

1 A planet has a radius half the Earth's radius and a mass a quarter of the Earth's mass. What is the approximate gravitational field strength on the surface of the planet?

A 1.6 N kg⁻¹ ☐

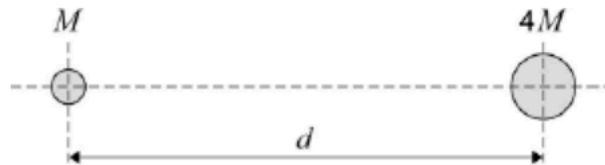
B 5.0 N kg⁻¹ ☐

C 10 N kg⁻¹ ☐

D 20 N kg⁻¹ ☐

(Total 1 mark)

2 Two stars of mass M and $4M$ are at a distance d between their centres.



The resultant gravitational field strength is zero along the line between their centres at a distance y from the centre of the star of mass M .

What is the value of the ratio $\frac{y}{d}$?

A $\frac{1}{2}$ ☐

B $\frac{1}{3}$ ☐

C $\frac{2}{3}$ ☐

D $\frac{3}{4}$ ☐

(Total 1 mark)

3

The planet Venus may be considered to be a sphere of uniform density $5.24 \times 10^3 \text{ kg m}^{-3}$. The gravitational field strength at the surface of Venus is 8.87 N kg^{-1} .

- (a) (i) Show that the gravitational field strength g_s at the surface of a planet is related to the density ρ and the radius R of the planet by the expression

$$g_s = \frac{4}{3} \pi G R \rho$$

where G is the gravitational constant.

(2)

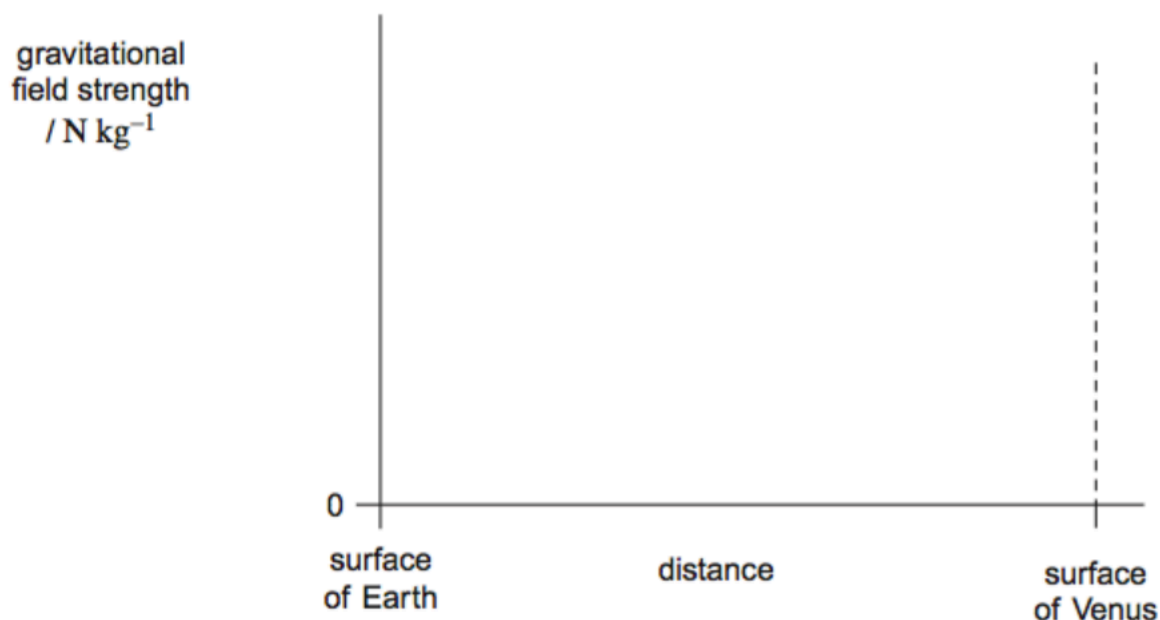
- (ii) Calculate the radius of Venus.

