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 | 32% (58 Marks) |

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**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 |
| For 2 marks students MUST have indicated lines are closer together  The field lines on the left are closer together/denser/has more field lines/the vertical asymptote favours the left | 1 |
| 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 22.00 is accelerating down the ramp at 2.16 m s-2. **(7 marks)**

1. 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** |
| Normal  Weight  Friction  Net force  22.00  **Minus 1 mark if friction not indicated and this not shown subtracted from vector** | |

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
| (1) | 1-3 |
| **Total** | 4 |

**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  (1 mark) |  | |
| The horizontal velocity of a projectile changes by  9.8 m s-1 each second | False  (1 mark) | 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  (1 mark) | 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  (1 mark) |  | |

**Question 4**

A car goes around a 32.0 m radius curve on a banked track that is inclined at 12.0o. 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. You must se a vector diagram to assist with your calculation. **(3 marks)**

|  |  |
| --- | --- |
| **Description** | **Marks** |
| Vector diagram  Net force (Fc)  mg  120 | 1 |
|  | 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. **(4 marks)**

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
|  | 1-2 |
| **Total** | **3** |

1. 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** |
| 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

Claire

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** |
| Ethan torque (in terms of )    Claire torque (in terms of )    Claire has feet on floor as has bigger torque on her side and needs to compensate | 1-3 |
| (4/5 mark if this equation shown with 1.23 missing.  3/5 if 23.9N answer, no equation ) | 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** |
|  | 1 |
|  | 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 and fired at 22.0o below the horizontal plane. Ignore air resistance. **(5 marks)**

|  |  |
| --- | --- |
| **Description** | **Marks** |
| Finds initial horizontal and vertical components of speed | 2 |
| Finds time in air      Quadratic solution is  \*\* May also use | 1-2 |
| Finds range | 1 |
| **Total** | **5** |

Can use V2 = u2 + 2as, v = 15.79ms-1, then v = u + at to find t.

**Question 9 (6 marks)**

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.

1. Are the wires carrying the current in the same direction or in opposite directions?

Justify your choice with the aid of a diagram. (3 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
| Opposite | 1 |
| 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 Repulsion/attraction of wires does not explain choice.  Diagram must clearly show field lines adding between wires when currents are opposite | 1  1 |
| **Total** | 3 |

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
|  | 1-2 |
| **Total** | **3** |

**Question 10**

A hump back bridge is constructed so it has a radius of 50.0 m. What is the maximum speed a motorcyclist can travel across the top of the bridge without ‘lifting off the bridge’? **(3 marks)**



= mg 1

v2 = r g

v = √(50 x 9.8) 1

= 22.1 m s-1 1

**Question 11**

Jacob is freewheeling his mountain bike down a hillside track composed of gravel and sand. The bike remains stable when Jacob is going in a straight line but when he reaches a curved section of the track his wheels slide away and he crashes.

Explain why Jacob is more likely to crash when going into a curved section of the track.

**(3 marks)**

A centripetal force is required to maintain a circular path. (1)

The centripetal force is provided by the friction between the mountain bike tyre and the track (1)

Gravel cannot supply the required friction therefore he slides away. (1)

**Question 12**

A canoeist paddles at a constant velocity from one bank directly across a river which is flowing at 3.50 m s-1. If the canoeist is travelling at 1.50 m s-1 and the river is 35.0 m wide. Calculate the displacement when he reaches the opposite bank of the river? **(4 marks)**

Speed across river, v =

1.5 =

t = = 23.3 s (1)

Distance downstream = 3.5 x 23.3 = 81.6 m (1)

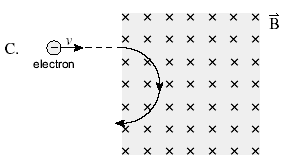
Displacement = √(81.62 + 352) = 88.8 m (1)

Direction, θ = tan-1 () = 23.2o to the bank (1)

**NB: Can’t write “66.8O below horizontal” this makes no sense.**

**Question 13 (6 marks)**

An electric field is used to accelerate an electron into a uniform perpendicular magnetic field of strength 230 μT. It follows a semi-circular path through the magnetic field of radius 350 mm, as illustrated at right.



