1

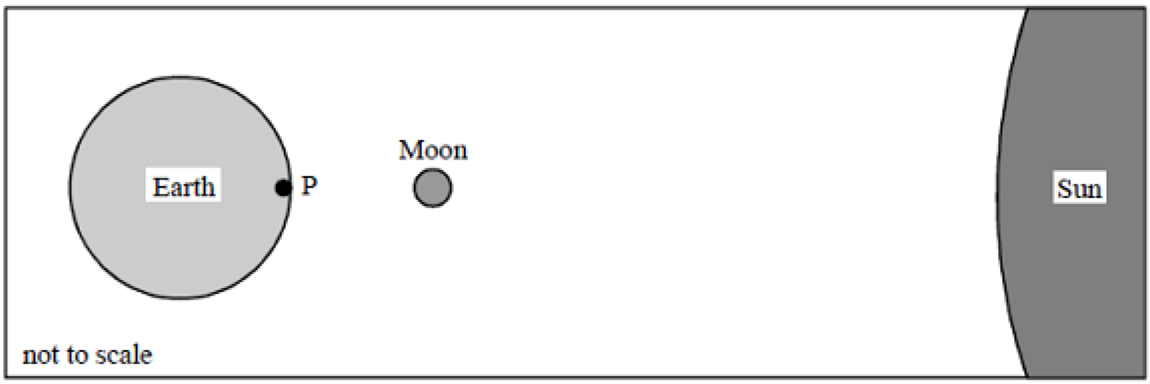
(a) Define *gravitational field strength* at a point in a gravitational field.

___

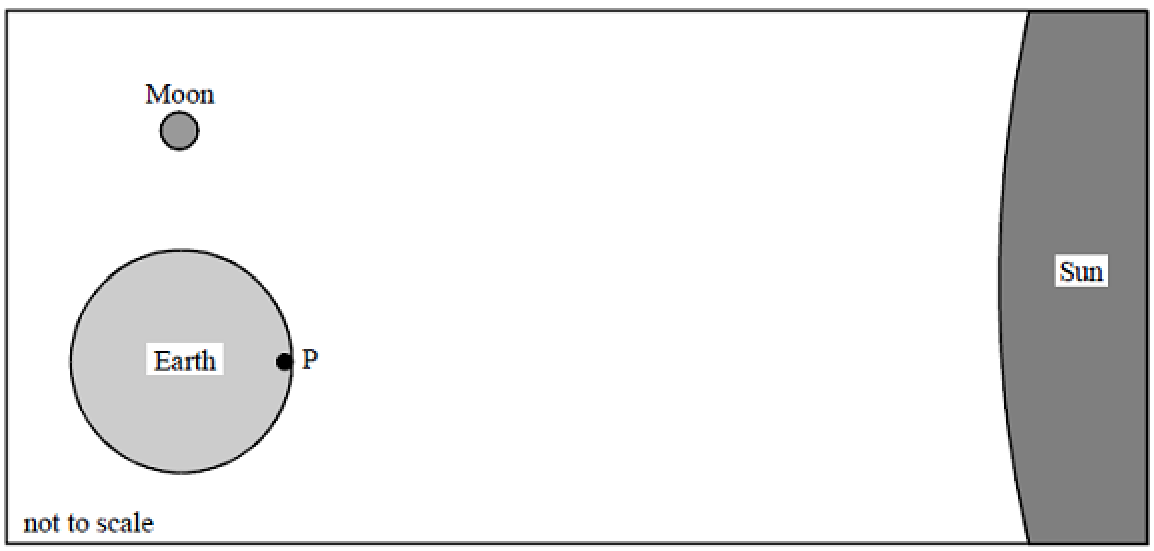
___

(1)

(b) Tides vary in height with the relative positions of the Earth, the Sun and the moon which change as the Earth and the Moon move in their orbits. Two possible configurations are shown in **Figure 1**.



Configuration A



Configuration B

Figure 1

Consider a 1 kg mass of sea water at position **P**. This mass experiences forces F_E, F_M and F_S due to its position in the gravitational fields of the Earth, the Moon and the Sun respectively.

(i) Draw labelled arrows on **both** diagrams in **Figure 1** to indicate the three forces experienced by the mass of sea water at **P**.

(3)

(ii) State and explain which configuration, **A** or **B**, of the Sun, the Moon and the Earth will produce the higher tide at position **P**.

