IB · DP · Physics

3 hours 15 questions

Structured Questions

10.1 Describing Fields

10.1.1 Gravitational & Electrostatic Fields / 10.1.2 Gravitational & Electrostatic Field Lines / 10.1.3 Gravitational & Electrostatic Potential / 10.1.4 Equipotential Surfaces

Easy (5 questions)	/56
Medium (5 questions)	/55
Hard (5 questions)	/39
Total Marks	**/150**

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Easy Questions

1 (a) Define the terms:

(i) Gravitational field

[2]

(ii) Electrostatic field

[2]

(4 marks)

(b) An equation to describe field strength is:

$$field\ strength = \frac{X}{Y}$$

Define X and Y in the equation above.

(2 marks)

(c) Based on your answer to part (b), define the terms in the following equations:

(i) $g = \frac{F}{m}$

[1]

(ii) $E = \dfrac{F}{Q}$

[1]

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(2 marks)

(d) The following text is about uniform electrostatic and gravitational fields.

Complete the following sentences by circling the correct words:

A gravitational field is a region of space in which objects with **mass / charge** will experience a force.

The direction of the gravitational field is always directed **away from / towards** the centre of the mass.

Gravitational forces are always **attractive / repulsive** and cannot be **attractive / repulsive**.

An electric field is a region of space in which objects with **mass / charge** will experience a force.

The electric field strength is a vector quantity, it is always directed **away from / towards** a positive charge and **away from / towards** a negative charge.

Opposite charges (positive and negative) **repel / attract** each other and like charges (positive-positive or negative-negative) **repel / attract** each other.

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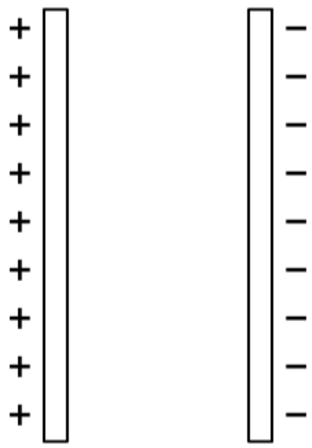
(3 marks)

2 (a) Draw the electric field lines around the positive and negative point charges below.

(3 marks)

(b) The diagram shows two parallel plates of opposite charge.



Draw the electric field lines between the two plates.

(3 marks)

(c) Electrostatic fields can be radial or uniform.

State the defining features of the equipotentials for:

(i) A radial field

[2]

(ii) A uniform field

[3]

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(5 marks)

(d) (i) On the diagram from part (a), draw the equipotential lines.

[2]

(ii) On the diagram from part (b), draw the equipotential lines.

[2]

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(4 marks)

3 (a) State the definition for the gravitational potential at a point.

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(2 marks)

(b) Explain why gravitational potential is always negative.

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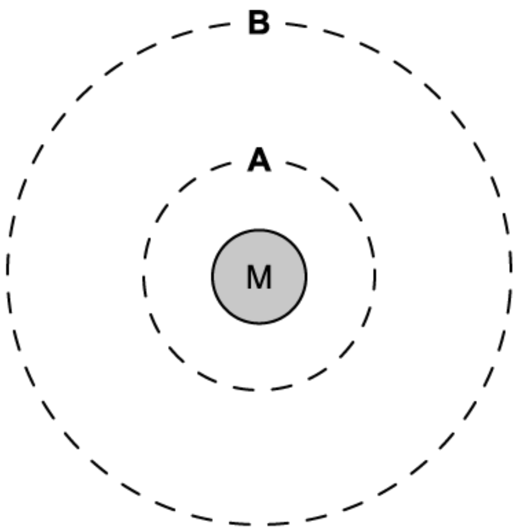
(2 marks)

(c) A satellite orbiting the moon, M, is moved from orbit A to orbit B:



The gravitational potential due to the moon of each of these orbits is:

Orbit A: –2.10 MJ kg^{-1}
Orbit B: –1.65 MJ kg^{-1}

Calculate the gravitational potential difference as the satellite moves from orbit A to orbit B.

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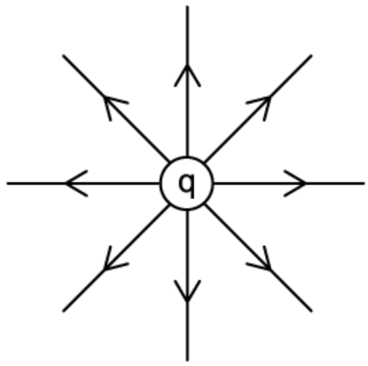
(3 marks)

(d) The satellite has a mass of 950 kg.