(a) Calculate the speed needed for the electron to follow the semi-circular path. (3 marks)

r = v = (1)

∴ v = (1)

= 1.41 x 107 m s-1 (1)

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

W = q V = EK (1)

EK =  mv2 = (9.11 x 10-31 )(1.41 x 107)2 = 9.11 x 10-17 J (1)

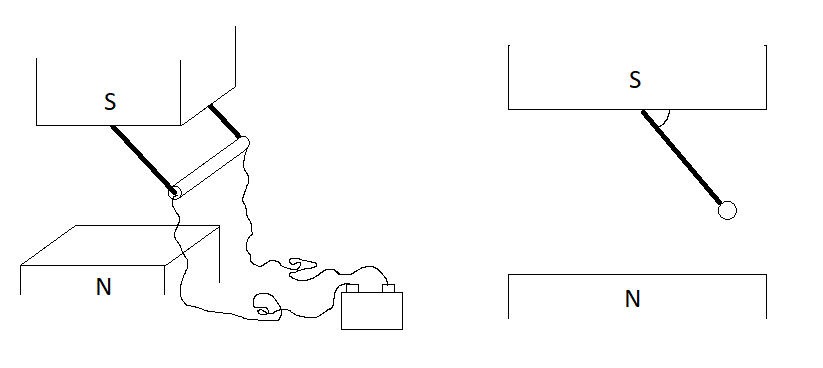
∴ V = = = (1)

|  |  |
| --- | --- |
| **Section Two: Problem-solving** | **48%(86 Marks)** |

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Question 14 (10 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.



String

Loose wire

Rod

Simplified 2D view

Detailed View

When everything is connected, the rod swings to one side and remains in the position shown

in the simplified 2D view.

1. 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 14 (continued)**

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
| **Total** | **1** |

1. Calculate the magnitude of the magnetic force acting on the rod. (2 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1-2 |
| **Total** | **2** |

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
| Finds weight force | 1 |
| Sums weight and magnetic forces, equating to tension  mg  FE | 1-2 |
| Halves tension between two strings | 1 |
| **Total** | **4** |

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1-2 |
| **Total** | **2** |

**Question 15 (17 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 × 1017 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.

1. Calculate the gravitational force that the Milky Way places on the CMDG. (4 hmarks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
| (1 + 1+ 1 marks)  1 mark | 1-4 |
| **Total** | **4** |

1. 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 × 1029 N. (3 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
|  | 1-2 |
| **Total** | **3** |

**Question 15 (continued)**

1. 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    Force of MW on Sun  (must show different r in each formula) | 1 |
| Establish relationship between forces and distance | 1-2 |
| Uses question data to give relationship between distances | 1-2 |
| Solves for distance between Sun and centre of MW      or | 1-2 |
| **Total** | **7** |

1. 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** |
| Milky Way | 1 |
| Some of the MW mass would be further from the centre than the Sun. | 1 |
| 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 16 (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**

**B**

**C**

20.00

Support Strut

Mounting Bracket

Ground

1. 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 | 1 |
| Has all 4 terms | 1 |
| Calculation      The strut can support this force (No mark awarded for this statement, without supporting evidence) | 1-3 |
| **Total** | **5** |

**Question 16 (continued)**

1. 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 × 103 N.

(4 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
|  | 1 |
| down (Mathematically down is correct, however common sense suggests that it would apply an upward force- both accepted. However no horizontal component)  () |  |
| **Total** | **4** |

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

1. 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** |
| 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 |
| This produces a larger clockwise torque about point A | 1 |
| 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 17 (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 the bottom rail, through the armature and returns via the top rail.

Rail

Armature

I

I

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, , such that the force is given by:

* is the force on the armature in Newtons (N)
* is the inductance per unit length in Henries per metre (H m-1)
* is the current in the railgun circuit in Amperes (A)

1. 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** |

1. 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 | 1 |
| Refers to | 1 |
| Describes how these formula show  “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.” (cannot substitute B into F = IlB as B is the field around one wire, not the net field due to both wires) | 1 |
| **Total** | **3** |

**Question 17 (continued)**

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

prototype railgun.

