1)

(a) (i) Define gravitational field strength and state whether it is a scalar or vector quantity.

[2 marks]

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(a) (ii) A mass m is at a height h above the surface of a planet of mass M and radius R. The gravitational field strength at height h is g. By considering the gravitational force acting on mass m, derive an equation from Newton's law of gravitation to express g in terms of M, R, h and the gravitational constant G.

[2 marks]

(b) (i) A satellite of mass $2520\,\text{kg}$ is at a height of $1.39 \times 10^7\,\text{m}$ above the surface of the Earth. Calculate the gravitational force of the Earth attracting the satellite. Give your answer to an appropriate number of significant figures.

[3 marks]

force attracting satellite .... N

(b) (ii) The satellite in part (b)(i) is in a circular polar orbit. Show that the satellite would travel around the Earth three times every 24 hours.

[5 marks]

(c) State and explain **one** possible use for the satellite travelling in the orbit in part (b)(ii).

[2 marks]

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2)

(a) Define the gravitational potential at a point in a gravitational field.

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(2 marks)

(b) **Figure 5**, which is not drawn to scale, shows the region between the Earth (**E**) and the Moon (**M**).

Figure 5

(b) (i) The gravitational potential at the Earth's surface is $-62.6\,\text{MJ kg}^{-1}$. Point **X** shown in **Figure 5** is on the line of centres between the Earth and the Moon At **X** the resultant gravitational field is zero, and the gravitational potential is $-1.3\,\text{MJ kg}^{-1}$.

Calculate the minimum amount of energy that would be required to move a Moon probe of mass 1.2×10^4 kg from the surface of the Earth to point **X**. Express your answer to an appropriate number of significant figures.

answer = ... J

(3 marks)

(b) (ii) Explain why, once the probe is beyond **X**, no further energy would have to be supplied in order for it to reach the surface of the Moon.

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(1 mark)

(b) (iii) In the vicinity of the Earth's orbit the gravitational potential due to the Sun's mass is $-885\,\text{MJ kg}^{-1}$. With reference to the variation in gravitational potential with distance, explain why the gravitational potential due to the Sun's mass need not be considered when carrying out the calculation in part (b)(i).

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(2 marks)

(c) The amount of energy required to move a manned spacecraft from the Earth to the Moon is much greater than that required to return it to the Earth. By reference to the forces involved, to gravitational field strength and gravitational potential, and to the point **X**, explain why this is so.

The quality of your written communication will be assessed in your answer.

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(6 marks)

3)

(a) State Newton's law of gravitation.

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(2 marks)

(b) In 1798 Cavendish investigated Newton's law by measuring the gravitational force between two unequal uniform lead spheres. The radius of the larger sphere was 100 mm and that of the smaller sphere was 25 mm.

(b) (i) The mass of the smaller sphere was 0.74 kg. Show that the mass of the larger sphere was about 47 kg.

density of lead = 11.3×10^3 kg m^{-3}

(2 marks)

(b) (ii) Calculate the gravitational force between the spheres when their surfaces were in contact.

answer = ... N

(2 marks)

(c) Modifications, such as increasing the size of each sphere to produce a greater force between them, were considered in order to improve the accuracy of Cavendish's experiment. Describe and explain the effect on the calculations in part (b) of doubling the radius of both spheres.

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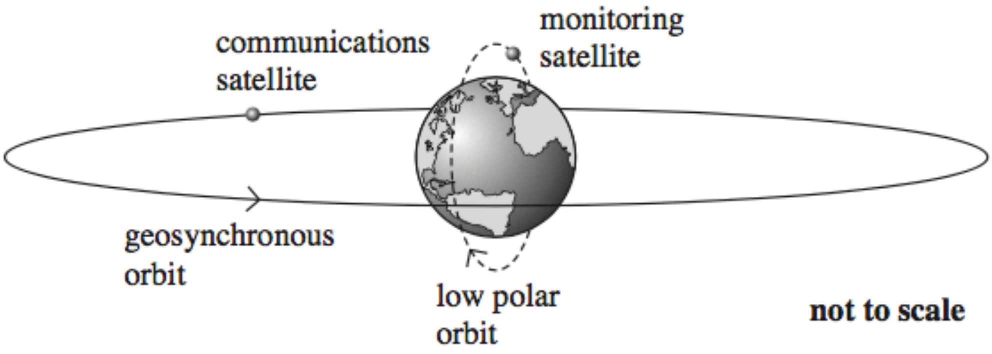
(4 marks)

4)

Figure 1 shows the orbits of two Earth satellites, a communications satellite in a geosynchronous orbit and a monitoring satellite in a low orbit that passes over the poles.

Figure 1



(a) The time period, T, of any satellite in a circular orbit around a planet is proportional to $r^{3/2}$, where r is the radius of its orbit measured from the centre of the planet.
For a satellite in a low orbit that passes over the poles of the Earth, T is 105 minutes when r is 7370 km.

(a) (i) Calculate the height above the surface of the Earth, in km, of a satellite in a geosynchronous circular orbit.
Give your answer to an appropriate number of significant figures.

height above surface .... km
(4 marks)

(a) (ii) Calculate the centripetal force acting on the polar orbiting satellite if its mass is 650 kg.

centripetal force .... N

(2 marks)

(b) These geosynchronous and polar satellites have different applications because of their different orbits in relation to the rotation of the Earth.

Compare the principal features of the geosynchronous and polar orbits and explain the consequences for possible uses of satellites in these orbits.

In your answer you should explain why:

- a low polar orbit is suitable for a satellite used to monitor conditions on the Earth.
- a geosynchronous circular orbit above the Equator is especially suitable for a satellite used in communications.

The quality of your written communication will be assessed in your answer.

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(a) (i) State the relationship between the *gravitational potential energy*, E_p, and the *gravitational potential*, V, for a body of mass m placed in a gravitational field.

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(1 mark)

(a) (ii) What is the effect, if any, on the values of E_p and V if the mass m is doubled?

value of E_p ....

value of V ....

(2 marks)

(b) **Figure 3**

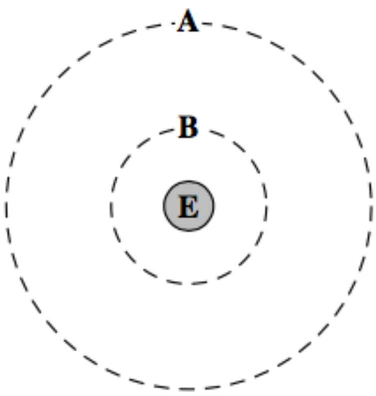

Figure 3 shows two of the orbits, **A** and **B**, that could be occupied by a satellite in circular orbit around the Earth, **E**.
The gravitational potential due to the Earth of each of these orbits is:

orbit **A**	$-12.0\ \mathrm{MJ\,kg^{-1}}$
orbit **B**	$-36.0\ \mathrm{MJ\,kg^{-1}}$.

(b) (i) Calculate the radius, from the centre of the Earth, of orbit **A**.

answer = ... m

(2 marks)

(b) (ii) Show that the radius of orbit **B** is approximately 1.1×10^4 km.

(1 mark)

(b) (iii) Calculate the centripetal acceleration of a satellite in orbit **B**.

answer = ... $\mathrm{m\,s^{-2}}$

(2 marks)

(b) (iv) Show that the gravitational potential energy of a 330 kg satellite decreases by about 8 GJ when it moves from orbit **A** to orbit **B**.

(1 mark)

(c) Explain why it is not possible to use the equation $\Delta E_p = mg\Delta h$ when determining the change in the gravitational potential energy of a satellite as it moves between these orbits.

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(1 mark)