____

____

____

(2)

(c) Calculate the magnitude of the gravitational force experienced by 1 kg of sea water on the Earth's surface at **P**, due to the **Sun**'s gravitational field.

radius of the Earth's orbit $= 1.5 \times 10^{11}$ m

mass of the Sun $= 2.0 \times 10^{30}$ kg

universal gravitational constant, G $= 6.7 \times 10^{-11}$ Nm^2 kg^{-2}

(3)

(Total 9 marks)

2 For an object, such as a space rocket, to escape from the gravitational attraction of the Earth it must be given an amount of energy equal to the gravitational potential energy that it has on the Earth's surface. The minimum initial vertical velocity at the surface of the Earth that it requires to achieve this is known as the escape velocity.

(a) (i) Write down the equation for the gravitational potential energy of a rocket when it is on the Earth's surface. Take the mass of the Earth to be M, that of the rocket to be m and the radius of the Earth to be R.

(1)

(ii) Show that the escape velocity, v, of the rocket is given by the equation

$$v = \sqrt{\frac{2GM}{R}}$$

(2)

(b) The nominal escape velocity from the Earth is 11.2 km s^{-1}. Calculate a value for the escape velocity from a planet of mass four times that of the Earth and radius twice that of the Earth.

(2)

(c) Explain why the actual escape velocity from the Earth would be greater than the nominal value calculated from the equation given in part (a)(ii).

____

____

____

(2)

(Total 7 marks)

3 (a) State the law that governs the magnitude of the force between two point masses.

____

____

____

____

(2)

(b) The table shows how the gravitational potential varies for three points above the centre of the Sun.

distance from centre of Sun/10^8 m	**gravitational potential/10^{10} J kg^{-1}**
7.0 (surface of Sun)	–19
16	–8.3
35	–3.8

(i) Show that the data suggest that the potential is inversely proportional to the distance from the centre of the Sun.

(2)

(ii) Use the data to determine the gravitational field strength near the surface of the Sun.

(3)

(iii) Calculate the change in gravitational potential energy needed for the Earth to escape from the gravitational attraction of the Sun.

mass of the Earth	=	6.0×10^{24} kg
distance of Earth from centre of Sun	=	1.5×10^{11} m

(3)

(iv) Calculate the kinetic energy of the Earth due to its orbital speed around the Sun and hence find the minimum energy that would be needed for the Earth to escape from its orbit. Assume that the Earth moves in a circular orbit.

(3)

(Total 13 marks)

4 (a) State, in words, Newton's law of gravitation.

(2)

(b) Some of the earliest attempts to determine the gravitational constant, G, were regarded as experiments to "weigh" the Earth. By considering the gravitational force acting on a mass at the surface of the Earth, regarded as a sphere of radius R, show that the mass of the Earth is given by

$$M = \frac{gR^2}{G},$$

where g is the value of the gravitational field strength at the Earth's surface.

(2)

(c) In the following calculation use these data.

radius of the Moon	$= 1.74 \times 10^{6}$ m
gravitational field strength at Moon's surface	$= 1.62$ N kg $^{-1}$
mass of the Earth M	$= 6.00 \times 10^{24}$ kg
gravitational constant G	$= 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Calculate the mass of the Moon and express its mass as a percentage of the mass of the Earth.

(3)
(Total 7 marks)

5 Both gravitational and electric field strengths can be described by similar equations written in the form

$$a = \frac{bc}{d^2}.$$

(a) Complete the following table by writing down the names of the corresponding quantities, together with their SI units, for the two types of field.

symbol	*gravitational field* quantity	SI unit	*electrical field* quantity	SI unit
a	gravitational field strength			
b			$\frac{1}{4\pi\varepsilon_0}$	m F^{-1}
c				
d				

(4)

(b) Two isolated charged objects, A and B, are arranged so that the gravitational force between them is equal and opposite to the electric force between them.

(i) The separation of A and B is doubled without changing their charges or masses. State and explain the effect, if any, that this will have on the resultant force between them.

(ii) At the original separation, the mass of A is doubled, whilst the charge on A and the mass of B remain as they were initially. What would have to happen to the charge on B to keep the resultant force zero?

(3)
(Total 7 marks)

6 Communications satellites are usually placed in a *geo-synchronous orbit*.

(a) State **two** features of a geo-synchronous orbit.

(2)

(b) Given that the mass of the Earth is 6.00×10^{24} kg and its mean radius is 6.40×10^{6} m,

(i) show that the radius of a geo-synchronous orbit must be 4.23×10^{7} m,

(ii) calculate the increase in potential energy of a satellite of mass 750 kg when it is raised from the Earth's surface into a geo-synchronous orbit.

(6)
(Total 8 marks)

7 (a) (i) Explain what is meant by *gravitational field strength*.

(1)

(ii) Describe how you would measure the gravitational field strength close to the surface of the Earth. Draw a diagram of the apparatus that you would use.