Calculate the work done in moving the satellite from orbit A to orbit B.

(2 marks)

4 (a) The diagram shows the electric field lines of a charged conducting sphere of radius *r* and charge *q*.



State and explain the charge on the conducting sphere.

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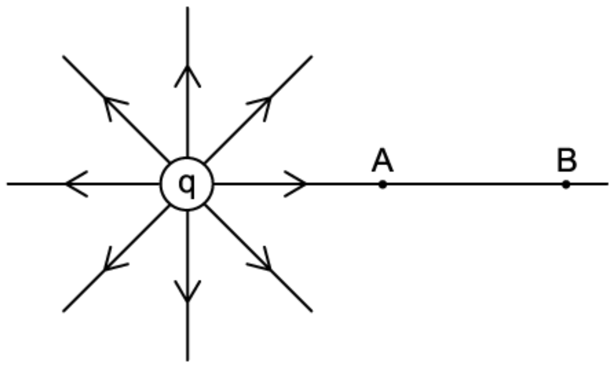
(2 marks)

(b) Two points A and B are located on the same field line.



Explain why electric potential decreases from A to B.

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(2 marks)

(c) A proton is placed at A and released from rest. The magnitude of the work done by the electric field in moving the proton from A to B is 2.5×10^{-16} J. Point A is at a distance of 0.1 m from the centre of the sphere and point B is at a distance of 0.5 m.

Calculate the electric potential between points A and B.

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(3 marks)

(d) The concept of potential is also used in the context of gravitational fields. Suggest why scientists describe different types of fields using the same terminology.

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(1 mark)

5 (a) The gravitational potential, V_g around a planet can be calculated using the equation:

$$V_g = -\frac{Gm}{r}$$

Where *G* is the gravitational constant, *m* is the mass of the planet and *r* is the distance from the centre of the planet.

The mass of the Earth is 5.97×10^{24} kg.

Calculate the gravitational potential at a point 4.23×10^{7} m from the centre of the Earth.

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(2 marks)

(b) The gravitational potential on the surface of the Earth is -6.25×10^{7} J kg^{-1}.

Calculate the gravitational potential difference between the surface of the Earth and a point 4.23×10^{7} m from the centre of the Earth from part (a).

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(3 marks)

(c) Calculate the work done in taking a 5.0 kg mass from the surface of the Earth to a point 4.23×10^{7} m from the centre of the Earth.

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(2 marks)

(d) (i) State the magnitude of the gravitational potential at a point where the Earth's gravitational effect is negligible.

[1]

(ii) Calculate the gravitational potential difference between the Earth's surface (from part b) and the point where the Earth's gravitational effect is negligible

[3]

(iii) Calculate the work done in taking the 5.0 kg mass from the surface of the Earth to the point where the Earth's gravitational effect is negligible.

[2]

(6 marks)

Medium Questions

1 (a) (i) State what is meant by the gravitational field strength at a point.

[1]

(ii) Show that the potential V at a distance r above the surface of a planet with radius R is given by $g(R + r)$.

[2]

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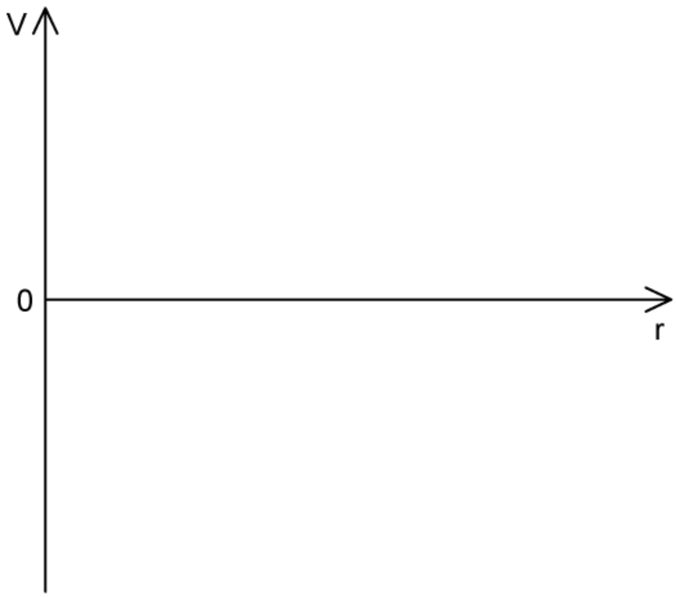
(3 marks)

(b) Sketch a graph on the axes provided below to show the relationship between the gravitational potential V with distance r above the surface of the planet.



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(2 marks)

(c) An asteroid, with an initial negligible speed, is gathering pace and is now on a collision-course with the planet.