1. 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) | I2 (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 | |

1. 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** |

No error bars – lose 2 marks

**Question 17 (continued)**

Calculate the gradient of your line of best fit from the graph. Include units, construction lines and show your working. (4 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
| Shows construction lines | 1 |
| Uses points from graph, not straight from table | 1 |
| Reasonable answer with units    or H m-1 (-1 mark for more than 2 sf, -1 mark if no / incorrect unit) | 2 |
| **Total** | **4** |

1. Using the gradient, determine the inductance per unit length () of the railgun used in this experiment. (3 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
| Shows working relating gradient to    (cannot sub F/I for gradient) | 2 |
| (-1 mark for more than 2 sf, -1 mark if no / incorrect unit) | 1 |
| **Total** | **3** |

**Question 18 (14 marks)**

A student designed and built a motor 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.

1. Explain the interaction between the current in the coil and the magnets that causes a motor’s coil to spin. (4 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
| When current flows in the coil,   * the sides perpendicular to the magnetic field (or mentions right hand slap rule) experience * a force, * at right angles to the side. | 1-3 |
| The two forces produce an unbalanced torque, or a couple causing the motor to spin. Have awarded marks even if the words ‘unbalanced torque’ were not mentioned. Next time must be mentioned. | 1 |
| **Total** | **4** |

1. Explain the purpose of the commutator and brushes. (4 marks)

The brushes provide a sliding electrical contact to the rotating commutator (1),

the commutator reverses the current flow (1)

every half turn of the coil or after 180o (1) so that

the torque always acts in the same direction or armature spins/rotates in the same direction. (1) Must mention correct terminology in the future such as torque.

(c) The motor coil carries 1.50 A current when first starting to rotate. Calculate the total

torque produced by this motor during start-up if the magnetic flux density produced by a pair of rare earth magnets in the region of the motor coil is 0.125 T. (6 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
| or | 1 |
| (number of turns, conversion to m, correct area or r, magnitude, unit | 1-5 |
| **Total** | **6** |

**Question 19 (13 marks)**

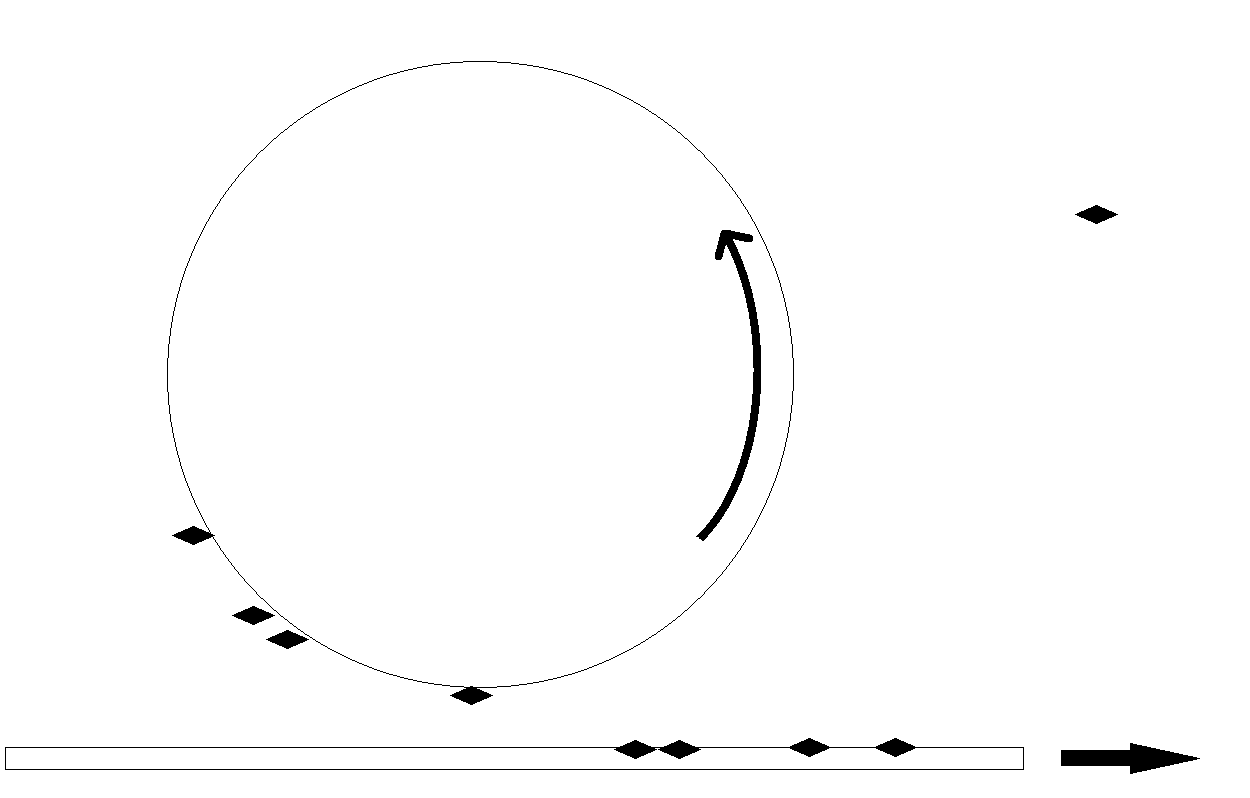
A laser printer works on principles of electric fields. Dry and positively charged toner flakes (the printer ink) are attracted to a negatively charged drum. The paper is fed underneath the drum as it rotates and the toner flakes drop from the drum to the paper. The paper is able to grab hold of the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