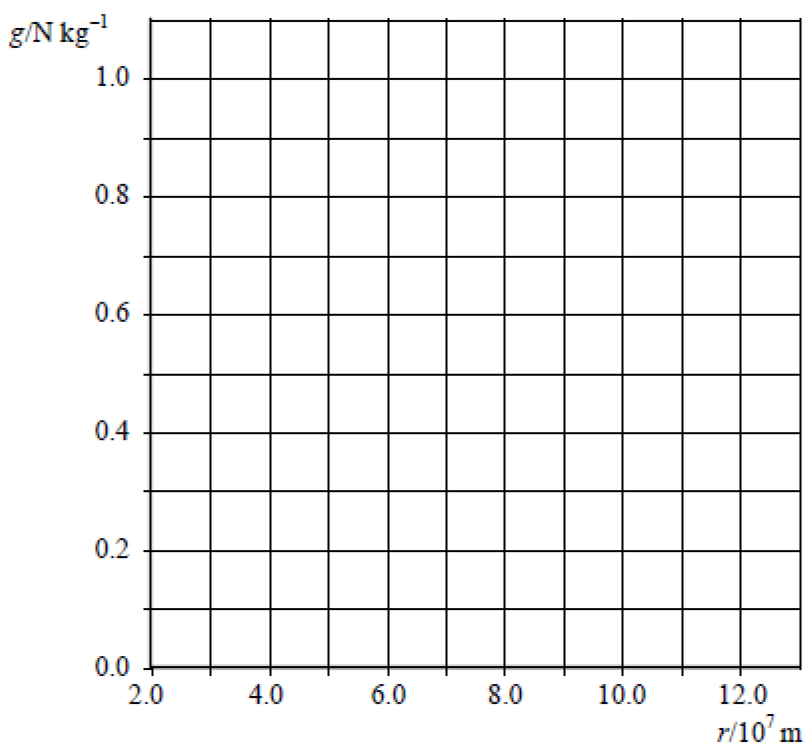
(6)

(b) (i) The Earth's gravitational field strength (g) at a distance (r) of 2.0×10^7 m from its centre is 1.0 N kg^{-1}. Complete the table with the 3 further values of g.

g/N kg^{-1}	1.0			
$r/10^7$ m	2.0	4.0	6.0	8.0

(2)

(ii) Below is a grid marked with g and r values on its axes. Draw a graph showing the variation of g with r for values of r between 2.0×10^7 m and 10.0×10^7 m.



(2)

(iii) Estimate the energy required to raise a satellite of mass 800 kg from an orbit of radius 4.0×10^7 m to one of radius 10.0×10^7 m.

(3)

(Total 14 marks)

8 (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.

____

____

(1)

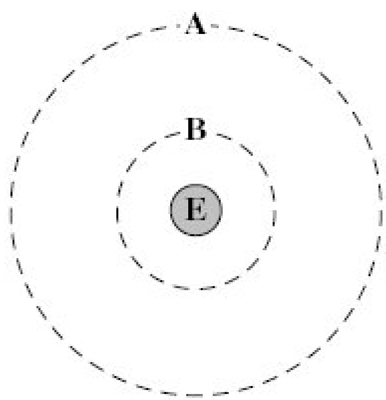
(ii) What is the effect, if any, on the values of E_p and V if the mass m is doubled?

value of E_p ____

value of V ____

(2)

(b)



The diagram above 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 MJ kg^{-1}
orbit **B** – 36.0 MJ kg^{-1}.

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

answer = ____________________ m

(2)

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

(1)

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

answer = ____________________ m s^{-2}

(2)

(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)

(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.

____

____

____

____

(1)

(Total 10 marks)

9 A spacecraft of mass m is at the mid-point between the centres of a planet of mass M_1 and its moon of mass M_2. If the distance between the spacecraft and the centre of the planet is d, what is the magnitude of the resultant gravitational force on the spacecraft?

A $\frac{Gm(M_1 - M_2)}{d}$

B $\frac{Gm(M_1 + M_2)}{d^2}$

C $\frac{Gm(M_1 - M_2)}{d^2}$

D $\frac{Gm(M_1 + M_2)}{d}$

(Total 1 mark)

10 Two satellites P and Q, of equal mass, orbit the Earth at radii R and $2R$ respectively. Which one of the following statements is correct?

A P has less kinetic energy and more potential energy than Q.

B P has less kinetic energy and less potential energy than Q.

C P has more kinetic energy and less potential energy than Q.

D P has more kinetic energy and more potential energy than Q.

(Total 1 mark)

11 A small mass is situated at a point on a line joining two large masses m_1 and m_2 such that it experiences no resultant gravitational force. Its distance from the centre of mass of m_1 is r_1 and its distance from the centre of mass of m_2 is r_2.

