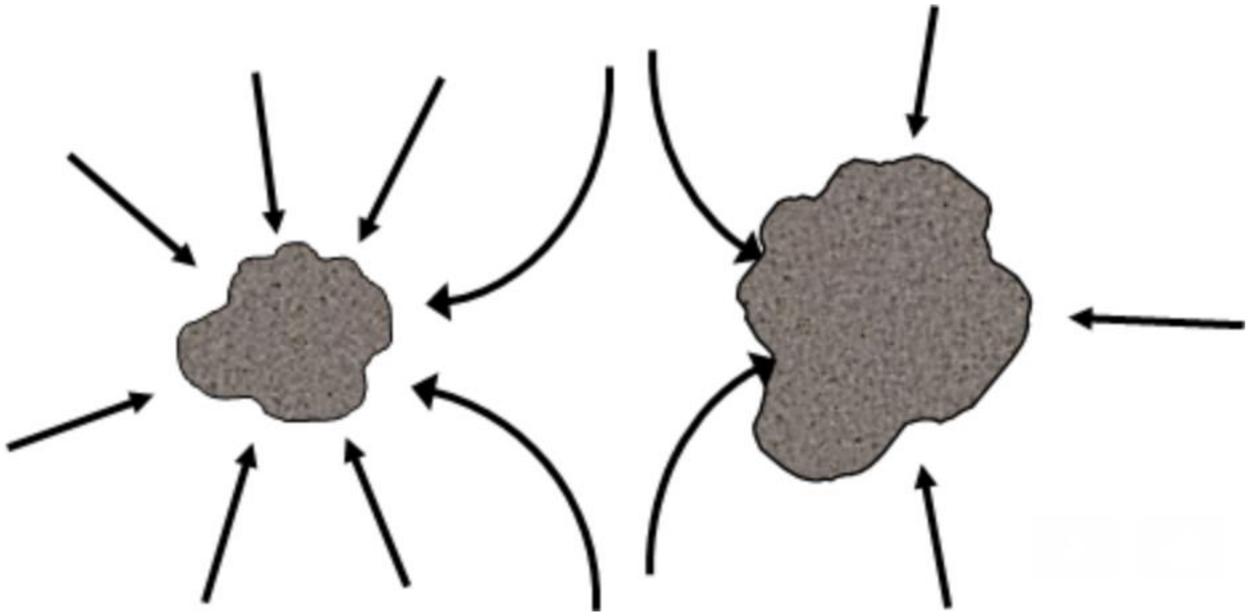
Section One: Short reponse **30% (54 Marks)**

Question 1

The diagram below is of two asteroids in close proximity. The gravitational field in this region has also been included.



Which asteroid (left or right) has the larger mass? Explain your choice. (3 marks)

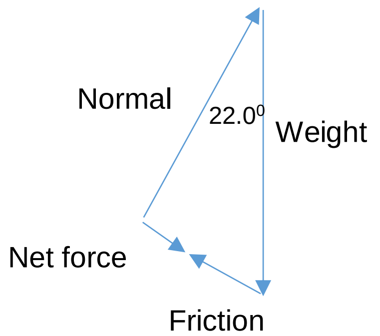
Description	Marks
Left	1
Describes how field shape shows evidence of answer “The field lines on the left are closer together/denser/has more field lines/the vertical asymptote favours the left”	1
Explains relationship between field and mass “This is caused by the larger mass which produces a larger gravitational field strength”/”Denser field lines is an indication of larger mass”	1
Total	**3**

Question 2

A 600 g block on a ramp inclined at 22.0^0 is accelerating down the ramp at 2.16 m s^{-2}.

(a) Draw a labelled vector diagram showing the relationship between the physical forces and the net force acting on the block. Include the angle in the diagram. (3 marks)

Description	Marks
All vectors labelled showing forces in correct positions	1
Arrow heads show correct relationship/directions	1
Places angle in correct corner	1
Total	**3**



(b) Calculate the frictional force acting on the block. (3 marks)

Description	Marks
Finds net force $\sum F = ma = 0.600 \times 2.16 = 1.296\ N$	1
Uses vector relationship to find friction $\sum F = F_{\|\|} - F_{friction}$ $F_{friction} = F_{\|\|} - \sum F$ $F_{friction} = mgsin\theta - \sum F$ $F_{friction} = 0.600 \times 9.8 \times \sin(22.0) - 1.296 = 0.907\ N$	1-2
Total	**3**

Question 3

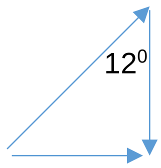
State whether the following statements are true or false for an ideal projectile, ignoring air resistance. If **false**, explain why. (6 marks)

Description	Marks
As per table below (one mark for each table entry)	1
Total	**1**

Statement	True or False?	If **false**, why?
A projectile only accelerates towards the ground	True	
The horizontal velocity of a projectile changes by 9.8 m s^{-1} each second	False	The horizontal velocity is constant/ This should be for vertical velocity
The velocity of all projectiles at their highest point is 0 m s^{-1}	False	May still have horizontal/only vertical is 0 m s^{-1}
The range of the projectile depends on the time in the air and the initial horizontal velocity	True	

Question 4

A car goes around a 32.0 m radius curve on a banked track that is inclined at 12.0^0. A net force of 1790 N is applied to the car which keeps the car in a horizontal plane. Calculate the mass of the car. Use a vector diagram to assist with your calculation. (3 marks)

Description	Marks
Vector diagram 	1
$mg = \frac{F}{tan\theta}$ $m = \frac{F}{gtan\theta} = \frac{1790}{9.8tan12} = 859\ kg$	1-2
Total	**3**

Question 5

Mars has 10.7% the mass of Earth and has a radius 53.2% of that of the Earth.

(a) Calculate the gravitational field strength on the surface of Mars. (3 marks)

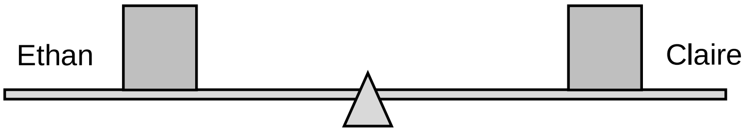
Description	Marks
$g = \frac{GM}{r^2}$	1
$g = \frac{6.67\times10^{-11}\times0.107\times5.97\times10^{24}}{(0.532\times6.37\times10^6)^2} = 3.71\ N\ kg^{-1}$	1-2
Total	**3**

The parachute of a 56.0 kg NASA Mars rover fails as it descends to the surface of Mars. Ignoring air resistance, what is the acceleration of the rover close to the surface of Mars? (1 mark)

Description	Marks
Gives same answer as part (a)	1
Total	**1**

Question 6

Ethan and Claire sit either side of the fulcrum of a see-saw, as shown in the diagram below. The plank of the see-saw has a 12.5 kg centre of mass located at the fulcrum.



