H2 Physics Revision Topic : Gravitation

Structured Questions Name: ______________________

1 **(a)** Explain why an object moving at a constant speed in a circular path experiences a force towards the centre of the circle.

....

....

....

.... [2]

(b) A trinary star system consists of three stars A, B and C of equal mass M. The three stars are equidistant from one another and rotate at constant speed in a circular path of radius R about the centre X, as illustrated in Fig. 7.1.

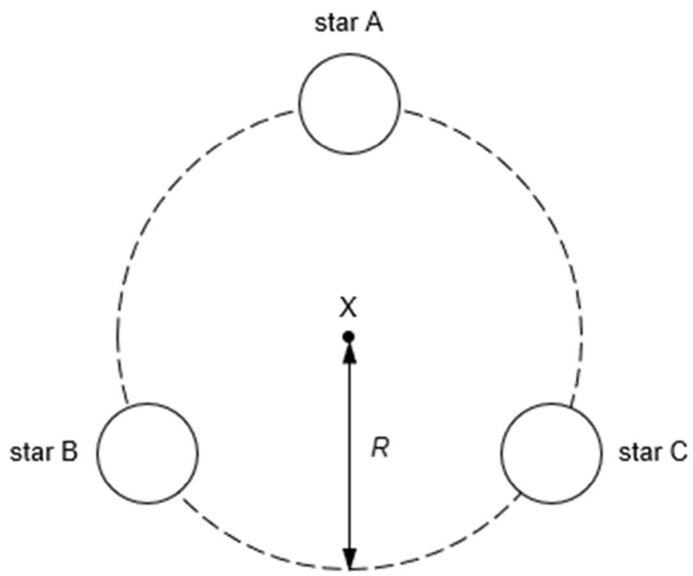

Fig. 7.1 (not to scale)

(i) Show that the centres of any two stars are separated by a distance 1.73R.

[1]

(ii) On Fig. 7.1, draw and label arrows to show the forces acting on star A. [2]

1 **(iii)** In terms of G, M and R,

1. determine the gravitational potential energy of the trinary star system.

gravitational potential energy = ... [2]

2. use **(b)(ii)** to determine the resultant force experienced by each star.

resultant force = ... [2]

3. hence determine the kinetic energy of the trinary star system.

kinetic energy = ... [2]

1 **(iv)** The speed of each of the three stars suddenly increased by the same magnitude.

State and explain the subsequent motion of the stars.

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....

....

.... [2]

(c) A space probe travels in a circular orbit of radius *d* around the trinary star system, as illustrated in Fig. 7.2.

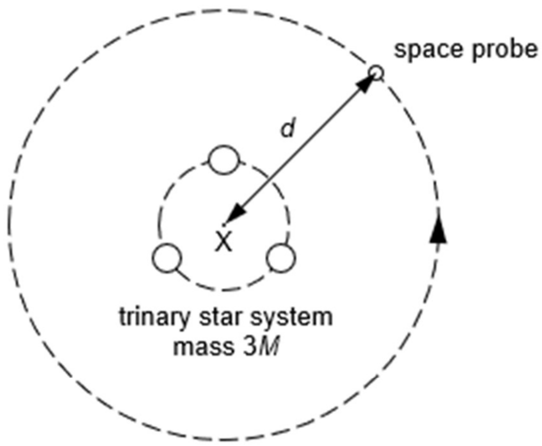


Fig. 7.2 (not to scale)

It can be assumed that the effective mass of the trinary star system is a point mass at its centre and is equal to $3M$.

The mission of the space probe is to observe the trinary star system.

The orbital period of the trinary star system is T.

1 **(i)** Discuss the advantage

1. if the orbital period of the space probe is equal to T.

....

.... [1]

2. if the orbital period of the space probe is smaller than T.

....

.... [1]

3. if the space probe rotates about its own axis with the same period as its orbital period.

....

.... [1]

(ii) A small component of the space probe was dislodged from the space probe when it is at the position shown in Fig. 7.2.