What is the value of the ratio $\frac{r_1}{r_2}$?

A $\frac{m_1^2}{m_2^2}$

B $\frac{m_2^2}{m_1^2}$

C $\sqrt{\frac{m_1}{m_2}}$

D $\sqrt{\frac{m_2}{m_1}}$

(Total 1 mark)

12 Which one of the following gives a correct unit for $\left(\frac{g}{G}\right)^2$?

A N m^{-2}

B N kg^{-1}

C N m

D N

(Total 1 mark)

13 The gravitational field strength at the surface of the Earth is 6 times its value at the surface of the Moon. The mean density of the Moon is 0.6 times the mean density of the Earth.

What is the value of the ratio $\left(\frac{\text{radius of Earth}}{\text{radius of Moon}}\right)$?

A 1.8

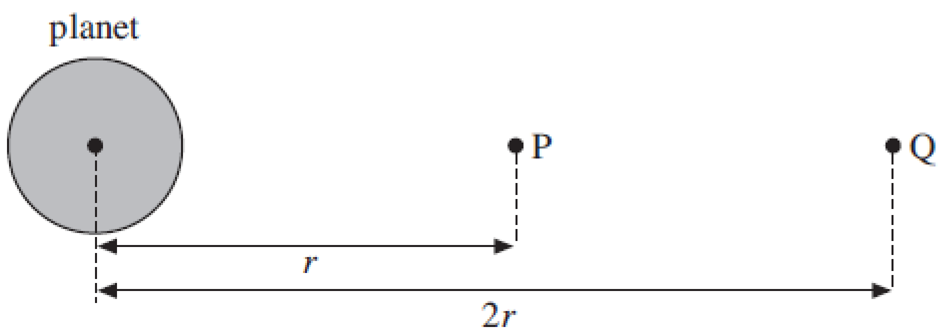
B 3.6

C 6.0

D 10

(Total 1 mark)

14 The diagram shows two points, P and Q, at distances *r* and 2*r* from the centre of a planet.



The gravitational potential at P is −16 kJ kg^{-1}. What is the work done on a 10 kg mass when it is taken from P to Q?

A – 120 kJ

B – 80 kJ

C + 80 kJ

D + 120 kJ

(Total 1 mark)

15 The Earth moves around the Sun in a circular orbit with a radius of 1.5×10^8 km.
What is the Earth's approximate speed?

A $1.5 \times 10^3 \text{ms}^{-1}$

B $5.0 \times 10^3 \text{ms}^{-1}$

C $1.0 \times 10^4 \text{ms}^{-1}$

D $3.0 \times 10^4 \text{ms}^{-1}$

(Total 1 mark)

16 The gravitational field strength on the surface of a planet orbiting a star is 8.0 N kg^{-1}. If the planet and star have a similar density but the diameter of the star is 100 times greater than the planet, what would be the gravitational field strength at the surface of the star?

A 0.0008 N kg^{-1}

B 0.08 N kg^{-1}

C 800 N kg^{-1}

D 8000 N kg^{-1}

(Total 1 mark)

17 Which one of the following statements about Newton's law of gravitation is correct?

Newton's law of gravitation explains

A the origin of gravitational forces.

B why a falling satellite burns up when it enters the Earth's atmosphere.

C why projectiles maintain a uniform horizontal speed.

D how various factors affect the gravitational force between two particles.

(Total 1 mark)

18 Two satellites, P and Q, of the same mass, are in circular orbits around the Earth. The radius of the orbit of Q is three times that of P. Which one of the following statements is correct?

A The kinetic energy of P is greater than that of Q.

B The weight of P is three times that of Q.

C The time period of P is greater than that of Q.

D The speed of P is three times that of Q.

(Total 1 mark)

19 If an electron and proton are separated by a distance of 5×10^{-11} m, what is the approximate gravitational force of attraction between them?

A 2×10^{-57} N

B 3×10^{-47} N

C 4×10^{-47} N

D 5×10^{-37} N

(Total 1 mark)

Mark schemes

1

(a) force acting per unit mass **or** $g = F / m$ **or** $g = \frac{GM}{R^2}$ with terms defined

(1)

(b) (i) direction of F_E correct in each diagram

B1

direction of F_M correct in each diagram

B1

direction of F_S correct in each diagram

B1

F_S must be distinguished from F_M

penalty of 1 mark for any missing labelling

(3)

(ii) sun and moon pulling in same direction / resultant of F_M and F_S is greatest / clear response including summation of F_M and F_S

M1

configuration A

A1

(2)

(c) $F = GMm / R^2$

C1

correct substitution $\frac{6.7 \times 10^{-11} \times 2.0 \times 10^{30}}{(1.5 \times 10^{11})^2}$