Rotating Drum

0.750 m s-1

Toner flakes

Paper



2.25 cm

50.0 µm

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.

1. 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** |
| -1 for negative 𝛥 V since 𝛥V = -3 – (-7) = 4  (2 sig fig ignored in this instance) | 1-2 |
| Drum to Paper/ Down/ To paper from drum. A mark was awarded for ‘to paper’ although not the best answer. | 1 |
| **Total** | **3** |

**Question 19 (continued)**

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
| The formula 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** |

1. 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 | 1 |
| Gravitational force | 1 |
| 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** |

**Question 19 (continued)**

1. 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 | 1 |
|  | 1 |
| **or** | 1-2 |
| This maximum speed allowed is less than the speed of the drum, which is 0.750 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** |

If either v or Fc were not calculated, no marks were awarded for making a comparison between FE and Fg

**End of Section Two**

|  |  |
| --- | --- |
| **Section Three: Comprehension** | **20% (36 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 20 (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 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 the 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.

Geostationary Orbit

Earth

Cable

Counterweight

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:

You should be familiar with the first term in the above expression. The second term is the inertial(centrifugal) acceleration where is the rotation speed in radians per second (9.32 × 10-5 radians per second for Earth) and 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 inertial acceleration, thus any cable material further than this point will be pulled out by the inertial 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(stretching) strength as the strongest, lightest materials already well developed on Earth. Carbon nanotubes and diamond nanothreads are possibly suitable candidates; more research is required.

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
| It is expensive to reach space. | 1 |
| **Total** | **1** |

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

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

**Question 20 (continued)**

1. 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** |
| A space elevator cable needs a tensile strength higher than any well-known material. | 1-2 |
| Carbon nanotubes and diamond nanothreads may be suitable candidates | 1 |
| **Total** | **3** |

1. 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 (not centripetal) | 1-2 |
| Inertial force/Tension, acting away from Earth (not centrifugal) | 1-2 |
| **Total** | **4** |

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
| The cable section beyond the geostationary orbit keeps the cable tight by applying a tension force larger than gravitational force. | 1-2 |
| A large mass is required just beyond the geostationary orbit to provide adequate centripetal force so that a shorter length of the cable can be used. | 1-2 |
| **Total** | **4** |

1. The geostationary orbit around Earth occurs at an orbital radius of 35,800 km.
2. Calculate the apparent gravitational field at this point. (3 marks)

|  |  |
| --- | --- |
| **Description** | **Marks** |
|  | 1 |
| If second term is absent, g = 0.311 N kg-1 | 1 |
| (no marks for follow through if radius of the Earth is added on to r) | 1 |
| **Total** | **3** |

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

|  |  |
| --- | --- |
| **Description** | **Marks** |
| .  Further away from the geostationary orbit the apparent gravitational field is stronger. Marks were also awarded for ‘decreases’ since very complex concept | 1 |
| **Total** | **1** |

**Question 21 (18 marks)**

**Model Rocket**

A group of students built and used a model rocket to investigate force and motion. The rocket had a total mass of 250.0 g and was powered by a stiff spring which could be compressed by 25.0 cm. A parachute inside the rocket was programmed to open after the rocket had reached its maximum height. The diagrams below show how the rocket was launched and how the parachute deployed for the descent.