Ethan has a 32.0 kg mass and Claire a 28.0 kg mass. Claire sits 1.23 times further from the fulcrum than Ethan. One of the children has their feet on the floor, pushing on it so that the see-saw is in equilibrium. Which child is touching the floor and what is the magnitude of this pushing force?

(5 marks)

Description	Marks
$let\ l\ be\ the\ length\ of\ Ethan\ to\ pp$ Ethan torque (in terms of l) $32.0 \times 9.8 \times l = 313.6l$ Claire torque (in terms of l) $28.0 \times 9.8 \times 1.23l = 337.5l$ Claire has feet on floor as has bigger torque on her side and needs to compensate	1-3
$\sum \tau_{cw} = \sum \tau_{acw}$ $337.5l = 313.6l + F \times 1.23l$ $F = \dfrac{337.5 - 313.6}{1.23} = 19.4\ N$	1-2
Total	**5**

Question 7

Two spheres with equal but opposite electric charge are placed 7.55 cm apart and experience 5.11×10^{-4} N of attractive force. Calculate the magnitude of the electric charge on each sphere.
(3 marks)

Description	Marks
$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \quad where\ q_1 = q_2$	1
$q = \sqrt{4F\pi\varepsilon_0 r^2}$ $q = \sqrt{4 \times 5.11 \times 10^{-4} \times 3.14 \times 8.85 \times 10^{-12} \times 0.0755^2} = 1.80 \times 10^{-8}\ N$	1-2
Total	**3**

Question 8

Calculate the range of a projectile fired at 5.60 m s^{-1}, launched from a height of 12.5 m above the ground. The projectile is fired at 22.0^0 below the horizontal plane and you should ignore air resistance.
(4 marks)

Description	Marks
Finds initial horizontal and vertical components of speed $u_h = ucos\theta = 5.60cos22 = 5.192\ m\ s^{-1}$ $u_v = -usin\theta = -5.60sin22 = -2.098\ m\ s^{-1}$	1
Finds time in air $s_v = u_v t + \frac{1}{2}at^2$ $-12.5 = -2.098t + \frac{1}{2}(-9.8)t^2$ Quadratic solution is $t = 1.3974\ s$ ** May also use $t = t_{up} + t_{down}$	1-2
Finds range $s_h = u_h t = 5.192 \times 1.3974 = 7.26\ m$	1
Total	**4**

Question 9

Two identical wires are arranged so they are parallel and each carries 1.32 A. The magnetic flux density exactly half way between the wires is 30.0 µT – only the wires are responsible for this magnetic field.

(a) Are the wires carrying the current in the same direction or in opposite directions? Justify your choice. (2 marks)

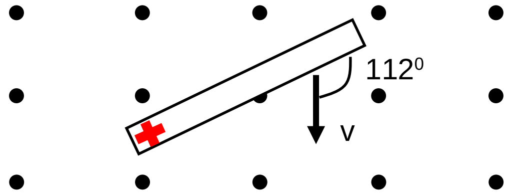
Description	Marks
States direction "Opposite"	1
Justifies based on flux information "Wires running in the same direction would create magnetic fields that oppose each other, which would mean no flux present – there is flux so wires must be opposite"	1
Total	**2**

(b) Calculate the distance halfway between both wires. (3 marks)

Description	Marks
$B = \frac{\mu_0}{2\pi}\frac{I}{r}$ $where\ B\ is \frac{30}{2} = 15\ \mu T$	1
$15.0 \times 10^{-6} = \frac{4\pi\times10^{-7}}{2\pi}\frac{1.32}{r}$ $r = 1.76 \times 10^{-2}\ m$	1-2
Total	**3**

Question 10

A 0.800 m metal rod is moving down through a magnetic field at 12.0 m s^{-1} as shown in the diagram below. The magnetic flux density it 29.0 mT.



(a) On the diagram, indicate which region of the rod would accumulate positive charge. (1 mark)

Description	Marks
Shows positive charge on far left side of rod (see above)	1
Total	**1**

(b) Calculate the magnitude of the emf across the rod. (4 marks)

Description	Marks
$\varepsilon = vBl$	1
$= 12.0 \times 29.0 \times 10^{-3} \times 0.800 \times \sin(112) = 0.258\ V$	1-3
Total	**4**

Question 11

A transformer uses principles of electromagnetism to manipulate an input voltage to a higher or lower value. Describe how a transformer achieves its purpose by referring to Faraday's law and the components of a transformer; primary windings, soft iron core and secondary windings.

(5 marks)

Description	Marks
States that input voltage produces an alternating magnetic field	1
States that the soft iron core directs/intensifies the field within the secondary windings	1
States that the secondary windings have an induced emf because of the alternating field **and** states this is Faraday's law	1-2
States that the output voltage to input voltage ratio matches the ratio of the secondary windings to primary windings	1
Total	**5**

Question 12

An AC generator uses 200 windings in the armature, which has a 20.0 cm^2 cross sectional area within a 150 mT field. Calculate the rms voltage the generator outputs when operating at 115 Hz.

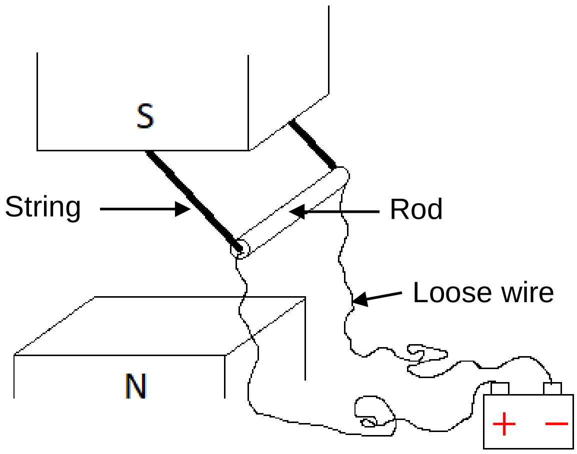
(5 marks)

Description	Marks
Max emf $\varepsilon_{max} = 2\pi NBAf$ $\varepsilon_{max} = 2 \times 3.14 \times 200 \times 0.150 \times \frac{20.0}{100^2} \times 115 = 43.35\ V$	1-3
RMS value $\varepsilon_{rms} = \frac{\varepsilon_{max}}{\sqrt{2}}$ $\varepsilon_{rms} = \frac{43.35}{\sqrt{2}} = 30.7\ V$	1-2
Total	**5**

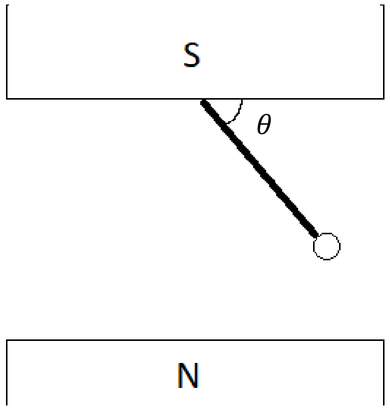
Section Two: Problem-solving **(90 Marks)**

Question 13 **(15 marks)**

A 20.0 cm long conducting rod forms a circuit with a 3.00 V battery, connected via some loose wires which dangle freely from either end of the rod. The rod is also tethered to a magnet via a pair of strings and can swing freely. Another magnet sits below the rod to create a uniform 0.500 T field. The rod's uniform distributed mass is 0.0900 kg and has a 2.00 Ω resistance. You may assume the mass of the string and loose wires are negligible and the resistance of the loose wires is negligible.