C1

$(5.95$ **or** 5.96 **or** 5.9 **or** $6.0) \times 10^{-3}$ N kg^{-1}

A1

(3)

[9]

2

(a) (i) g.p.e. = $G\frac{Mm}{R}$ **must be equation** (*condone* "*V* =")

B1

1

(ii) equate with k.e. **must be seen**

M1

cancelling **correct *m*** must be seen

A1

2

(b) correct ratios taken ($\frac{v^2}{v_E^2} = 2$)

C1

v = 15.8(4) km s^{-1}

A1

2

(c) mention of air resistance

M1

k.e. of rocket → internal energy of rocket and atmosphere/
work is done against air resistance

A1

2

[7]

3 (a) force is proportional to the product of the two masses

B1

force is inversely proportional to the square of their separation (condone radius between masses)
or
equation M0 : masses defined A1 separation defined A1

B1

2

(b) (i) appreciation that potential x distance from centre of sun = constant
or calculation of *Vr* for two sets of values (1.33 × 10^{20})
or uses distance ratio to calculate new *V* or *r*

C1

calculation of all three + conclusion
or uses distance ratios twice+ conclusion
conclusion must be more than 'numbers are same'
(condone 'signs' and no use of powers of 10)

A1

2

(ii) $V = GM/r$ and $g = GM/r^2$
or

$g = V/r$ (no mark for E or $g = V/d$ or $E = V/r$)

B1

substitution of one set of data to obtain GM (1.33×10^{20})
or $19 \times 10^{10}/7 \times 10^{8}$ seen

B1

271 N kg^{-1} (m s^{-2}) (J kg^{-1} m^{-1})

B1

3

(iii) potential energy of the Earth = $(-)GMm/r$
or potential difference formula + $r^2 = \infty$
or potential at position of Earth = -8.87×10^{8} J kg^{-1}
(from $Vr = 1.33 \times 10^{20}$)

C1

correct substitution (allow ecf for GM from (ii))
or
potential energy = potential x mass of Earth

C1

change in PE = 5.32×10^{33} J (cnao)
Fd approach is PE so 0 marks

A1

3

(iv) speed of Earth round Sun = $2\pi r/T$ or $\sqrt{\frac{GM}{r}}$
or 3.0×10^4 m s^{-1}

or KE= $\frac{GMm}{2r}$

B1

KE of Earth = ½ 6×10^{24} × their v^2 (2.68×10^{33}J)

B1

energy needed = difference between (iii) and orbital KE
(2.64×10^{33} J)

or KE in orbit = half total energy needed to
escape (−1 for AE)

B1

3

[13]

4 (a) attractive force between two particles (or point masses) **(1)**
proportional to product of masses and inversely proportional to square of separation [or distance] **(1)**

2

(b) (for mass, m, at Earth's surface) $mg = \frac{GMm}{R^2}$ **(1)**

rearrangement gives result **(1)**

2

(c) $M_{\text{moon}} \left(= \frac{gR^2}{G} \right) = \frac{1.62 \times (1.74 \times 10^6)^2}{6.62 \times 10^{24}}$ **(1)**

= 7.35×10^{22} kg **(1)**

$\frac{M_{\text{moon}}}{M_{\text{earth}}} = \frac{7.35 \times 10^{22}}{6.00 \times 10^{24}}$ (= 0.0123) ∴ 1.23%

3

[7]

5 (a)

________	$N\,kg^{-1}$	electric field strength	$N\,C^{-1}$ or $V\,m^{-1}$	**(1)**
gravitational constant	$N\,m^2\,kg^{-2}$	________	________	**(1)**
mass	kg	charge	C	**(1)**
distance (from mass to point)	m	distance (from charge to point)	m	**(1)**

(4)

(b) (i) none **(1)**

both F_E and $F_G \propto \frac{1}{r^2}$ (hence both reduced to $\frac{1}{4}$ [affected equally] **(1)**

(ii) charge on B must be doubled **(1)**

(3)

[7]

6 (a) period = 24 hours or equals period of Earth's rotation **(1)**
remains in fixed position relative to surface of Earth **(1)**
equatorial orbit **(1)**
same angular speed as Earth or equatorial surface **(1)**

max 2

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **(1)**

$T = \frac{2\pi}{\omega}$ **(1)**

$$r\left(=\frac{GMT^2}{4\pi^2}\right)^{1/3} = \left(\frac{6.67\times10^{-11}\times6\times10^{24}\times(24\times3600)^2}{4\pi^2}\right)^{1/3}$$ **(1)**

(gives $r = 42.3 \times 10^3$ km)