On Fig. 7.2, sketch the subsequent path of this component. [1]

(iii) Given that M is 1.39×10^{30} kg and d is 1.05×10^{11} m, determine the minimum velocity required for the space probe to escape the gravitational field of the trinary star system.

minimum velocity = ... m s^{-1} [3]

2 **(a)** State one similarity and one difference between the electric field lines and the gravitational field lines around an isolated positively charged metal sphere.

similarity: ....

....

difference: ....

.... [2]

(b) **(i)** Define *gravitational potential* at a point.

....

....

.... [2]

(ii) Use your answer in **(b)(i)** to explain why the gravitational potential near an isolated mass is always negative.

....

....

....

....

....

.... [3]

(c) A spherical planet has mass 6.00×10^{24} kg and radius 6.40×10^{6} m. The planet may be assumed to be isolated in space with its mass concentrated at its centre.

A satellite of mass 340 kg is to be raised from the planet to a height of 9.00×10^{5} m above the surface of the planet.

(i) Calculate the increase in potential energy of the satellite.

increase in potential energy = ... J [2]

2

(ii) On the axes of Fig. 1.1, sketch a graph to show the variation of the gravitational force on the satellite with distance between the planet and the satellite, as the satellite is raised from the planet to its final position.

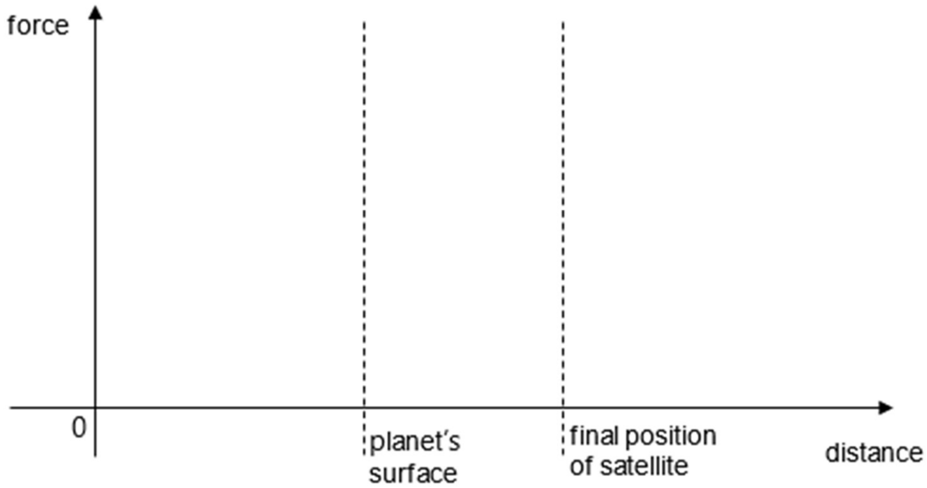


Fig. 1.1

[2]

(iii) State what the area under the graph in **(c)(ii)** represents.

....

....

.... [1]

[Total: 12]

3 **(a)** State what is meant by *angular velocity*.

....

.... [1]

(b) A binary star system consists of two stars S_1 and S_2, each in a circular orbit about a point P, as shown in Fig. 7.1. The two stars rotate with the same angular velocity ω.

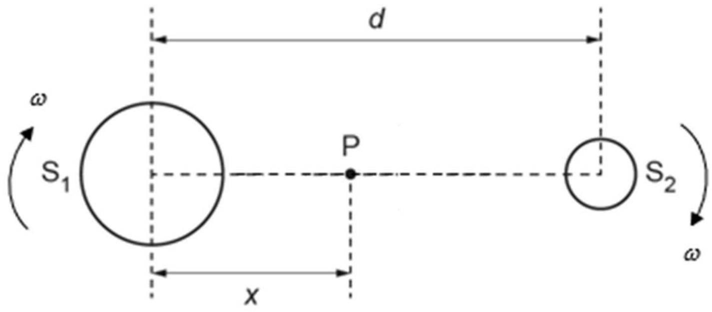


Fig. 7.1

The separation d of the centres of S_1 and S_2 is 1.8×10^{12} m. Point P is at a distance x from the centre of star S_1. The period of rotation of the stars is 44.2 years.

(i) Calculate ω.