Detailed View



Simplified 2D view

When everything is connected, the rod swings to one side and remains in the position shown in the simplified 2D view.

(a) By drawing a positive and negative sign, label the polarity of the battery in the diagram above. (1 mark)

Description	Marks
See above (one mark for positive and negative labelled correctly)	1
Total	**1**

Question 13 (continued)

(b) Calculate the current through the rod. (1 mark)

Description	Marks
$I = \frac{V}{R} = \frac{3.00}{2.00} = 1.50\ A$	1
Total	**1**

(c) Calculate the magnetic force acting on the rod. (2 marks)

Description	Marks
$F = IBl = 1.50 \times 0.500 \times 0.200 = 0.150\ N$	1-2
Total	**2**

(d) Calculate the tension in one of the pieces of string. (4 marks)

Description	Marks
Finds weight force $F_g = mg = 0.0900 \times 9.8 = 0.882\ N$	1
Sums weight and magnetic forces, equating to tension $T = \sqrt{F_g^2 + F_{B^2}}$ $T = \sqrt{0.882^2 + 0.150^2} = 0.8947\ N$	1-2
Halves tension between two strings $T = \frac{0.8947}{2} = 0.447\ N$	1
Total	**4**

(e) Calculate the angle the string makes with the magnet face (θ in diagram). (2 marks)

Description	Marks
$\theta = \tan^{-1}\frac{F_g}{F_B} = \tan^{-1}\frac{0.882}{0.150} = 80.3^0$	1-2
Total	**2**

(f) The battery is removed and the loose wires left dangling, disconnected. The rod swings like a pendulum and comes to a complete stop in 5.60 s. The rod is returned to its starting position, prior to when the battery was removed. The loose wires that were connected to the battery are connected together. The rod is let go, swings like a pendulum but this time comes to a complete stop in 2.90 s. Explain the difference in time. (5 marks)

Description	Marks
States an induced emf forms when cutting flux lines "As the rod swings, it cuts through flux lines which will induce an emf according to Faraday's law"	1
Compares the open circuit vs closed circuit scenario "When the wires are connected, a current can flow around the circuit made by the rod and wires. When the wires are disconnected no current can flow"	1-2
States a retardation force slows the rod in the closed circuit scenario, in response to a new magnetic field being produced – reducing the time until stopping "When a current flows, it will produce a magnetic field that opposes the change in field caused by the movement of the rod – these fields interact to create a force that opposes the motion of the rod. This makes the coil slow down faster"	1-2
Total	**5**

Question 14 **(16 marks)**

A satellite galaxy is a galaxy that is bound to a parent galaxy. Just as a star is the dominant source of gravitational field within a solar system, causing satellite planets to orbit around it, a large parent galaxy is the dominant source of a gravitational field, causing smaller satellite galaxies to orbit around it. The Canis Major Dwarf Galaxy (CMDG) is proposed to be a satellite galaxy of the Milky Way. The CMDG has an average distance of 4.84×10^{17} km from the centre of the Milky Way and contains 1 billion stars. This makes the CMDG much smaller than the Milky Way which contains 250 billion stars. For these questions, you may assume the mass of each galaxy is a point mass at its centre and that the mass of our Sun is an average star's mass.

(a) Calculate the gravitational force that the Milky Way places on the CMDG. (3 marks)

Description	Marks
$F_g = \frac{GMm}{r^2}$ $F_g = \frac{6.67\times10^{-11}\times250\times10^9\times1.99\times10^{30}\times10^9\times1.99\times10^{30}}{(4.84\times10^{20})^2}$ $F_g = 2.819 \times 10^{29} = 2.82 \times 10^{29}\ N$	1-3
Total	**3**

(b) Calculate the velocity of the CMDG if it were to maintain a circular orbit about the Milky Way. If you could not obtain an answer to part (a) you may use 2.75×10^{29} N. (3 marks)

Description	Marks
$F_C = \frac{mv^2}{r}$ $v = \sqrt{\frac{F_C r}{m}}$	1
$v = \sqrt{\frac{2.819\times10^{29}\times4.84\times10^{20}}{10^9\times1.99\times10^{30}}} = 2.62 \times 10^5\ m\ s^{-1}$ $(answer\ is\ 2.59 \times 10^5\ m\ s^{-1}\ if\ used\ value\ in\ question)$	1-2
Total	**3**

(c) The Sun lies on the line between the centre of the Milky Way and the CMDG. The CMDG attracts the Sun with a force 0.350 % that of the Milky Way. Calculate the distance of the Sun from the centre of the Milky Way. (7 marks)

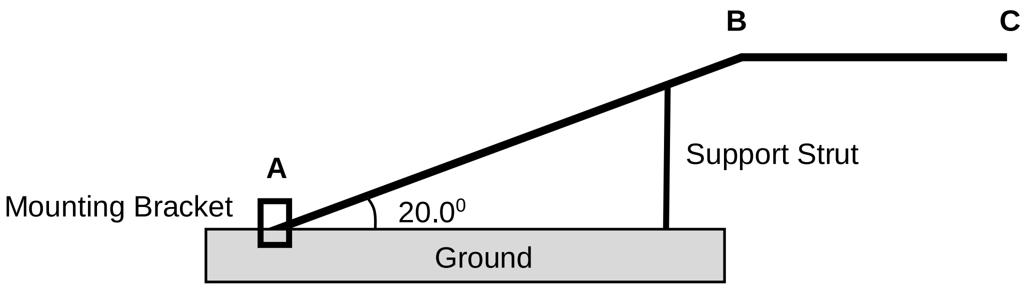
Description	Marks
Force of CMDG on Sun $F_{CMDG} = \frac{GM_{CMDG}m_s}{r_1^2}$ Force of MW on Sun $F_{MW} = \frac{GM_{MW}m_s}{r_2^2}$	1
Establish relationship between forces and distance $\frac{F_{CMDG}}{F_{MW}} = \frac{\frac{GM_{CMDG}m_s}{r_1^2}}{\frac{GM_{MW}m_s}{r_2^2}} = \frac{M_{CMDG}/r_1^2}{M_{MW}/r_2^2} = \frac{1/r_1^2}{250/r_2^2} = \frac{r_2^2}{250r_1^2}$	1-2
Uses question data to give relationship between distances $0.00350 = \frac{1}{250}\left(\frac{r_2}{r_1}\right)^2$ $\frac{r_2}{r_1} = 0.9354$	1-2
Solves for distance between Sun and centre of MW $r_1 + r_2 = 4.84 \times 10^{17}\ km$ $\frac{r_2}{0.9354} + r_2 = 4.84 \times 10^{17}$ $r_2 = 2.34 \times 10^{17}\ km$ or $2.34 \times 10^{20}\ m$	1-2
Total	**7**