(ii) $\Delta V = GM\left(\frac{1}{R} - \frac{1}{r}\right)$ **(1)**

$= 6.67 \times 10^{-11} \times 6 \times 10^{24} \times \left(\frac{1}{6.4 \times 10^{6}} - \frac{1}{4.23 \times 10^{7}}\right)$

$= 5.31 \times 10^{7}$ (J kg^{-1}) **(1)**

$\Delta E_p = m\Delta V$ ($= 750 \times 5.31 \times 10^{7}$) $= 3.98 \times 10^{10}$ J **(1)**

(allow C.E. for value of ΔV)

[alternatives:

calculation of $\frac{GM}{R}$ (6.25×10^{7}) or $\frac{GM}{r}$ (9.46×10^{6}) **(1)**

or calculation of $\frac{GMm}{R}$ (4.69×10^{10}) or $\frac{GMm}{r}$ (7.10×10^{9}) **(1)**

calculation of both potential energy values **(1)**
subtraction of values or use of $m\Delta V$ with correct answer **(1)**]

6

[8]

7 (a) (i) force per unit mass (allow equation with defined terms)

B1

(1)

(ii) diagram of method that will work
(pendulum / light gates / solenoid and mechanical gate / strobe photography / video)

B1

pair of measurements (eg length of pendulum and (periodic) time / distance and time of fall – could be shown on diagram)

M1

instruments to measure named quantities (may be on diagram)

A1

correct procedure (eg calculate period for range of lengths, measure the time of fall for range of heights)

B1

good practice – series of values and averages / use of gradient of graph

B1

appropriate formula and how g calculated

B1

(6)

(b) (i) evidence of gr^2 being used

C1

values of 0.25, 0.11, 0.06(25)
no s.f. penalty here unless values given as fractions

A1

(2)

(ii) points correctly plotted on grid (e.c.f.) **B1**

smooth curve of high quality at least to 10×10^7 m, no intercept on r axis **B1**

(2)

(iii) attempt to use area under curve **B1**

evidence of × 800 kg **B1**

$(4.3 – 5.3) \times 10^9$ J **B1**

or

use of equation for potential $\Delta E_G = m(g_1r_1 – g_2r_2)$ **B1**

evidence of × 800 kg **B1**

$(4.7 – 4.9) \times 10^9$ J **B1**

max 2 if assumed values of G and M used

allow calculation of GM from graph followed by substitution into $\Delta E_G = M_G(m / r_1 – m / r_2)$ for 3 marks

(3)

[14]

8 (a) (i) relationship between them is $E_p = mV$ (allow $\Delta E_p = m\Delta V$) [or V is energy per unit mass (or per kg)] **(1)**

1

(ii) value of E_p is doubled **(1)**

value of V is unchanged **(1)**

2

(b) (i) use of $V = -\frac{GM}{r}$ gives $r_A = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{12.0 \times 10^6}$ **(1)**

$= 3.3(2) \times 10^7$ (m) **(1)**

2

(ii) since $V \propto (-)\frac{1}{r}\left(\text{or } \frac{r_A}{r_B} = \frac{v_B}{v_A} = \frac{36.0}{12.0} = 3\right) r_B = \frac{3.32 \times 10^7 \text{ m}}{3}$ **(1)**

(which is ≈ 1.1×10^4 km)

1

(iii) centripetal acceleration $g_B = \frac{GM}{r_B^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.11 \times 10^7)^2}$ **(1)**

[allow use of 1.1 × 10^7 m from (b)(ii)]

= 3.2 (m s^{-2}) **(1)**

[**alternatively**, since $g_B = (-)\frac{v_B}{v_a}, g_B = \frac{36.0 \times 10^6}{1.11 \times 10^7}$ **(1)**

= 3.2 (m s^{-2}) **(1)**]

2

(iv) use of $\Delta E_p = m\Delta V$ gives $\Delta E_p = 330 \times (-12.0 - (-36.0)) \times 10^6$ **(1)**

(which is 7.9 × 10^9 J or ≈ 8 GJ)

1

(c) *g* is not constant over the distance involved

(**or** *g* decreases as height increases
or work done per metre decreases as height increases
or field is radial and/or not uniform) **(1)**

1

[10]

9 C

[1]

10 C

[1]

11 C

[1]

12 A

[1]

13 B

[1]

14 C

[1]

15 D

[1]

16 C

[1]

17 D

[1]

18 A

[1]

19 C

[1]

Examiner reports

1 (a) Most candidates managed to give an acceptable definition of gravitational field strength. Those who did not usually failed because they omitted to mention unit mass or because they confused field strength with potential or potential energy.

(b) (i) This part was also well done. Some candidates gave confused labelling, showed their forces in the wrong direction, or omitted to show the forces on both of the diagrams.