ω = ... rad s^{-1} [2]

(ii) Show that the ratio of the masses of the stars is given by

3

$$\frac{\text{mass of } S_1}{\text{mass of } S_2} = \frac{d - x}{x}$$

[2]

(iii) The ratio in **(ii)** is 1.5. Determine the mass of S_1.

mass of S_1 = …………………… kg [4]

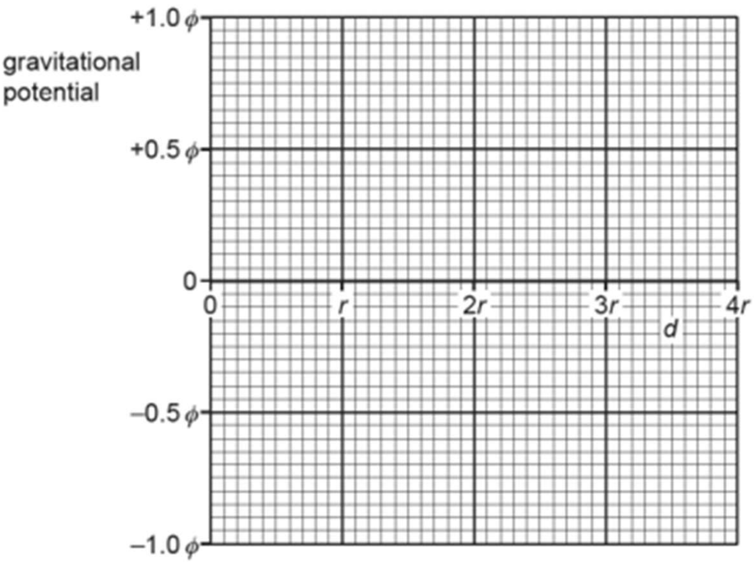
3 **(c)** **(i)** Define *gravitational potential* at a point.

....

.... [2]

(ii) An isolated solid sphere of radius *r* may be assumed to have its mass *M* concentrated at its centre. The magnitude of the gravitational potential at the surface of the sphere is ϕ.

On Fig. 7.2, show the variation of the gravitational potential with distance *d* from the centre of the sphere for values of *d* from *r* to 4*r*.



[2]

Fig. 7.2

4 **(a)** **(i)** A satellite is orbiting the Earth in a circular orbit with a period of 24 hours. State two circumstances under which this satellite will be a geostationary satellite.

1..

....

2..

....[2]

(ii) State one advantage and one disadvantage of geostationary satellites.

Advantage:..

....

....

....

Disadvantage:..

....

....

....

[2]

(b) Fig. 8.1 shows a pair of stars of equal mass *m* which move in circular orbits around their common centre of mass (C.M.).

In this question consider the stars to be point masses situated at their centres.

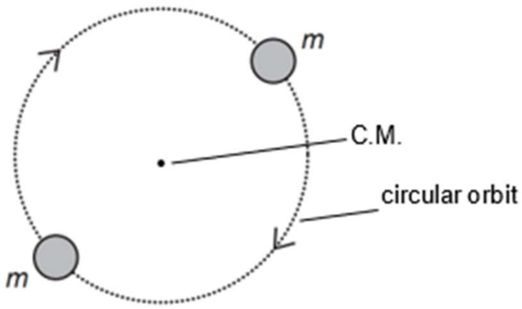


Fig. 8.1

4

(i) By considering the forces acting on the stars, explain why they must always be diametrically opposite in such an orbit.

....

....

....

....[2]

(ii) The centres of the two stars are separated by a distance R of 3.6×10^{10} m. The stars have an orbital period T of 20.5 days.

Calculate the mass m of each star.

m = ... kg [3]

4

(c) Saturn is a massive planet with a mass of 5.68×10^{26} kg and radius 5.82×10^{4} km.

(i) Calculate the gravitational potential V_S on the surface of Saturn.

V_S = ... [3]

(ii) State a physical meaning to your answer to part **(c)(i)**.

....

....

....

....[1]

(d) Titan is the largest moon of Saturn. It has a mass of 1.35×10^{23} kg and a radius of 2.58×10^{3} km. The distance between the centres of Titan and Saturn is 1.22×10^{6} km.