(d) Neither the Milky Way nor the CMDG is a point mass – they are each a distributed mass of stars with large amounts of empty space. Which galaxy (Milky Way or CMDG) being modelled as a distributed mass would have the biggest impact on your answer to part (c)? Justify your response (3 marks)

Description	Marks
States the correct galaxy "Milky Way"	1
Refers to the Sun being inside the distributed mass "Some of the MW mass would be further from the centre than the Sun."	1
Justifies the effect the distributed mass has on gravitational force "Some of the MW mass would attract the Sun to the centre of the MW while others would attract it away from the centre."	1
Total	**3**

Question 15 **(15 marks)**

A junior engineer is tasked with analysing the safety of a new scaffold, designed to extend over surfaces that could not hold scaffolding. Platform AB is 12.5 kg and 2.00 m long. Platform BC is 6.20 kg and is 0.800 m long. A mounting bracket is located at point A which secures the platform to the ground and is free to rotate. A 75.0 kg worker stands on point C. A strut helps support the platforms by taking on a compression force, located 1.80 m along platform AB. The strut is rated to hold a maximum of 1.40 kN.



(a) Assuming the force of the strut acts vertically upwards onto AB, will the strut be able to support the platform and worker? Justify your answer. (5 marks)

Description	Marks
Checks torques balance around point A $\sum \tau_{acw} = \sum \tau_{cw}$	1
Has all 4 terms $F_{AB}r_{AB\perp} + F_{BC}r_{BC\perp} + F_{man}r_{man\perp} = F_s r_{s\perp}$	1
Calculation $12.5 \times 9.8 \times \frac{2.00}{2} cos20 + 6.20 \times 9.8 \times \left(2.00cos20 + \frac{0.800}{2}\right) + 75.0 \times 9.8 \times (2.00cos20 + 0.800) = F_s \times 1.80cos20$ $F_s = 1.314 \times 10^3 = 1.31 \times 10^3\ N$ The strut can support this force	1-3
Total	**5**

(b) Calculate the force the mounting bracket applies to the platform. Include the direction of this force. If you could not obtain an answer to part (a), you may use 1.31 × 10^3 N. (4 marks)

Description	Marks
Balances vertical forces (or reattempts torque from a new pp) $\sum F_v = 0$	1
Includes all terms (F_{brack}) may be assumed up or down at first $F_{AB} + F_{BC} + F_{man} + F_{brack} = F_s$	1
$12.5 \times 9.8 + 6.20 \times 9.8 + 75.0 \times 9.8 + F_{brack} = 1.314 \times 10^3$ $F_{brack} = 393\ N\ down$ $(or\ 392\ N\ using\ rounded\ answer\ from\ part\ a)$	1-2
Total	**4**

(c) If the strut was moved closer to point A, while still remaining vertical, explain what would happen to the force in the strut. (2 marks)

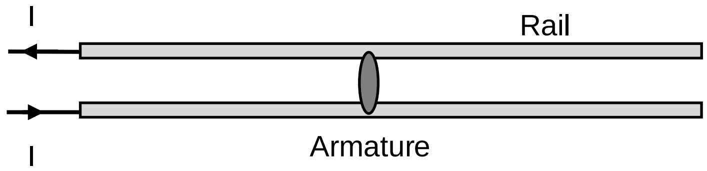
Description	Marks
States perpendicular distance decreases "The distance from the pivot point (point A) to the line of action of the strut decreases."	1
States force must increase to maintain same torque "To maintain equilibrium, the strut must provide more force to produce the required anticlockwise torque."	1
Total	**2**

(d) The junior engineer suggests making platform BC longer and thinner – his argument being the mass of platform BC would stay the same, so the strut could still hold the weight of the workers and they could reach further. Explain whether the junior engineer's idea is physically sound. (4 marks)

Description	Marks
States perpendicular distance increases "As the length of BC increases, the distance from the pivot point (point A) to the line of action of the BC platform and worker increases."	1
States clockwise torque increases "This produces a larger clockwise torque about point A"	1
States the extra cw torque is supported by an increase in force of strut – not physically sound idea "To maintain equilibrium, the strut must provide more force to produce the required anticlockwise torque. Thus the strut may break".	1-2
Total	**4**

Question 16 **(17 marks)**

A railgun is a device that utilises electromagnetic forces to accelerate and launch high speed projectiles. This has potential uses in weapons as well as launching objects into space. A railgun has two conducting rails (hence the name), aligned parallel like railway tracks. An armature (the projectile) can slide along these rails. A current is passed down one rail, through the armature and returns via the other rail.



The current passing through the rails produces a magnetic field into the space between the rails. The magnetic field of each rail contributes to create a net flux between the rails. The armature carries the same current as the rails but it flows perpendicular to the magnetic field produced by the rails. The magnitude of the magnetic force on the armature depends on the square of the current. Other factors such as the distance between the rails and magnetic permeability of air can be combined into one scaling factor, L', such that the force is given by:

$$F = \frac{L' I^2}{2}$$

- F is the force on the armature in newtons (N)
- L' is the inductance per unit length in henries per metre (H m^{-1})
- I is the current in the railgun circuit in amperes (A)

(a) State the direction of the magnetic force acting on the armature in the diagram of the railgun shown above. (1 mark)

Description	Marks
To the right	1
Total	**1**

(b) By referring to formulae from the Formula and Data Booklet, justify why the force is proportional to the square of the current. (3 marks

Description	Marks
Refers to $F = IlB$	1
Refers to $B = \frac{\mu_0}{2\pi} \frac{I}{r}$	1
Describes how these formula show $F \alpha I^2$ "The force is proportional to the current and to the magnetic field. As the magnetic field is also proportional to the current, the force is proportional to the square of the current."	1
Total	**3**