(ii) Explanations were often not clear: some candidates created a difficulty by referring to the resultant force when they probably were thinking of the resultant force of only F_M and F_S. A few candidates sought to give explanations relating to the distances between the Earth and the Sun or Moon, highlighting the need to advise candidates not to rely on judgements of distance from diagrams which are not to scale.

(c) This calculation was done well by most of the candidates. A few tried to use an equation for potential rather than force and some made processing errors, often forgetting to square the orbital radius even though they had shown it as being squared in their equation.

2 (a) (i) Several candidates failed to write *an equation* for this part . simply giving one term.

(ii) Few candidates were able to relate the kinetic energy to the gravitational potential energy to produce a convincing development of the escape velocity equation.

(b) This part was usually done well.

(c) Answers to this part were frequently too loosely phrased to gain credit. References to *wind resistance* and *friction* were commonplace.

3 (a) This was done well by the majority of candidates. A common error was to state that the force is inversely proportional to the square of the radius.

(b) (i) Most candidates knew a method of showing the inverse proportionality. However, many used only two of the sets of data or provided only a series of numbers without any explanation of what they were doing or providing any conclusion. In the worst cases, answers were set out poorly and any reasoning was hard to follow.

(ii) Although many arrived at the correct answer, there were many dubious equations to justify the final result. To gain full credit, candidates were expected to write down an appropriate gravitational field equation from which to proceed. Some recalled the value for *G* although the questions asked them to 'use the data'.

(iii) There were relatively few correct answers to this part. Many candidates could not identify an appropriate equation to use or did not realise that they had the value for *GM* from earlier parts. Some determined the energy needed for the Earth to move from the surface of the Sun to the position of the Earth's orbit. Those who recalled *G,* having no value for the mass of the Sun, determined the energy required for the Earth to escape from the Earth.

(iv) Most were able to gain some credit for this part, gaining marks for calculating the speed of the Earth in its orbit and/or for use of the KE formula. Many either ignored the last part or added the KE in orbit to their answer to part (iii).

4 Missing from most attempted statements in part (a) were the expected references to point masses and to an attractive force. Many candidates simply tried to put the well-known formula into words, whilst others referred to the sum of the masses rather than the product of them.

The equation $g = -GM / r^2$ is given in the *Data booklet* and mechanical rearrangement of it leads directly to the expression in part (b). However, this was not what was required by the wording of the question, and the many candidates who tried this approach were not given any marks. The acceptable starting point was to equate the gravitational force with mg.

Answers to part (c) were frequently completely successful, making an interesting contrast with the earlier parts of this question. The main problems here were omission of kg after the mass of the moon, significant figure penalties, and arithmetical slips – typically forgetting to square the denominator.

5 Although part (a) was relatively novel, most candidates could handle the comparison of gravitational and electric fields. The gaps in the second line of the table could be filled directly by use of the *Data Booklet*, but most of the other entries required a little more thought. Derived units were sometimes quoted (but not accepted) for the electric field strength: candidates were expected to know that this is N C^{-1} or V m^{-1}. In the fourth line, distance (or radius) *squared* was a surprisingly common wrong answer.

In pan (b)(i) quite a large number of candidates did not state that the resultant force would be unchanged, even though they had correctly considered the separate effects of a $1 / r^2$ relationship on both the gravitational and electric forces. The most frequent wrong response was that the force (presumably the resultant force) would decrease by a factor of four. In part (b)(ii) many candidates stated that the charge should be increased, without indicating that it should be doubled – this was expected for the mark to be awarded.

6 Two appropriate features of a geo-synchronous orbit were usually given by the candidates in part (a), but the marks for them were often the last that could be awarded in this question. The required radius in part (b)(i) came readily to the candidates who correctly equated the gravitational force on the satellite with $m\omega^2 r$, applied $T = 2\pi/\omega$, and completed the calculation by substituting T = 24 hours and the values given in the question. Other candidates commonly presented a tangled mass of unrelated algebra in part (b)(i), from which the examiners could rescue nothing worthy of credit.

In part (b)(ii) an incredible proportion of the candidates assumed that it was possible to calculate the increase in the potential energy by the use of mg Δh, in spite of the fact that the satellite had be raised vertically through almost 36,000 km. These attempts gained no marks. Other efforts started promisingly by the use of $V = -GM / r$, but made the crucial error of using $(4.23 \times 10^7 - 6.4 \times 10^6)$ as r in the denominator. Some credit was available to candidates who made progress with a partial solution that proceeded along the correct lines, such as evaluating the gravitational potential at a point in the orbit of the satellite. Confusion between the mass of the Earth and the mass of the satellite was common when doing this.