Estimate the speed of the asteroid when it reaches the top of the planet's atmosphere, which stretches for 15 km above the planet's surface.

Use the following data:

- Radius of the planet = 3.0×10^6 m
- Gravitational field strength at the top of the atmosphere = 2.5 N kg^{-1}

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(3 marks)

(d) As the asteroid enters the planet's atmosphere, it begins as a small point of light which grows much brighter and faster as it moves towards the surface of the planet.

Discuss these observations. Your answer should make reference to *g* as well as the effect of the planet's atmosphere.

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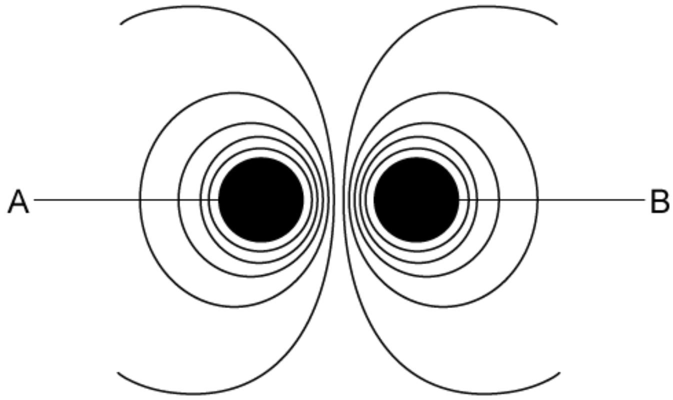
(4 marks)

2 (a) Two charged objects, A and B, are brought close together. The equipotential lines around each object is shown.



(i) Label a position at which the electric field strength is the strongest with the letter S.

[1]

(ii) Label a position at which the electric field strength is weakest with the letter W.

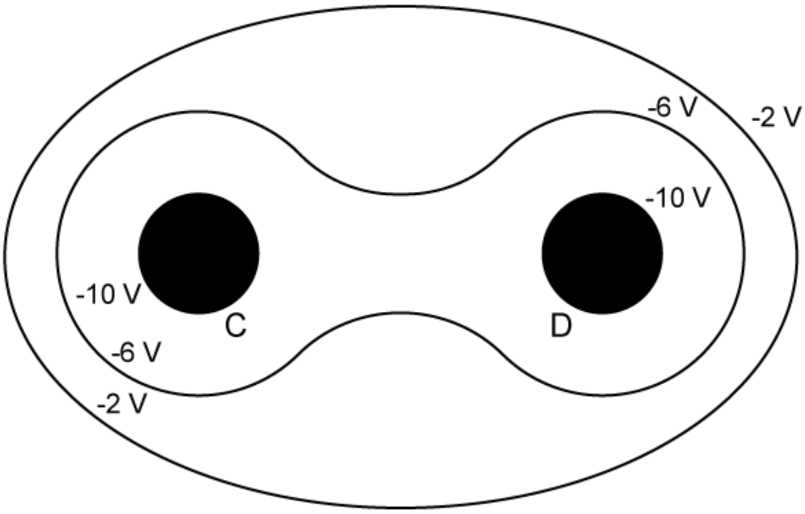
[1]

(2 marks)

(b) Identify the electric charge on objects A and B and explain your answer.

(3 marks)

(c) A different pair of equally charged objects, C and D, are brought close together. Equipotential lines at –10 V, –6 V and –2 V around C and D are shown.



Draw electric field lines between C and D.

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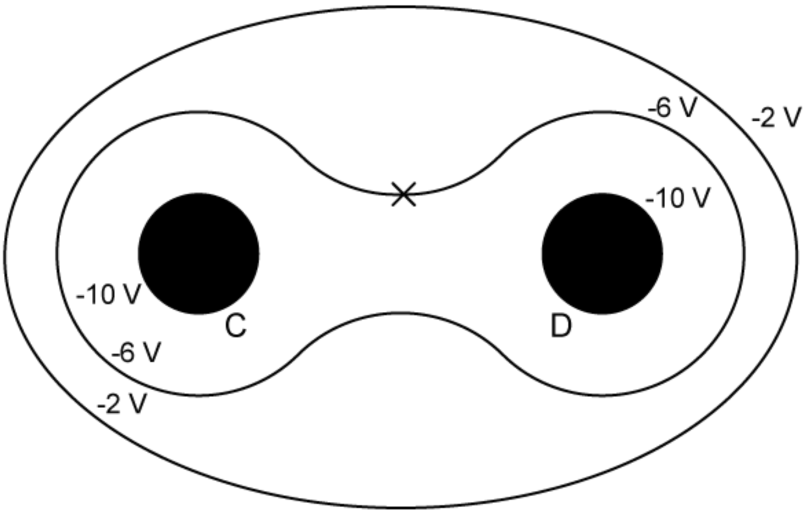
(3 marks)

(d) Objects C and D are now given a charge of –3.5 nC and –4.0 nC respectively.