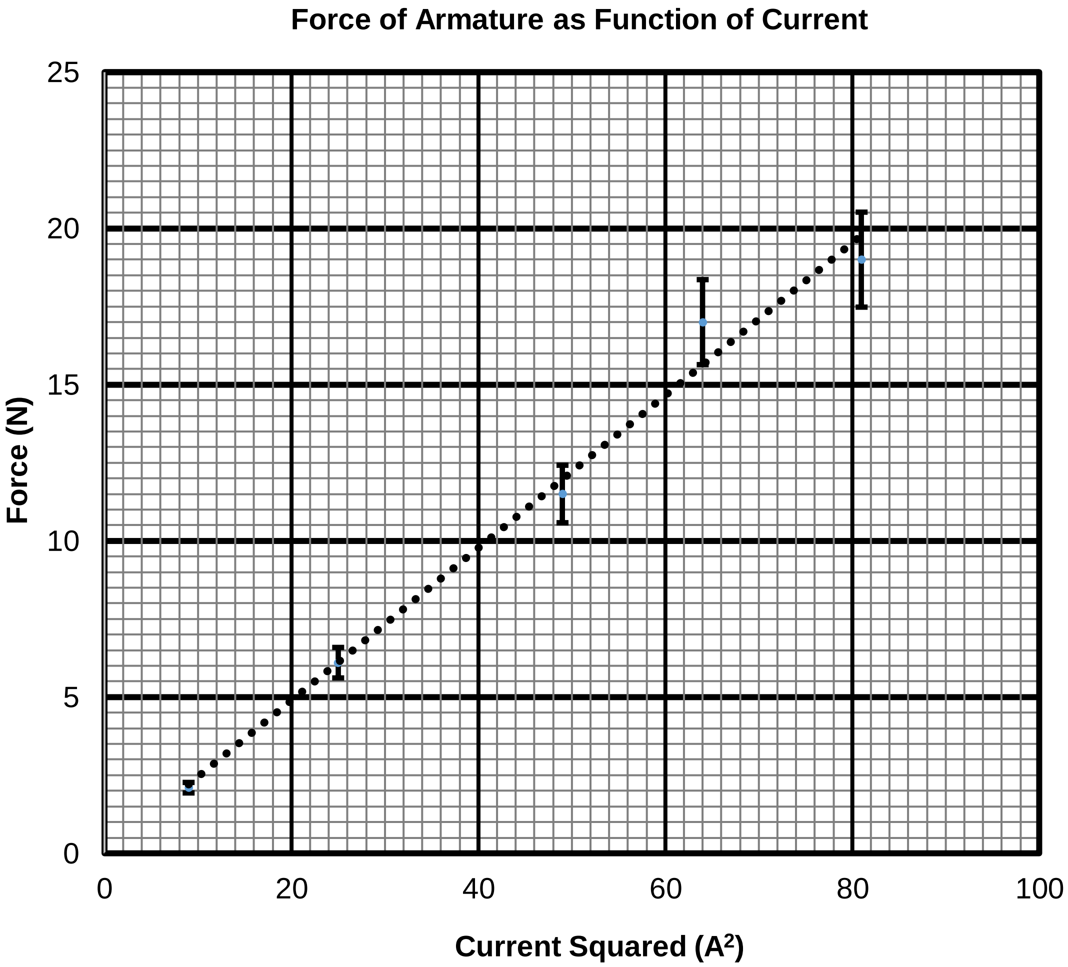
NASA testing obtained the following measurements for how force varied with current for a prototype railgun.

(c) NASA estimates the force measurements have an 8% uncertainty. Complete the absolute force uncertainty column in the table above. (1 mark)

Description	Marks
See completed table below. One mark for column completed correct.	1
Total	**1**

Current (A)	Force (N)	Force uncertainty (N)	I^2 (reference only *no marks*)
3.0	2.1	**0.17**	9.0
5.0	6.1	**0.49**	25
7.0	11.5	**0.92**	49
8.0	17.1	**1.4**	64
9.0	19.1	**1.5**	81

(d) Produce a line graph for NASA's experiment which includes error bars on the grid provided. You must manipulate the data such that the graph shows a linear relationship between the relevant variables of NASA's experiment. You may use the empty column in the table for additional working. (5 marks)



Description	Marks
Labelled axes, with units	1
Squares Current (or sqrt F)	1
Suitable scale and accurate points	1
Size of error bars	1
Line of best fit through error bars	1
Total	**5**

See next page

Question 16 (continued)

(e) Calculate the gradient of your line of best fit from the graph. Include units and show working. (3 marks)

Description	Marks
Shows working to determine gradient	1
Uses points from graph, not straight from table	1
Reasonable answer with units $\approx 0.25\ N\ A^{-2}$ or $H\ m^{-1}$	1
Total	**3**

Question 16 (continued)

(f) Using the gradient, determine the inductance per unit length (L') of the railgun used in this experiment. (2 marks)

Description	Marks
Shows working relating gradient to L' $gradient = \frac{F}{I^2}$ and $\frac{F}{I^2} = \frac{L'}{2}$ $L' = gradient * 2$	1
$L' = 0.25 \times 2 = 0.50\ H\ m^{-1}$	1
Total	**2**

(g) NASA scientists discover that the force acting on the armature reduces the further the armature moves along the rails in response to the magnetic force. Describe a likely explanation for the reduction in force. (2 marks)

Description	Marks
Identifies resistance increases “As the armature gets further along the rails, the total resistance of the circuit increases”	1
Identifies force will reduce due to lower current “Less current will flow, reducing the force.”	1
or	
Identifies increase in velocity results in larger back emf “As the armature accelerates, there will be a larger rate in change of flux, increasing the amount of induced back emf”	1
Identifies force will reduce due to lower current “Less current will flow because of the back emf, reducing the force.”	1
Total	**2**

Question 17 **(14 marks)**

A student designed and built motor is made from 200 windings of insulated copper wire, formed into a 6.00 cm x 9.00 cm rectangular coil. The student attaches a 12.0 V car battery to the coil via a split ring commutator and conducting brushes. A pair of strong rare earth magnets provided an external magnetic field. The students were delighted that their motor spun at 1200 rpm.

(a) Explain the interaction between the current in the coil and the magnets that causes a motor's coil to spin. (3 marks)

Description	Marks
Describes relationship between current, field and force. "The current in the coil experiences a force when flowing perpendicular to the magnetic field produced by the magnets ($F = IlB$)"	1-2
Describe how force produces unbalanced torques, thus spinning "The magnetic force acts away from the centre of rotation, causing an unbalanced torque, causing the motor to spin ($\tau = Fr$)"	1
Total	**3**

(b) Explain why the motor has a maximum rate of rotation, even if friction is negligible. (4 marks)

Description	Marks
States coil rotation causes back emf "As the motor coil spins in the magnetic field, a back emf is induced which opposes the original driving emf."	1
States at some rotation speed, back emf matched driving emf "At some high speed, the back emf is large enough to balance the original driving emf, resulting in zero net emf."	1
States when net emf is zero, no current and no torque "At this speed, no current will flow in the coil, so no more force/torque"	1
States no torque, no rotational acceleration – max speed "This will stop the coil getting any faster – max speed is reached"	1
Total	**4**

Question 17 (continued)

(c) Calculate the magnetic flux density produced by the pair of rare earth magnets in the region of the motor coil. You will need to consider how the DC motor is acting as an AC generator while it has its maximum rate of rotation. (4 marks)