Give your answer to an appropriate number of significant figures.

radius = _____ m

(3)

- (b) At a certain time, the positions of Earth and Venus are aligned so that the distance between them is a minimum.
 Sketch a graph on the axes below to show how the magnitude of the gravitational field strength g varies with distance along the shortest straight line between their surfaces.
 Consider only the contributions to the field produced by Earth and Venus.
 Mark values on the vertical axis of your graph.



(3)

(Total 8 marks)

- 4** Two identical uniform spheres each of radius R are placed in contact. The gravitational force between them is F .

The spheres are now separated until the force of attraction is $\frac{F}{9}$.

What is the distance between the **surfaces** of the spheres after they have been separated?

- A** $2R$
- B** $4R$
- C** $8R$
- D** $12R$

(Total 1 mark)

5

A satellite of mass m is in a circular orbit at height R above the surface of a uniform spherical planet of radius R and density ρ .

What is the force of gravitational attraction between the satellite and the planet?

A $\frac{\pi\rho GmR}{3}$

B $\frac{2\pi\rho GmR}{3}$

C $\frac{\pi\rho GmR^2}{3}$

D $\frac{2\pi\rho GmR^2}{3}$

(Total 1 mark)

6

The following data refers to two planets, P and Q.

	Radius / km	Density / kg m ⁻³
planet P	8000	6000
planet Q	16 000	3000

The gravitational field strength at the surface of P is 13.4 N kg⁻¹.

What is the gravitational field strength at the surface of Q?

A 3.4 N kg⁻¹

B 13.4 N kg⁻¹

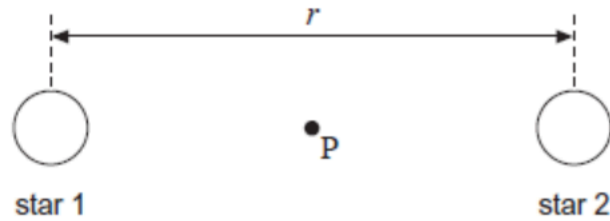
C 53.6 N kg⁻¹

D 80.4 N kg⁻¹

(Total 1 mark)

7

The diagram shows an isolated binary star system. The two stars have equal masses, M , and the distance between their centres is r .



The point P is half-way between the two stars.

What is the gravitational field strength at P?

A zero

B $-\frac{GM}{r^2}$

C $-\frac{2GM}{r^2}$

D $-\frac{4GM}{r^2}$

(Total 1 mark)

8

In the equation $X = \frac{ab}{r^n}$, X represents a physical variable in an electric or a gravitational field, a is a constant, b is either mass or charge and n is a number.

Which line, **A** to **D**, in the table provides a consistent representation of X , a and b according to the value of n ?

The symbols E , g , V and r have their usual meanings.

	n	X	a	b
A	1	E	$\frac{1}{4\pi\epsilon_0}$	charge
B	1	V	$\frac{1}{4\pi\epsilon_0}$	mass
C	2	g	G	mass
D	2	V	G	charge

(Total 1 mark)

9

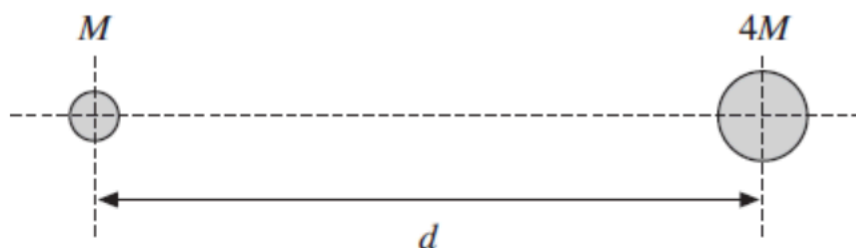
The gravitational field strengths at the surfaces of the Earth and the Moon are 9.8 N kg^{-1} and 1.7 N kg^{-1} respectively. If the mass of the Earth is $81 \times$ the mass of the Moon, what is the ratio of the radius of the Earth to the radius of the Moon?