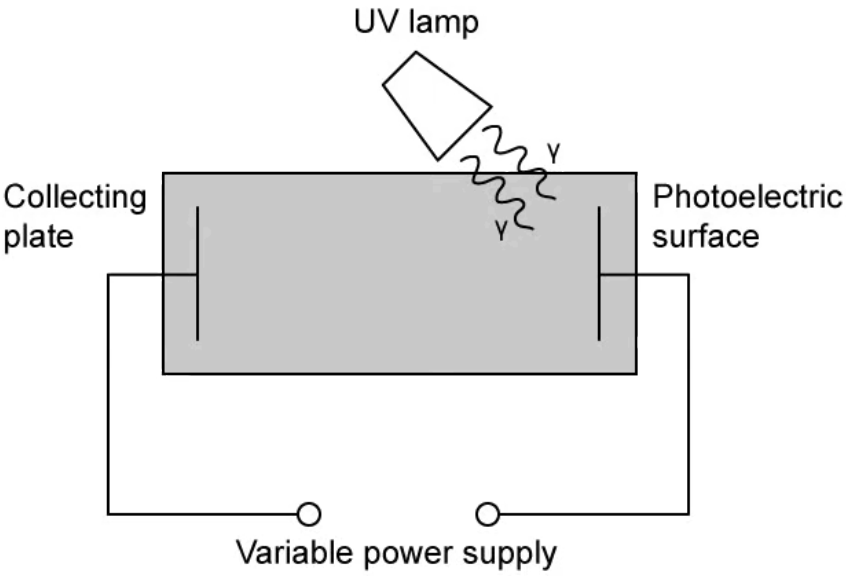
X is a position at –6 V which is equidistant from both C and D.



Determine the potential due to object C at the position labelled X.

(4 marks)

3 (a) Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a metallic, photoelectric surface as shown.



The photoelectric surface is grounded, and the variable power supply is adjusted so that the electric potential of the collecting surface is 1.5 V.

Describe the properties of the electric field between the photoelectric surface and the collecting plate.

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(2 marks)

(b) On the diagram, draw and label equipotential lines at 0.5 V and at 1.0 V.

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(2 marks)

(c) Electrons are released from the photoelectric surface and move toward the collecting plate.

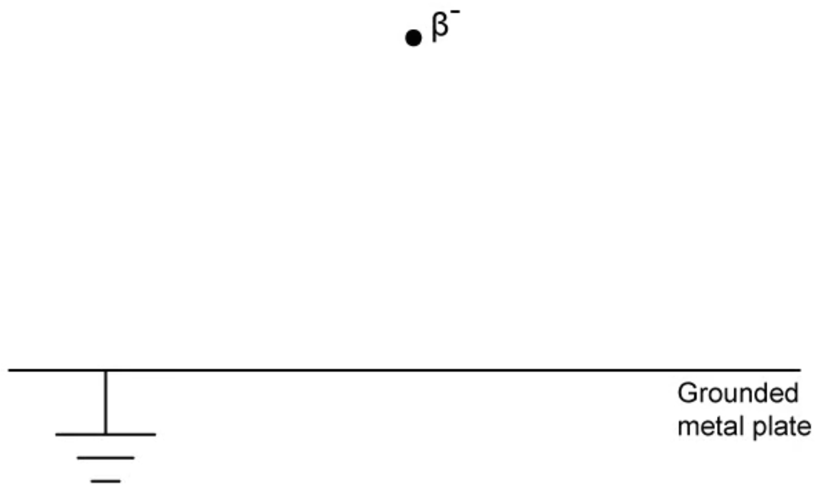
Determine the work done by the electric field on the electrons as they arrive at the midpoint between the photoelectric surface and the collecting plate.

(2 marks)

(d) Describe the motion of the electrons between the photoelectric plate and the collector plate. Your answer should consider the field at the edges of the plates.

(4 marks)

4 (a) A β^- particle is placed above a grounded metal plate.



Sketch the electric field lines between the β^- particle and the metal plate.

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(3 marks)

(b) The β^- particle is replaced with an α particle at the same position above the grounded metal surface.

Outline the similarities and differences between the electric field now created to that in part (a).

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(3 marks)

(c) The grounded metal surface is removed in order to analyse the combined electric field created between the α particle and the β^- particle.