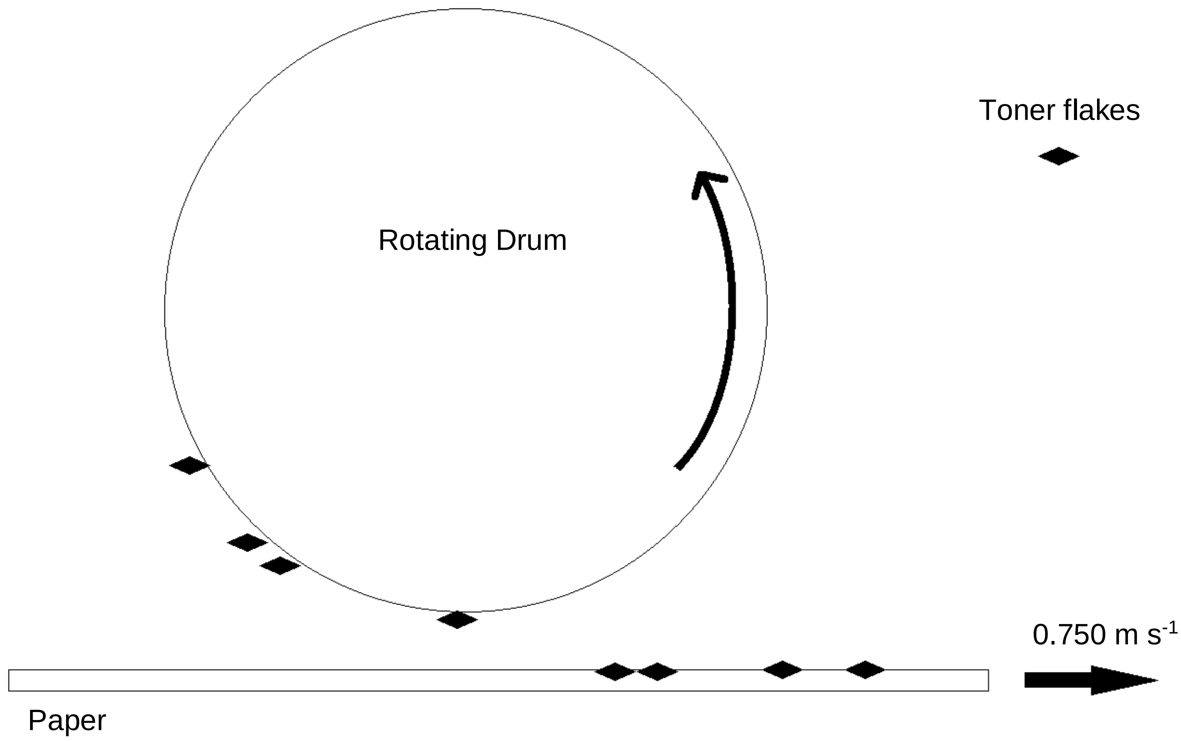
Description	Marks
The AC rms value of back emf will equal the input DC emf at max speed $\varepsilon_{rms} = 12.0\ V\ \therefore \varepsilon_{peak} = 12.0 \times \sqrt{2} = 16.97\ V$	1
Convert rpm to hz $f = \frac{1200}{60} = 20\ Hz$	1
Use emf to find mag flux $\varepsilon_{peak} = 2\pi BANf$ $B = \frac{\varepsilon_{peak}}{2\pi ANf} = \frac{16.97}{2\pi(0.06\times0.09)\times200\times20} = 0.125\ T$	1-2
Total	**4**

(d) The motor coil carries 1.50 A current when first starting to rotate. Calculate the max torque produced by this motor during start-up. If you could not obtain an answer to part (c), you may use a magnetic flux density of 0.150 T. (3 marks)

Description	Marks
$\tau = 2NFr$ $F = IlB$ $\tau = 2NIlBr$ or $\tau = NBIA$	1
$\tau = 2NIlBr$ $\tau = 2 \times 200 \times 1.50 \times 0.09 \times 0.125 \times \frac{0.06}{2}$ $\tau = 0.202\ N\ m$ (or 0.243 N m if using 0.15 T)	1-2
Total	**3**

Question 18 **(13 marks)**

A laser printer works on principles of electric fields. Dry and positively charged toner flakes (the printer ink) are attracted to a negatively charged drum. The paper is fed underneath the drum as it rotates and the toner flakes drop from the drum to the paper. The paper is able to grab hold of the toner flakes as the paper is even more negatively charged than the drum.



The diagram is not to scale and exaggerates elements of the design to make it clear. The drum is 4.50 cm in diameter. The minimum distance between the drum and paper is 50.0 µm. Each flake of toner is 1.89×10^{-8} g. The paper moves past the drum at 0.750 m s^{-1} and the drum rotates at the same rate so that it can print clear images onto the paper as they move past each other.

(a) The drum has a -3.00 V potential and the paper has a -7.00 V potential. Estimate the electric field strength in the space in between the paper and closest point on the drum. Include a direction in your answer. (3 marks)

Description	Marks
$E = \frac{V}{d}$ $E = \frac{4.00}{50.0 \times 10^{-6}} = 8.0 \times 10^{4}\ V\ m^{-1}$	1-2
Drum to Paper/ Down	1
Total	**3**

Question 18 (continued)

(b) Describe why your previous answer is only an estimate. (2 marks)

Description	Marks
Describes limitation of applied formula in current scenario "The formula $E = \frac{V}{d}$ can be used to find the electric field between parallel plates where their length is larger than their separation. As the the drum is not a flat edge, the electric field is only an estimate."	1-2
Total	**2**

(c) A single toner flake carries a positive 5.60 nC. By comparing the magnitude of the electrical force and gravitational force acting on the toner, explain whether gravitational forces need to be considered in the design of the laser printer. (3 marks)

Description	Marks
Electric force $F = Eq = 8.0 \times 10^{4} \times 5.60 \times 10^{-9} = 4.48 \times 10^{-4}\ N$	1
Gravitational force $F = mg = 1.89 \times 10^{-11} \times 9.8 = 1.85 \times 10^{-10}\ N$	1
Compares magnitudes to validate decision "As the electrical force is many orders of magnitude higher than gravity, gravity can be considered negligible in the design of the printer"	1
Total	**3**

(d) During a malfunction where paper is no longer fed in, but the drum keeps spinning at its operating speed, the electric field keeping the flakes attached to the drum is 9.91×10^{-2} N C^{-1}. Determine whether the toner flakes would remain attached to the drum during the malfunction. (5 marks)

Description	Marks
Electric force $F = Eq = 9.91 \times 10^{-2} \times 5.60 \times 10^{-9} = 5.55 \times 10^{-10}\ N$	1
$\sum F = F_E - F_g$ $\sum F = 5.55 \times 10^{-10} - 1.85 \times 10^{-10} = 3.70 \times 10^{-10}\ N$	1
$F_c = \frac{mv^2}{r}$ $v = \sqrt{\frac{F_c r}{m}} = \sqrt{\frac{3.70 \times 10^{-10} \times \frac{0.045}{2}}{1.89 \times 10^{-11}}} = 0.663\ m\ s^{-1}$ **or** $F_c = \frac{mv^2}{r} = \frac{1.89 \times 10^{-11} \times 0.75^2}{\frac{0.045}{2}} = 4.72 \times 10^{-10}\ N$	1-2
Compares calculation to question data “This maximum speed allowed is less than the speed of the drum, thus the toner flakes will not remain attached to the drum” **Or** The required centripetal force is greater than the net force acting on the flakes so they will not remain on the drum.	1
Total	**5**

End of Section Two

Section Three: Comprehension 20% (37 Marks)

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

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.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 40 minutes.