8 Many very good answers were seen in part (a) (i), expressed either fully in words or simply by quoting $E_p = mV$. The corresponding equation for an incremental change, $\Delta E_p = m\Delta V$, was also acceptable but mixed variations on this such as $E_p = m\Delta V$ (which showed a lack of understanding) were not. The consequences of doubling m were generally well understood in part (a) (ii), where most candidates scored highly, but some inevitably thought that E_p would be unchanged whilst V would double.

Candidates who were not fully conversant with the metric prefixes used with units had great difficulty in part (b), where it was necessary to know that 1 MJ $=10^6$ J, 1 GJ $=10^9$ J, and (even) 1 km = 10^3 m. Direct substitution into $V = (–)\ GM/r$ (having correctly converted the value of V to J $kg^{–1}$) usually gave a successful answer for the radius of orbit **A** in part (b) (i). A similar approach was often adopted in part (b) (ii) to find the radius of orbit **B**, although the realisation that $V \propto 1/r$ facilitated a quicker solution. Some candidates noticed that $V_\mathbf{B} = 3\ V_\mathbf{A}$ and guessed that $r_\mathbf{B} = r_\mathbf{A}/3$, but this was not allowed when there was no physical reasoning to support the calculation.

Part (b) (iii) caused much difficulty, because candidates did not always appreciate that the centripetal acceleration of a satellite in stable orbit is equal to the local value of g, which is equal to GM/r^2. This value turns out to equal to V/r, which provided an alternative route to the answer. Many incredible values were seen, some of them greatly exceeding 9.81 m $s^{–2}$.

Part (c) was generally well understood, with some very good and detailed answers from the candidates. Alternative answers were accepted: either that g is not constant over such large distances, or that the field of the Earth is radial rather than uniform.

9 Direct application of Newton's law of gravitation easily gave the answer in this question, which had a facility of 78%. A very small number of incorrect responses came from assuming that the law gives $F \propto (1\ /\ r)$ – represented by distractors A and D. Rather more (14%) chose distractor B; these students probably added the two component forces acting on the spacecraft instead of subtracting them.

10 This question provided poorer discrimination between candidates' abilities than any other question in this test. Candidates ought to know that satellites speed up as they move into lower orbits, and therefore gain kinetic energy if their mass is unchanged. It should also be clear that satellites lose gravitational potential energy as they move closer to Earth. Therefore it is surprising that only 55% of the candidates gave the correct answer. The fairly even spread of responses amongst the other distractors suggests that many candidates were guessing.

11 This question, which involved determining the position of the point between two masses at which there would be no resultant gravitational force, was repeated from an earlier examination. Two thirds of the responses were correct, the most common incorrect one being distractor D – the inverse of the required expression.

12 This question was on gravitational effects. Rearrangement of possible units to obtain the ratio of the quantities $g^2\ /\ G$ was required; almost 70% of the candidates could do this correctly but 20% chose distractor B (N kg^{-1} instead of N m^{-2}).

13 This question was more demanding algebraically and involved use of a density value to determine the ratio of Earth's radius to the Moon's radius. Slightly under half of the candidates chose the correct value; incorrect responses were fairly evenly spread between the other distractors and the question discriminated poorly. This suggests that many were guessing.

14 Candidates found this question, on gravitational potential, a little easier, because its facility was almost 60%. Whether the work done was positive or negative must have troubled many, because distractor B (-80 kJ rather than +80 kJ) was the choice of 28%.

15 This question where the purpose was to calculate the Earth's orbital speed, combined circular motion with gravitation. 62% of the students were successful, whilst incorrect answers were spread fairly evenly between the three incorrect responses.

16 This question which tested how g is connected to the diameter for two stars of similar density, was the most demanding question on the test – its facility was only 39%. Equating *mg* with GMm / R^2 and then substituting (4/3) π R^3ρ. for *M* ought to have shown that *g* is proportional to the product *Rρ*. Consequently, if *ρ* is taken to be the same, $g \propto R$. Yet 33% of the students suggested that *g* would be 100 times smaller (distractor A), and not 100 times bigger, when the diameter was 100 times larger.

17 This question involving statements about Newton's law of gravitation, had a facility of 85%. When pre-tested, this question had been found appreciably harder but was more discriminating than on this occasion.

18 This question with a facility of 41%, was also demanding. Here several factors - kinetic energy, weight, time period and speed - had to be considered for two satellites in different circular orbits. The three incorrect answers had a fairly even distribution of responses.

19 Data for the gravitational constant and the masses of the electron and proton had to be extracted from the Data Sheet (see Reference Material) for use in this question where the topic was the gravitational force between two particles. Over four-fifths of the students succeeded with this.