- A 3.7
- B 5.8
- C 14
- D 22

(Total 1 mark)

10

Two stars of mass M and $4M$ are at a distance d between their centres.



The resultant gravitational field strength is zero along the line between their centres at a distance y from the centre of the star of mass M .

What is the value of the ratio $\frac{y}{d}$?

- A $\frac{1}{2}$
- B $\frac{1}{3}$
- C $\frac{2}{3}$
- D $\frac{3}{4}$

(Total 1 mark)

11

Which one of the following statements about gravitational fields is **incorrect**?

- A Moving a mass in the direction of the field lines reduces its potential energy.
- B A stronger field is represented by a greater density of field lines.
- C Moving a mass perpendicularly across the field lines does not alter its potential energy.
- D At a distance r from a mass the field strength is inversely proportional to r .

(Total 1 mark)

12

A spherical planet of uniform density ρ has radius R .

Which line, **A** to **D**, in the table gives correct expressions for the mass of the planet and the gravitational field strength at its surface?

	mass of planet	gravitational field strength at surface
A	$\frac{4\pi R^2 \rho}{3}$	$\frac{4\pi G R \rho}{3}$
B	$\frac{4\pi R^3 \rho}{3}$	$\frac{4\pi G R \rho}{3}$
C	$\frac{4\pi R^2 \rho}{3}$	$\frac{4\pi G \rho}{3}$
D	$\frac{4\pi R^3 \rho}{3}$	$\frac{4\pi G \rho}{3}$

(Total 1 mark)

13

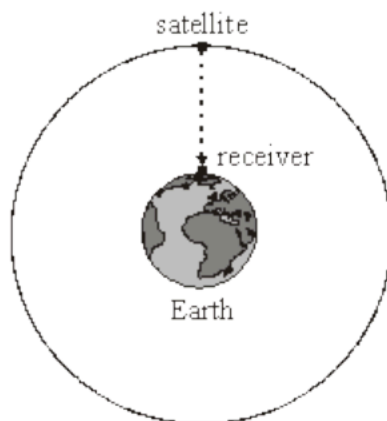
The gravitational field strength on the surface of a planet orbiting a star is 8.0 N kg^{-1} . If the planet and star have a similar density but the diameter of the star is 100 times greater than the planet, what would be the gravitational field strength at the surface of the star?

- 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)

14

The Global Positioning System (GPS) is a system of satellites that transmit radio signals which can be used to locate the position of a receiver anywhere on Earth.



- (a) A receiver at sea level detects a signal from a satellite in a circular orbit when it is passing directly overhead as shown in the diagram above.

- (i) The microwave signal is received 68 ms after it was transmitted from the satellite. Calculate the height of the satellite.

- (ii) Show that the gravitational field strength of the Earth at the position of the satellite is 0.56 N kg^{-1} .

mass of the Earth = $6.0 \times 10^{24} \text{ kg}$
 mean radius of the Earth = 6400 km

(4)

(b) For the satellite in this orbit, calculate

(i) its speed,

(ii) its time period.

(5)

(Total 9 marks)

15

A planet has a radius half of the Earth's radius and a mass a quarter of the Earth's mass. What is the approximate gravitational field strength on the surface of the planet?