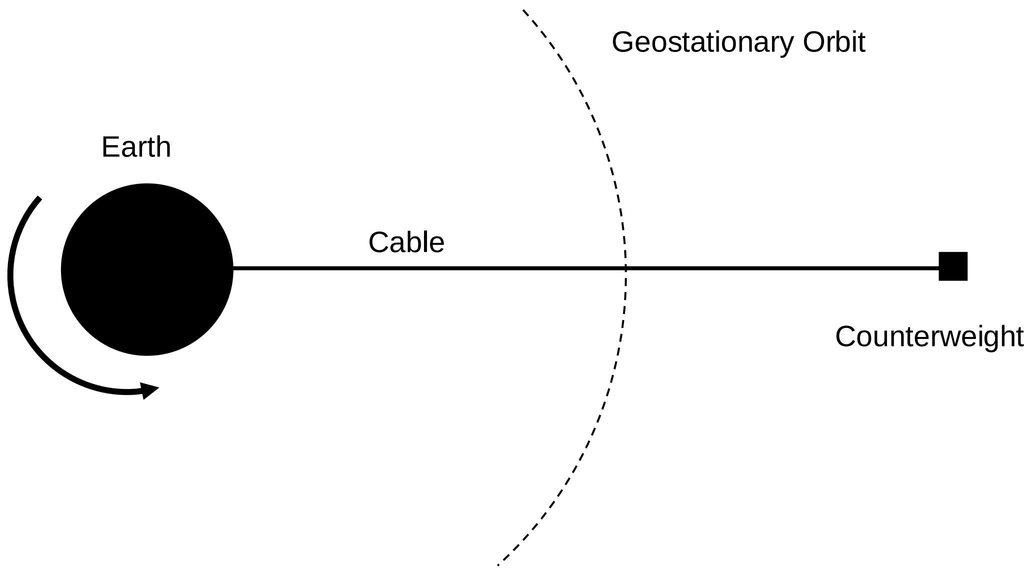
Question 19 (18 marks)

A space elevator for Earth

As of 2018, thousands of objects have been launched into space. This may make it sound like we have mastered space travel but there are lots of opportunity for innovation. In 2018, the cost to transfer objects to space sits around 40 000 AUD per kilogram, making spaceflight prohibitively expensive for all but the wealthiest nations and corporations. One means of reducing the cost is to do away with using combustion of fuel to provide the energy to escape the gravitational pull of the Earth and to replace it with….. an elevator.

Sound bizarre? Da Vinci invented the concept of the armoured tank, helicopter and even robots well before society had the materials to realise them – these were bizarre ideas in his time. The same is true of the space elevator. The idea and concept are sound and has been around since 19th Century; we just lack the right materials to make it happen.

The space elevator requires a cable, anchored at the equator, to extend out beyond the geostationary orbit of Earth and a counterweight of large mass attached at the end. To reach an orbital altitude, an elevator can move along the cable via mechanical means.



The section of cable below the geostationary orbit would fall to Earth under the influence of gravity. Beyond the geostationary orbital radius the gravity field is weaker and the cable, with added counterweight, keeps the cable held up, under tension.

In this course you have been exposed to the concept of a centripetal force. You may have also been exposed to the concept of a centrifugal force – an apparent force that pushes an object outside of its circular path. The centrifugal force is also called a "fictitious force" or "inertial force" because it is only felt in the frame of the rotating object, due to the effects of inertia, and is not due to any physical force. A good example is being a standing passenger on a bus as it turns a corner – you feel like you are being pushed away from the centre of rotation. This sensation of a pushing force is due to your inertia, not an actual force. Even though not a physical force, calculations can be performed which account for the centrifugal force. After all, when in the right frame, whether due to inertia or not, you can argue that you will be "pushed" into the side of the bus as it turns, fictitious force or not. The apparent gravitational field is due to a combination of the gravitational field and the centrifugal acceleration:

$$g = \frac{GM}{r^2} - \omega^2 r$$

You should be familiar with the first term in the above expression. The second term is the centrifugal acceleration where ω is the rotation speed in radians per second (9.32×10^{-5} radians per second for Earth) and r is the radius in metres. At some point along the cable, the two terms are equal and opposite. At this point the apparent gravitational field is zero and any object on the cable would not put weight onto the cable. Locations above this point experience smaller gravity and larger centrifugal acceleration, thus any cable material further than this point will be pulled out by the centrifugal force more than it is pulled in by the gravitational force.

To realise a space elevator, we need a material that has ten times as much tensile strength as the strongest, lightest materials already well developed on Earth. Carbon nanotubes and diamond nanothreads are possibly suitable candidates; more research is required.

(a) State one obstacle of modern space flight. (1 mark)

Description	Marks
Refers to cost "It is expensive to reach space"	1
Total	**1**

(b) Describe the basic structure of a space elevator. (2 marks)

Description	Marks
Refers to cable tethered at equator, counterweight beyond geostationary orbit "A cable is tethered to the equator and extends up, beyond the geostationary orbit with a counterweight attached"	1-2
Total	**2**

Question 19 (continued)

(c) Describe one obstacle from the article that needs to be overcome to build a working space elevator and what the possible solution is. (3 marks)

Description	Marks
States a lack of suitable material, in particular- with high tensile strength "A space elevator cable needs a tensile strength higher than any well-known material"	1-2
Refers to possible materials "Carbon nanotubes and diamond nanothreads may be suitable candidates"	1
Total	**2**

(d) State the two forces acting on the space elevator cable, including the direction they act in. (4 marks)

Description	Marks
One mark for force, one mark for direction	
Gravitational force, acting towards Earth	1-2
Centrifugal force/Inertial force/Tension, acting away from Earth	1-2
Total	**4**

(e) Explain how the use of a counterweight allows a shorter cable to be used than if designed without a counterweight. (4 marks)

Description	Marks
Explains significance of cable extending beyond geostationary orbit "The cable section beyond the geostationary orbit keeps the cable tight by applying a centrifugal force larger than gravitational force"	1-2
Explains role of mass of counterweight "By having a large mass just beyond the geostationary orbit to provide centrifugal force, less mass is required further away, minimising the length of the cable.	1-2
Total	**4**

(f) The geostationary orbit around Earth occurs at an orbital radius of 35,800 km.