Sketch the electric field produced between an α particle and a β^- particle.

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(3 marks)

(d) Discuss whether there is a point of zero electric field for the diagram in part (c).

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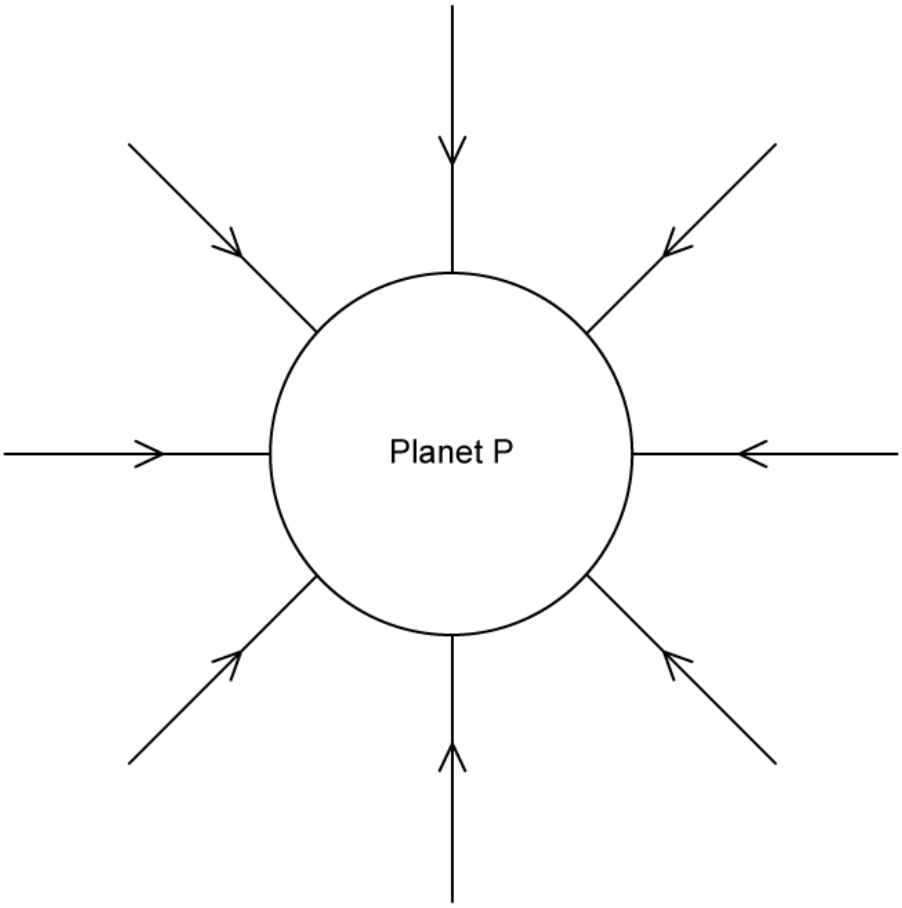
(2 marks)

5 (a) The diagram shows the gravitational field produced by planet P.



Outline how this diagram shows that the gravitational field strength of planet P decreases with distance from the surface.

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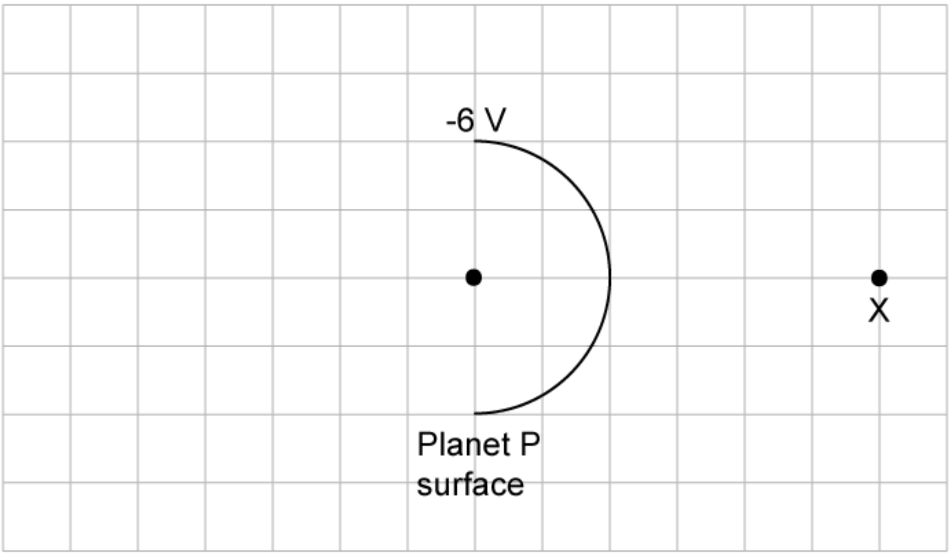
(2 marks)

(b) The diagram shows part of the surface of planet P. The gravitational potential at the surface of planet P is –6 V and the gravitational potential at point X is –2 V.