(i) A space probe is at the mid-point between Titan and Saturn, heading directly towards Titan. Explain whether the space probe is gaining or losing gravitational potential energy at this point in time.

....

....

....

....[2]

4 **(ii)** Point E is the point between the centres of Saturn and Titan where the resultant gravitational field strength is zero. Calculate the distance between point E and the centre of Titan.

distance = ……………………….. km [3]

(e) As a result of bombardment of Titan by a meteor, a rock of mass m is ejected with an intial kinetic energy of K_T from Titan's surface.

Let the symbols V_S, V_T and V_E represent the gravitational potential on the surface of Saturn, Titan and at point E respectively.

(i) Using any of the symbols m, K_T, V_S, V_T and V_E, write an inequality that represents the condition for the rock being able to arrive on Saturn.

[1]

(ii) Using any of the symbols m, K_T, V_S, V_T and V_E, write an expression for the kinetic energy K_S of the rock when it arrives on the surface of Saturn.

[1]

5 A system comprising the star Musica and its exoplanet Arion can be considered as isolated in space. The centres of the two bodies are separated by a constant distance d, as illustrated in Fig. 3.1.

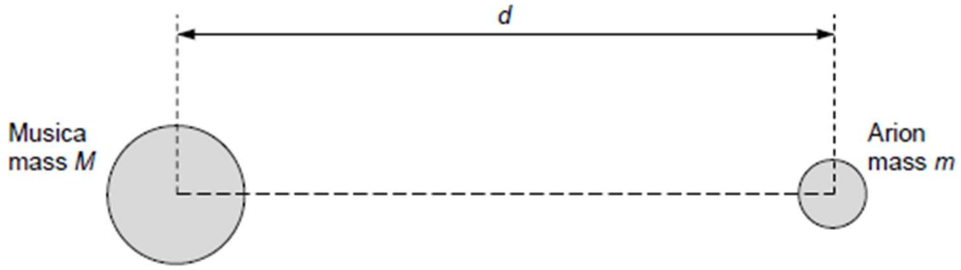


Fig. 3.1

Musica, of mass M, has a larger mass than Arion of mass m, such that $\frac{M}{m} = 240$.

The two bodies are in circular orbits about each other such that the centre of their orbits is at a fixed point.

Over a period of time equal to T of the orbits, the positions of the bodies are shown in Fig. 3.2.

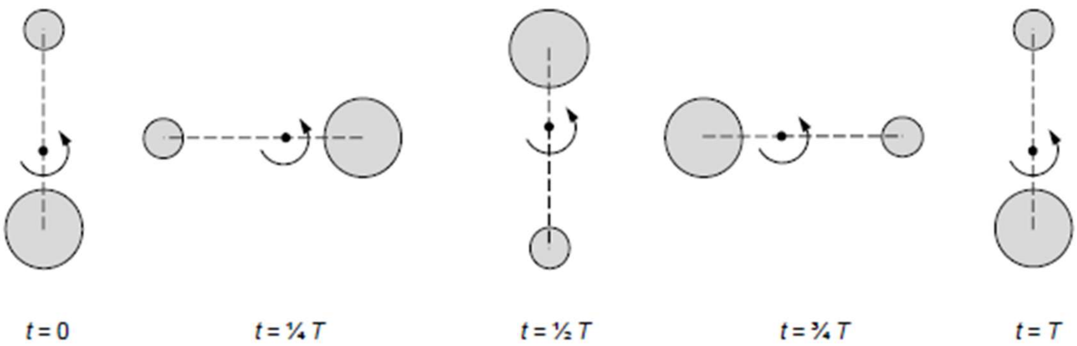


Fig. 3.2

The period T of each orbit is 2.7 years.

The separation d of the centres of Musica and Arion is 3.9×10^{11} m.

5 **(a)** **(i)** Explain why the centripetal forces acting on Musica and Arion are equal in magnitude.

....

....

....

.... [2]

(ii) Determine the radius of the orbit of Musica. Explain your working.

radius = ... m [3]

(b) Use your answers in **(a)** to determine the mass of Musica.

mass = ... kg [3]

[Total: 8]

6

The Earth may be assumed to be a uniform sphere of radius R and mass M. At its surface, the gravitational field strength is g. A satellite orbits the Earth at a height $0.30R$ above its surface.