(i) Calculate the apparent gravitational field at this point. (3 marks)

Description	Marks
$r = 3.58 \times 10^7 m$ and $\omega = 9.32 \times 10^{-5}\ rad\ s^{-1}$	1
$g = \frac{GM}{r^2} - \omega^2 r$	1
$g = \frac{6.67\times10^{-11}\times5.97\times10^{24}}{(3.58\times10^7)^2} - (9.32 \times 10^{-5})^2 \times 3.58 \times 10^7$ $= 2.73 \times 10^{-4}\ N\ kg^{-1}$	1
Total	**3**

(ii) State what happens to the value of the apparent gravitational field as the distance is increased beyond the geostationary orbit. (1 mark)

Description	Marks
Identifies the absolute value increases (or becomes more negative). "Further away from the geostationary orbit the apparent gravitational field is stronger"	1
Total	**1**

Question 20 **(18 marks)**

Metal detectors: a powerful tool to detect hidden metals

Metal detectors are used in civil engineering, archaeology, security, mining and by hobby "detectorists". The design is simple, and credit is given to Gustave Trouve, from France, as the inventor who used a metal detector to locate bullet fragments in patients.

Metal detectors work by transmitting a signal in the form of a magnetic field from a search coil, powered by an electrical supply. Historically, the search coil was round and operated by an AC supply as high as 20 kHz. This is true even if the metal detector was powered by a convenient portable battery- the DC of the battery must be converted into AC. The most powerful detectors produce fields as high as 0.800 T.

The magnetic field induces eddy currents in target metals, which in turn produce their own magnetic fields – this is the return signal. The return signals are detected by another coil in the metal detector which acts as a magnetometer (device for measuring magnetic fields).

Various coil shapes are used for metal detectors, each with distinct advantages. A pair of 'D' shaped coils arranged back to back to form a circle help minimise the effects of mineralisation in soil. Mineralisation is the tendency for some particles in the soil to mimic metals, which will alter the magnetic field signal of the metal detector. The soil in rural northern Australia, with its high iron content has a large mineralisation effect.

A key innovation of metal detector design was the introduction of pulse induction (PI). Rather than using a standard oscillating electric supply, PI detectors produce a relatively large magnetic field but over a much smaller time scale by driving large currents through the search coil. When no target metal is within proximity, the magnetic field in the magnetometer reduces at a uniform rate, producing predictable currents. In the presence of a target metal however, the magnetic field declines at a reduced rate. The time differences are small, but modern electronics allows the difference to be measured to give accurate results. The benefits of a PI mode of detection is that it penetrates deeper into the ground and is also better at ignoring mineralisation in the soil.

If you have ever been on a plane, chances are you walked through a metal detector. These use PI technology. While exact numbers are manufacturer specific, a walk-through PI detector typically sends out 100 pulses a second – each pulse lasting a few microseconds. The magnetic fields are safe to biological matter, even through repeat exposure. This makes metal detectors ideal for the detection of concealed weaponry with no adverse health effects.

(a) Describe why there are two distinct coils of wire in a metal detector. (2 marks

Description	Marks
States use of search coil "One coil produces a magnetic field from an electrical supply"	1
States use of magnetometer coil "Another coil detects the return magnetic field to detect the presence of a target metal"	1
Total	**2**

(b) State **one** advantage and **one** disadvantage described by the article when a battery is used to power a metal detector. (2 marks)

Description	Marks
States advantage of being portable “The use of a battery means the metal detector is portable and can be used away from electrical mains”	1
States disadvantage that the DC must be converted to AC “The battery supplies DC while the metal detector needs AC”	1
Total	**2**

(c) Explain why a metal detector must use an AC supply. (3 marks)

Description	Marks
States difference in magnetic fields produced between AC and DC “An AC supply creates a **changing** magnetic field, DC does not.”	1
States that change in magnetic field induces a current in target metal “The changing magnetic field in the presence of a conductor will induce eddy currents in the conductor”	1
States induced current produces another magnetic field which can be detected “Eddy currents in turn produce their own magnetic field. This field can be detected by the magnetometer in the metal detector”	1
Total	**3**

(d) State the benefit of a pair of ‘D’ shaped coils and where this type of detector may be used. (2 marks)

Description	Marks
States benefit “A pair of D shaped coils minimising the effect of mineralisation”	1
States location from article “This is useful in rural northern Australia where mineralisation is high”	1
Total	**2**

Question 20 (continued)

(e) An Australian one dollar coin has a 2.50 cm diameter. A powerful metal detector operating at 20.0 kHz passes over a one dollar coin, buried just under the surface.

(i) Calculate the maximum possible change in flux passing through the face of the coin as the metal detector field changes from 0.00 T to its peak field density in the presence of the coin. (2 marks)

Description	Marks
$\Delta\Phi = \Delta BA = B \times \pi r^2$ $\Delta\Phi = 0.800 \times \pi \times \left(\frac{0.025}{2}\right)^2 = 3.926 \times 10^{-4} = 3.93 \times 10^{-4}\ Wb$	1-2
Total	**2**

(ii) Using your answer from part (i), calculate the average induced emf in the coin. You may assume the coin behaves like a single coil of wire with an identical cross sectional area as the coin and that the flux changes linearly with time. (If you could not obtain an answer to part (i), you may use a value of 4.00×10^{-4} Wb) (3 marks)

Description	Marks
$t = \frac{1}{f} = \frac{1}{20.0 \times 10^3} = 5.00 \times 10^{-5}\ s$ Time for go from 0 Wb to max Wb: $t = \frac{1}{4} \times 5.00 \times 10^{-5} = 1.25 \times 10^{-5}\ s$	1-2
$\varepsilon = \frac{\Delta\Phi}{\Delta t} = \frac{4.00 \times 10^{-4}}{1.25 \times 10^{-5}} = 32.0\ V$	1
Total	**3**

(iii) State **two** reasons why your answers to part (i) and (ii) could be smaller in practice than these theoretical answers. (2 marks)

Description	Marks
One mark for each acceptable reason	
Mineralisation of the soil	1
Coin facing not perpendicular to magnetic field	1
Total	**2**
Accept other acceptable reasons	

(f) Describe why, in the presence of a target metal, the PI magnetic field decreases at a reduced rate. (2 marks)

Description	Marks
Refers to induced field opposing changes “When the magnetic field is in the presence of a target metal, it will induce eddy currents that produce their own field which oppose the change in flux.”	1
Relates opposition to a decreased rate of field reduction “This opposition to the change in flux causes a longer decay time of the original field.”	1
Total	**2**