- A 1.6 N kg⁻¹
- B 5.0 N kg⁻¹
- C 10 N kg⁻¹
- D 20 N kg⁻¹

(Total 1 mark)

16

At a distance R from a fixed charge, the electric field strength is E and the electric potential is V . Which line, **A** to **D**, gives the electric field strength and electric potential at a distance $2R$ from the charge?

	electric field strength	electric potential
A	$\frac{E}{2}$	$\frac{V}{4}$
B	$\frac{E}{2}$	$\frac{V}{2}$
C	$\frac{E}{4}$	$\frac{V}{2}$
D	$\frac{E}{4}$	$\frac{V}{4}$

(Total 1 mark)

17

A planet of mass M and radius R rotates so rapidly that loose material at the equator just remains on the surface. What is the period of rotation of the planet?

G is the universal gravitational constant.

A $2\pi\sqrt{\frac{R}{GM}}$

B $2\pi\sqrt{\frac{R^2}{GM}}$

C $2\pi\sqrt{\frac{GM}{R^3}}$

D $2\pi\sqrt{\frac{R^3}{GM}}$

(Total 1 mark)

18

The following data refer to two planets.

	radius/km	density/kg m ⁻³
planet P	8 000	6 000
planet Q	16 000	3 000

The gravitational field strength at the surface of P is 13.4 N kg⁻¹. What is the gravitational field strength at the surface of Q?

- A** 3.4 N kg⁻¹
B 13.4 N kg⁻¹
C 53.6 N kg⁻¹
D 80.4 N kg⁻¹

(Total 1 mark)

19

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	<i>gravitational field</i> quantity SI unit		<i>electrical field</i> quantity SI unit	
a	gravitational field strength			
b			$\frac{1}{4\pi\epsilon_0}$	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)

20

The gravitational potential difference between the surface of a planet and a point P, 10 m above the surface, is 8.0 J kg^{-1} . Assuming a uniform field, what is the value of the gravitational field strength in the region between the planet's surface and P?

- A** 0.80 N kg^{-1}
- B** 1.25 N kg^{-1}
- C** 8.0 N kg^{-1}
- D** 80 N kg^{-1}

(Total 1 mark)

21

The following data refer to two planets.

	radius / km	density / kg m^{-3}
planet P	8000	6000
planet Q	16000	3000

The gravitational field strength at the surface of P is 13.4 N kg^{-1} . What is the gravitational field strength at the surface of Q?

- A** 3.4 N kg^{-1}
- B** 13.4 N kg^{-1}
- C** 53.6 N kg^{-1}
- D** 80.4 N kg^{-1}

(Total 1 mark)

22

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

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

(3)

(Total 7 marks)

23

- (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.

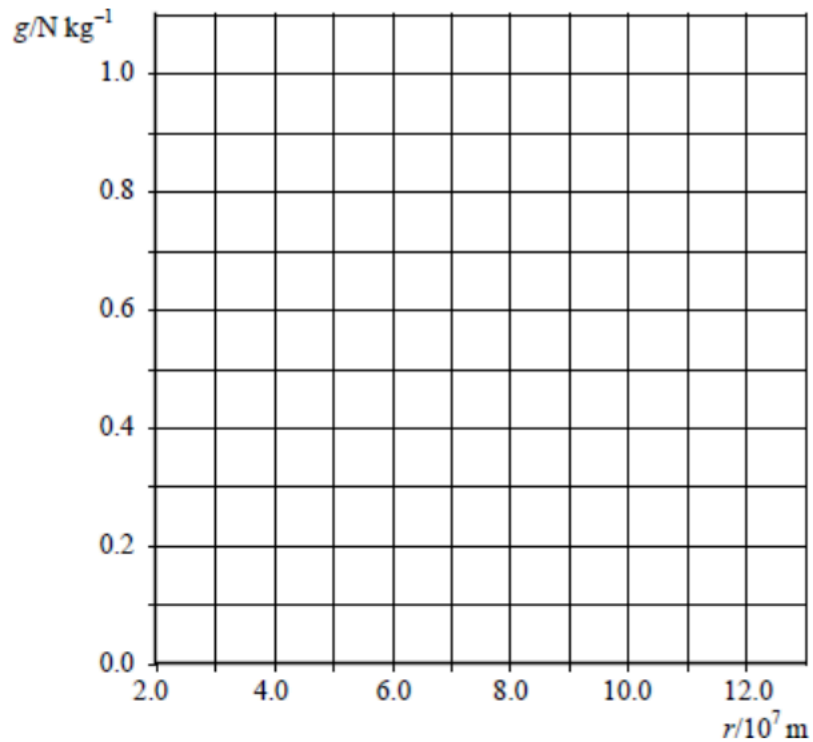
(6)

- (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 .