(a) Show that the gravitational field strength at this height is $0.59g$.

[2]

(b) Determine the angular speed of the satellite about the Earth. The radius R of the Earth is 6.4×10^6 m.

angular speed = ... rad s^{-1} [2]

(c) Calculate the time, in hours, for one complete orbit of the satellite.

time = ... h [2]

(d) Explain why the satellite does not fall towards the Earth even though the gravitational force is directed toward the centre of the Earth.

....

....

....

....[2]

[Total: 8]

6 Two stars A and B are separated by a distance of 1.2×10^{10} m as shown in Fig. 5.1. x is the distance from the centre of star A, in the direction toward the centre of star B.

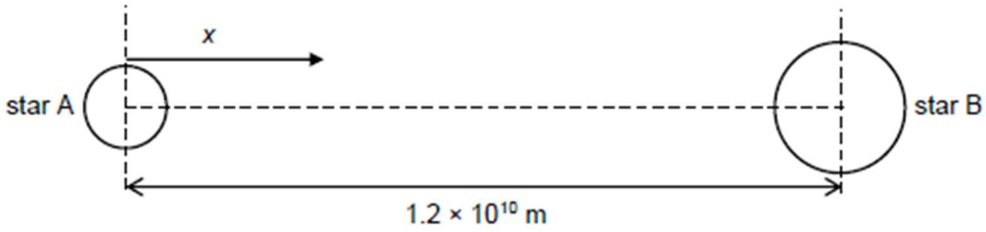


Fig. 5.1

The variation with x of the gravitational potential ϕ due to the two stars along the line joining their centres is shown in Fig. 5.2.

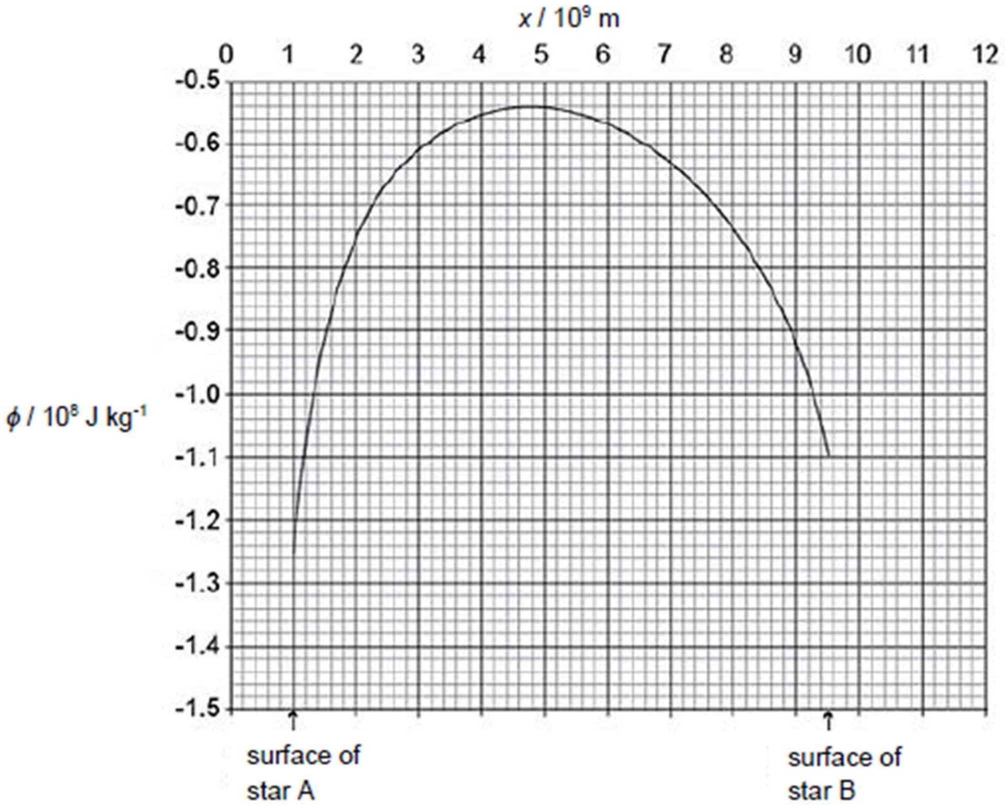


Fig. 5.2

A body is launched with kinetic energy E_K from the surface of star B.