On the grid, sketch and label the equipotential surface corresponding to a gravitational potential of –4 V.

(3 marks)

(c) A meteorite, very far from planet P, begins to fall to the surface with a negligibly small initial speed. The mass of planet P is 3.0×10^{21} kg and its radius is 2.3×10^{6} m.

Calculate the speed at which the meteorite will hit the surface, assuming planet P has no atmosphere.

(3 marks)

(d) Without detailed calculation, state and explain the effect on the meteorite's impact velocity if planet P's mass was twice as large.

(2 marks)

Hard Questions

1 (a) An object has a weight of 100 N at a distance of 200 km above the centre of a small planet.

Sketch a labelled graph to show the relationship between the gravitational force, *F*, between two masses and the distance, *r*, between them. Mark at least three points on the graph using the information provided in the question.

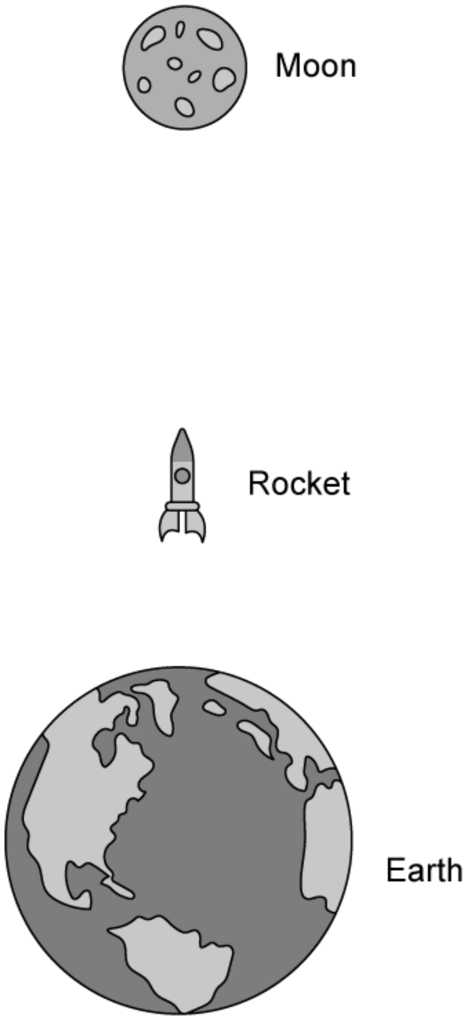
(3 marks)

(b) The distance along the Earth's surface from the North Pole to the Equator is 1×10^7 m.

Calculate the mass of the Earth.

(2 marks)

(c) A rocket is sent from the Earth to the moon. The moon has a radius of 1.74×10^6 m and the gravitational field strength on its surface is 1.62 N kg^{-1}. The radius of the Earth is 6370 km.



The distance between the centre of the Earth and the centre of the moon is 385 000 km.

Calculate the distance above the Earth's surface where there is no resultant gravitational field strength acting on the rocket.

(4 marks)

(d) The rocket will require a different amount of fuel to get to the moon than it will to return to the Earth.

Explain which journey will require the most fuel.

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(2 marks)

2 (a) A space shuttle of mass 2×10^6 kg is travelling from the Earth to the moon. It accelerates uniformly from launch at 5.25 m s^{-2}.It has enough propellant to provide thrust for the first 124 seconds.

The mass of the Earth is 5.97×10^{24} kg and the mean radius is 6.37×10^6 m.

Calculate the work done by the rocket during the first 124 seconds after launch. State any assumptions you have made.

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(3 marks)

(b) The Moon has a radius approximately 27% that of the Earth, and a mass of 1.2% that of the Earth.

Calculate the gravitational potential at the surface of the moon in terms of the gravitational potential on the surface of the Earth.