$g/\text{N kg}^{-1}$	1.0			
$r/10^7 \text{ m}$	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.

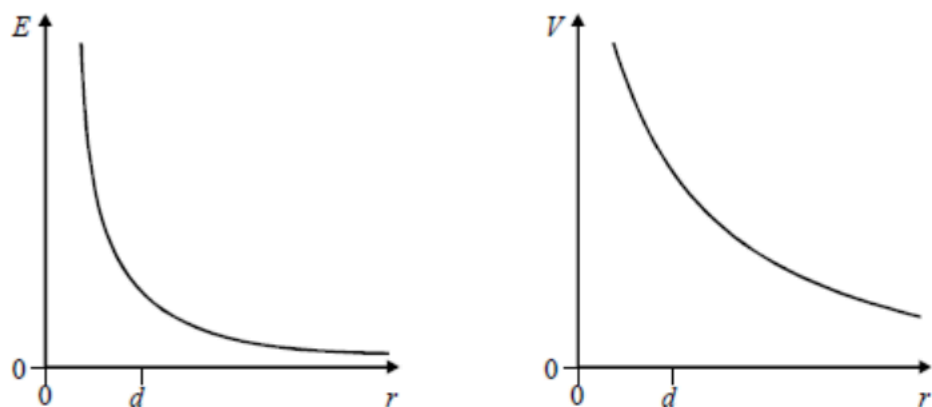
(3)

(Total 14 marks)

24

Graph 1 shows the variation of electric field strength E with separation r for two point charges.

Graph 2 shows the corresponding variation of electric potential V with separation.



Which line in the table correctly relates data for the two graphs?

	Magnitude of electric field strength at separation d	Magnitude of electric potential at separation d
A	Gradient of graph 2 at separation d	Area under graph 1 from separation d to ∞
B	Area under graph 2 from separation d to ∞	Area under graph 1 from separation d to ∞
C	Gradient of graph 2 at separation d	Gradient of graph 1 at separation d
D	Area under graph 2 from separation d to ∞	Gradient of graph 1 at separation d

(Total 1 mark)

Mark schemes

1 C

[1]

2 B

[1]

3 (a) (i) $M = \frac{4}{3} \pi R^3 \rho$ ✓

combined with $g_s = \frac{GM}{R^2}$ (gives $g_s = \frac{4}{3} \pi GR\rho$) ✓

Do not allow r instead of R in final answer but condone in early stages of working.

Evidence of combination, eg cancelling R^2 required for second mark.

2

$$(ii) R = \left(\frac{3g_s}{4\pi G\rho} \right) = \frac{3 \times 8.87}{4\pi 6.67 \times 10^{-11} \times 5.24 \times 10^3} \checkmark$$

gives $R = 6.06 \times 10^6$ (m) ✓

answer to **3SF** ✓

SF mark is independent but may only be awarded after some working is presented.

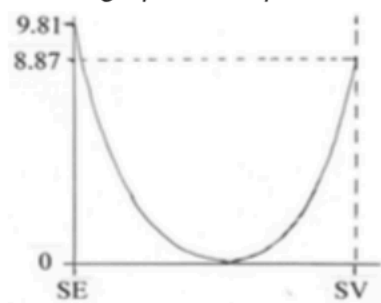
3

(b) line starts at 9.81 and ends at 8.87 ✓

correct shape curve which falls and rises ✓

falls to zero value near centre of and to right of centre of distance scale ✓

[Minimum of graph in 3rd point to be >0.5 and <0.75 SE-SV distance]



For 3rd mark accept flatter curve than the above in central region.