The body then arrives at the surface of the star A.

(a) Define *gravitational potential* at a point.

....

....[1]

6 **(b)** Use Fig. 5.2 to explain whether the kinetic energy of the body when it arrives at the surface of star A is less than, equal to, or larger than E_k.

....

....

....[2]

(c) State and explain the distance x at which the resultant gravitational field strength due to the two stars is zero.

....

....

....[2]

(d) Determine the ratio $\dfrac{\text{average density of star A}}{\text{average density of star B}}$.

ratio = ... [3]

[Total: 8]

7 **(a)** Explain why gravitational potential has a negative value.

....

....

....

.... [2]

(b) Fig. 2.1 shows the variation of the gravitational potential ϕ with distance d from the surface of a certain planet. Point P is at a distance of 1.0×10^7 m from the surface of the planet and point Q is on the surface of the planet.

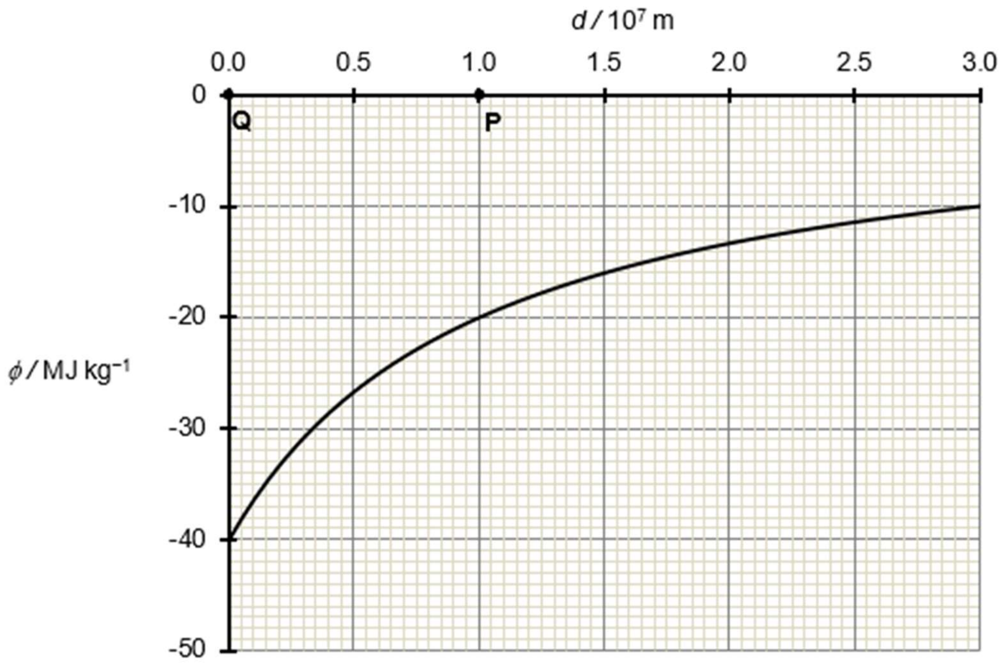


Fig. 2.1

(i) Determine the gravitational acceleration at point P.

gravitational acceleration = ... m s^{-2} [2]

7

(ii) Assuming that a 1.0 kg mass falls from point P toward point Q with the acceleration obtained in **(b)(i)** throughout the motion, calculate the increase in its kinetic energy.

increase in kinetic energy = ... J [2]

(iii) Indicate, using vertical double-head arrows, the parts of the graph that represent

1. your answer in **(b)(ii)**. Label this arrow **A**.

2. the actual increase in the kinetic energy of the 1.0 kg mass when the gravitational acceleration from P to Q is not constant. Label this arrow **B**.

[2]

8 **(a)** **(i)** Explain what is meant by the term *escape speed*.

....

....

....