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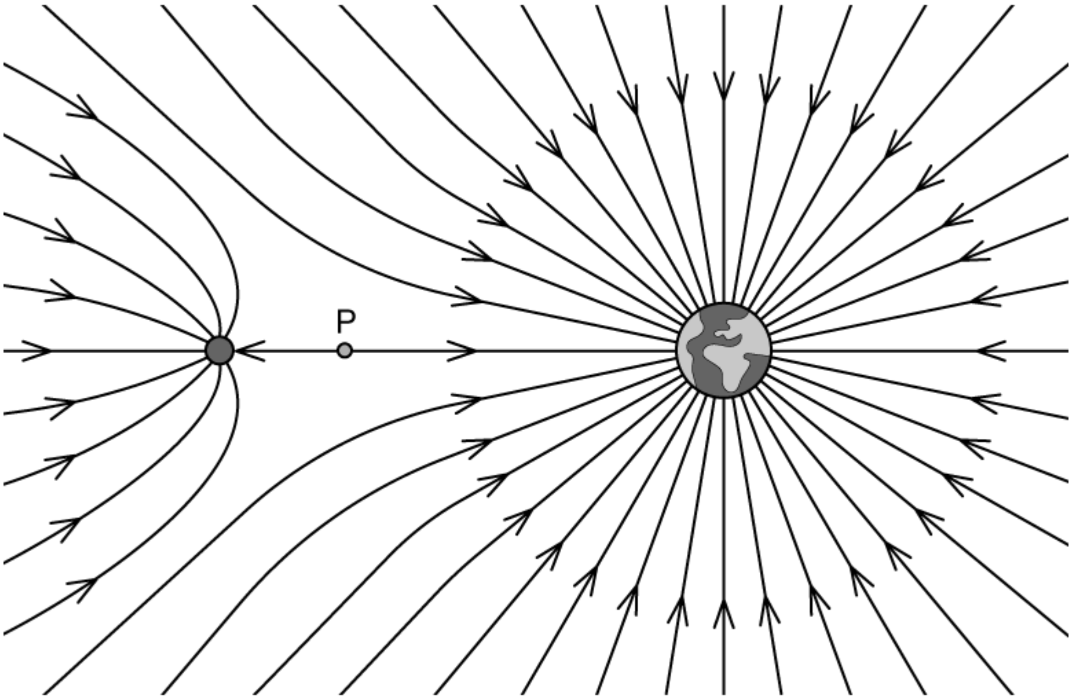
(2 marks)

(c) The gravitational field strength lines between the Earth and the moon can be drawn on a diagram.



Point P is the neutral point between the Earth and the moon where there is no resultant gravitational field.

Sketch the equipotential lines between the Earth and the moon on the diagram.

(3 marks)

3 (a) Imagine that it was possible to construct a tunnel through the centre of the earth, connecting a point on the surface to the diametrically opposite point. Assume that the earth is perfectly spherical with an evenly distributed mass and that the mass and volume of the tunnel, air resistance and friction are negligible.

Describe the variation in gravitational field strength and how speed of travel would vary if a person were to jump into the hole.

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(2 marks)

(b) Within a hollow sphere of uniform density, the gravitational field strength is zero.

Using this information, derive an expression for the gravitational field strength at any point in the tunnel in terms of:

- The distance from the centre of the earth = r
- The radius of the earth = R_e
- The gravitational field strength on the surface of the earth = g_{surf}

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(3 marks)

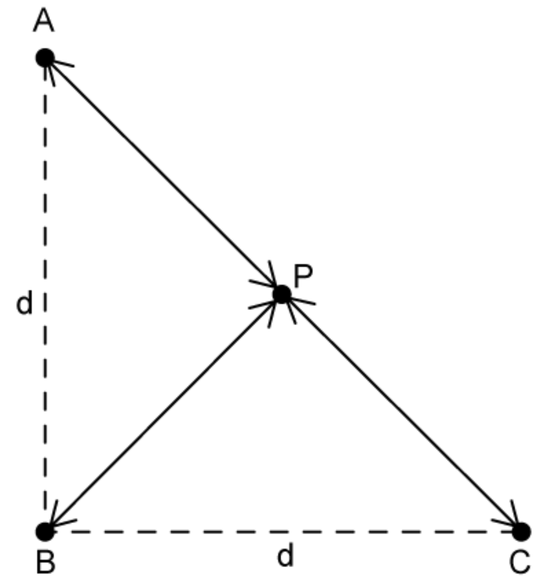
(c) This case is analogous to a mass bouncing on a spring where $F = ma = -kx$, and where in this situation $k = \frac{mg_{surf}}{R_e}$.

The time period for a mass on a spring, T, is equal to $2\pi\sqrt{\frac{m}{k}}$. For a satellite in orbit at a distance r, from the centre of a large body with mass M, the orbital speed can be obtained as $v = \sqrt{\frac{GM}{r}}$.

Using this information, show that the time for a traveller to reach the other end of the tunnel is the same as the time taken for a satellite in orbit just above the surface of the Earth to travel through half its orbit.