3

[8]

4 B

[1]

5 A

[1]

6 B

[1]

7	A	[1]
8	C	[1]
9	A	[1]
10	B	[1]
11	D	[1]
12	B	[1]
13	C	[1]

- 14** (a) (i) $h (= ct) (= 3.0 \times 10^8 \times 68 \times 10^{-3}) = 2.0(4) \times 10^7 \text{ m (1)}$
- (ii) $g = (-) \frac{GM}{r^2} \text{ (1)}$
 $r (= 6.4 \times 10^6 + 2.04 \times 10^7) = 2.68 \times 10^7 \text{ (m) (1)}$
 (allow C.E. for value of h from (i) for first two marks, but not 3rd)

$$g = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(2.68 \times 10^7)^2} \text{ (1)} \quad (= 0.56 \text{ N kg}^{-1})$$

4

- (b) (i) $g = \frac{v^2}{r} \text{ (1)}$

$$v = [0.56 \times (2.68 \times 10^7)]^{1/2} \text{ (1)}$$

$$= 3.9 \times 10^3 \text{ m s}^{-1} \text{ (1)} \quad (3.87 \times 10^3 \text{ m s}^{-1})$$

(allow C.E. for value of r from a(ii))

$$[\text{or } v^2 = \frac{GM}{r} = \text{(1)}]$$

$$v = \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{2.68 \times 10^7} \right)^{1/2} \text{ (1)}$$

$$= 3.9 \times 10^3 \text{ m s}^{-1} \text{ (1)}$$

$$(ii) \quad T \left(= \frac{2\pi r}{v} \right) = \frac{2\pi \times 2.68 \times 10^7}{3.87 \times 10^3} \quad (1)$$

$$= 4.3(5) \times 10^4 \text{ s } (1) \quad (12.(1) \text{ hours})$$

(use of $v = 3.9 \times 10^3$ gives $T = 4.3(1) \times 10^4 \text{ s} = 12.0 \text{ hours}$)

(allow C.E. for value of v from (i))

[alternative for (b):

$$(i) \quad v \left(\frac{2\pi r}{T} \right) = \frac{2\pi \times 2.68 \times 10^7}{4.36 \times 10^4} \quad (1)$$

$$= 3.8(6) \times 10^3 \text{ m s}^{-1} \quad (1)]$$

(allow C.E. for value of r from (a)(ii) and value of T)

$$(ii) \quad T^2 = \left(\frac{4\pi^2}{GM} \right) r^3 \quad (1)$$

$$\left(= \frac{4\pi^2}{6.67 \times 10^{-11} \times 6.0 \times 10^{24}} \times (2.68 \times 10^7)^3 \right) = (1.90 \times 10^9 \text{ s}^2) \quad (1)$$

$$T = 4.3(6) \times 10^4 \text{ s } (1)$$

5

[9]

15

C

[1]

16

C

[1]

17

D

[1]

18

B

[1]

19

(a)

_____	N kg^{-1}	electric field strength	N C^{-1} or V m^{-1}	(1)
gravitational constant	$\text{N m}^2 \text{ kg}^{-2}$	_____	_____	(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]

20

A

[1]

21

B

[1]

22

(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)
 $= 7.35 \times 10^{22} \text{ kg}$ (1)

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

3

[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) A1
- no s.f. penalty here unless values given as fractions (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 $\times 800$ kg B1
- $(4.3 - 5.3) \times 10^9$ J B1
- or** B1
- use of equation for potential $\Delta E_G = m(g_1 r_1 - g_2 r_2)$ B1
- evidence of $\times 800$ kg B1
- $(4.7 - 4.9) \times 10^9$ J B1
- max 2 if assumed values of G and M used B1
- 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)