When it is launched, the rocket leaves the spring and the spring returns to its original length. The compression in the spring provides the force necessary to launch the rocket and is given by F = k x where F is the force in newtons, k is the proportionality constant and x is the extension or compression of the spring in metres.

The graph below shows the force – compression characteristic of the spring.



By referring to the graph the energy can be calculated for a compression of 0.25 m:

The area under the curve is equivalent to the energy stored in the spring

= ½ (1000 x 0.25) = 125 J

1. Calculate the rocket’s speed as it leaves the spring. (2 marks)

If the potential energy stored in the spring is converted into kinetic energy then:

PE = KE (1)

mgh = ½ m v2

125 = ½ x 0.25 x v2

v2 = 125 / 0.125

v = 31.6 m s-1 (1)

1. What force(s) act on the rocket immediately after it leaves the spring? (2 marks)

The forces acting on the rocket are

* the decelerating forces of gravity and
* air resistance (friction)

1. If the rocket took 2.90 s to reach its maximum vertical height, calculate the uniform

deceleration of the rocket. (2 marks)

u = 31.6 m s-1

v = 0 m s-1 (1) info from question and formula

t = 2.90 s

a = ?

v = u + at

0 = 31.6 + a x 2.9

-31.6 / 2.9 = a

a = -10.9 m s-2 (1)

(d) Neglecting air resistance, calculate the maximum height the rocket could reach. (2 marks)

a = -9.80 m s-2

v = 0 m s-1 (1) info from question and formula

u = 31.6 m s-1

s = ?

v2 = u2 + 2as

02 = 31.62 + 2 x -9.80 x s

s = 31.62/(2 x 9.80)

s = 51.0 m (1)

(e) In fact the rocket DID experience air resistance. Is the value for the uniform

deceleration calculated in Question (c) consistent with the rocket experiencing air

resistance? Explain your answer. (2 marks)

* Yes The results of the deceleration ARE consistent with the rocket being subject to air resistance. (1)
* The air resistance would add an additional retarding force to the upward movement of the rocket thus increasing the rate at which its velocity is reduced. (1)

(f) Using the group’s results and your previous calculations, calculate the average

retarding force due to air resistance on the rocket. (2 marks)

If there was no air resistance the rocket would undergo deceleration at the rate of 9.8 m s-2. In this case the retarding force would be:

F = m a = 0.25 x 9.8 = 2.45 N (1)

If the rocket is subject to air resistance in addition to the gravitational force, the force would be F = m a = 0.25 x 10.9 = 2.73 N

The difference in these two forces is (2.73 – 2.45) = 0.275 N

The average retarding force due to air resistance is 0.275 N (1)

Or a = -9.8-(-10.9) =1.1ms-2

F=ma F= 0.25 x 1.1 = 0.275 N

Upon reaching its maximum height, the rocket begins to fall vertically to the ground. Soon after the start of its descent, the parachute opens and the rocket slowly returns to the ground.

A velocity – time graph of the descent is shown below.



(g) Use the graph to estimate the time it took for the parachute to open. Explain your

answer. (3 marks)

During the first 2 seconds of descent the rocket is accelerating at a fairly uniform acceleration. (1)

At time = 2 s the graph plateaus indicating there is a sudden change in velocity. (1) Accept 2.0 to 3.3 s

This would indicate that there is a sudden retarding force acting on the rocket. This is the time at which the parachute is deployed. (1)

As it descends, the air resistance on the rocket, is small compared to the retarding force of the parachute. The graph below shows how the combined rocket /parachute retarding force varies with time as they fall.



(h) Use the graph to determine the acceleration of the rocket 3 s after it begins its descent. (3 marks)

From the graph the retarding force at 3 seconds is 2 N. (1)

F = m a

2 = 0.25 x a

a = 2 / 0.25 = 8.0 m s-2

The acceleration at 3 seconds is 8.0 m s-2 downwards (1 +1 for direction)

**END OF EXAMINATION**