(1 mark)

4 (a) Three charges are fixed at the corners of a right-angled triangle.



The length of both the horizontal and vertical sides is *d*.

Show that the electric potential at point P, halfway between the −2Q and −6Q charge is given by $-\dfrac{2Q}{\sqrt{2}\,\pi\varepsilon_0 d}$.

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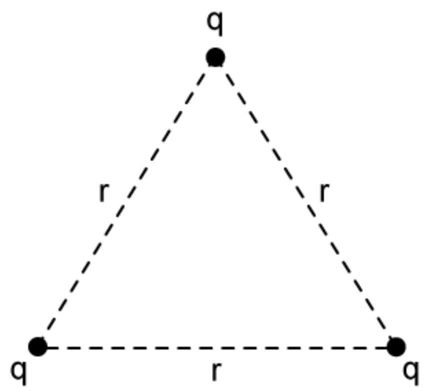
(2 marks)

(b) Before the discovery of quarks, scientists speculated that the subatomic particles might be made up of smaller particles.
If an electron was made up of three smaller, identical particles with charge *q*, which are brought in from an infinite distance to the vertices of an equilateral triangle, it would have this arrangement.



The radius of an electron is 2.82 fm.

Show that the work done in forming an electron consisting of 3 identical particles in this arrangement is given by:

$$\frac{e^2}{12\pi\varepsilon_0 r}$$

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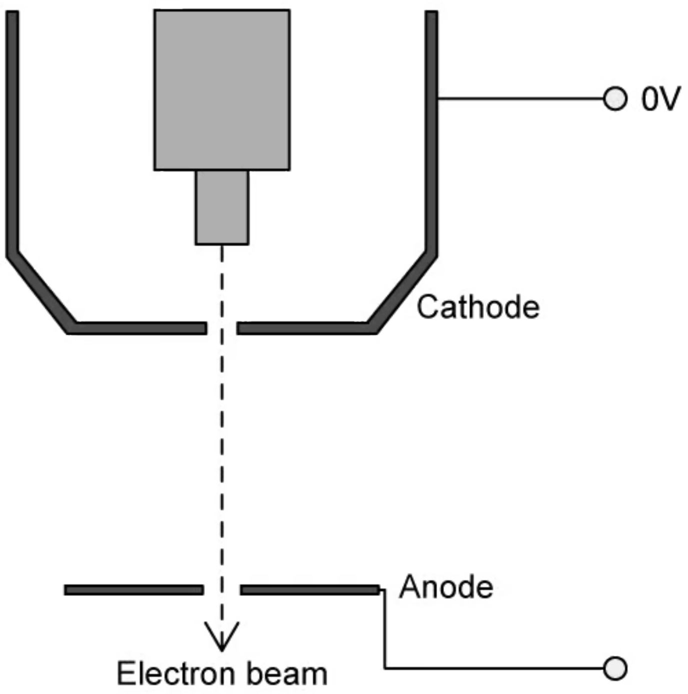
(5 marks)

(c) In an electron gun, electrons are released from a cathode and accelerated towards an anode. The electrons leave the electron gun at 10% of the speed of light.



Calculate the potential difference between the cathode and the anode.

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(2 marks)

5 (a) A science fiction film director is planning for a battle scene between two spacecrafts. The first spacecraft uses an electron gun to fire a beam of electrons at the second spacecraft from close range. The electron beam is created by accelerating electrons from rest between electrodes with a potential difference of 120 V.

To shield against the attack, the second aircraft creates a uniform electric field around itself and the electrons are stopped after 85 m. The director wishes to calculate the strength of the electric field, but is not aware of the equation $E = -\frac{\Delta V_e}{\Delta r}$.

Calculate the strength of the electric field without the use of this equation.

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(1 mark)

(b) After the failure of the first spacecraft to break through the electric shield of the second spacecraft a new weapon is to be designed. Instead of firing electrons, research is carried out to see if firing negatively charged ions with a charge of –2*e* and a mass of 2.26 × 10^{-26} kg would be more effective. The second spacecraft uses the same electric field as in part (a) to shield itself and that the electric field is uniform.

Calculate the magnitude of the minimum velocity at which these ions would need to be fired if they are to strike the second spacecraft from a distance of 1 km.

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(2 marks)

(c) Another option to attack the second spacecraft is to create a superweapon which can be fired from the aliens' home planet. As this weapon will fired from such a long way away from the second spacecraft, the spaceship and shield can be modelled as a charged particle carrying a charge of −130 C. The electrons fired by the superweapon have a kinetic energy of 12 MeV.

Calculate how close the electrons will come to the second spacecraft before they are stopped by the shield.

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(2 marks)