.... [2]

(ii) Mars has a radius of approximately 3.4×10^6 m and a mass of 6.4×10^{23} kg. Show that the escape speed from Mars is approximately 5 km s^{-1}.

[3]

(iii) Suggest why a rocket would be able to escape from Mars with an initial speed much less than the escape speed given in part **(a)(ii)**.

....

.... [1]

8 **(b)** Fig. 3.1 shows the Sun, Earth and Mars in alignment. Earth and Mars rotate around the Sun in the same directional sense.

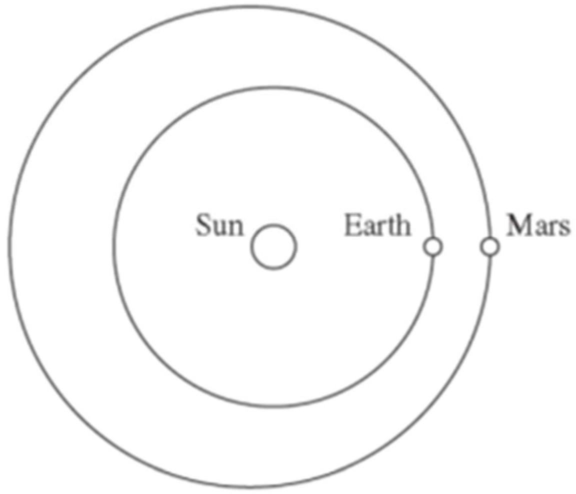


Fig. 3.1

A rocket of mass 2.05×10^6 kg leaves the surface of Mars closest to Earth and heads for Earth.

Fig. 3.2 below gives data relevant to the rocket at the start of its journey.

astronomical object (AO)	mass of AO / kg	distance of rocket from the centre of AO / m	rocket's gravitational potential due to AO / J kg^{-1}	sign of gravitational potential
Mars	6.4×10^{23}	3.4×10^6	1.26×10^7	
Earth	6.0×10^{24}	5.6×10^{10}		negative
Sun	2.0×10^{30}	2.3×10^{11}	5.80×10^8	

Fig. 3.2

(i) Complete Fig. 3.2 by calculating the magnitude of gravitational potential of the rocket due to the presence of Earth and the signs of the gravitational potential energies due to Mars itself and the Sun.

[2]

8

(ii) Calculate the total gravitational potential energy of the rocket on the surface of Mars.

total gravitational potential energy = ... J [2]

(c) **(i)** Derive an expression to show that for satellites in a circular orbit

$$T^2 \propto r^3$$

where T is the period of orbit and r is the radius of the orbit.

[2]

(ii) The orbits of the Earth and Mars can be approximated to be circular orbits around the Sun.

Hence, estimate the orbital period of Mars.

orbital period of Mars = ... days [3]

9 **(a)** Phobos is one of the two moons orbiting Mars. Fig. 1.1 shows Phobos and Mars.

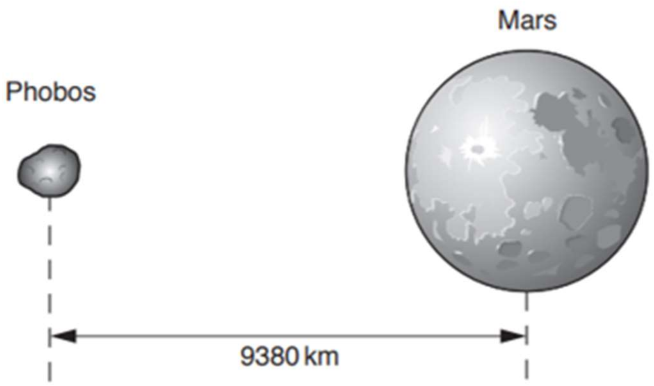


Fig. 1.1

The orbit of Phobos may be assumed to be a circle. The centre of Phobos is at a distance 9380 km from the centre of Mars and it has an orbital speed 2.14×10^{3} m s^{-1}.

(i) On Fig. 1.1, draw a cross to show the point where the net force acting on a third mass placed at that point is zero. [1]

(ii) Calculate the mass *M* of Mars.

M = ... kg [4]

9 **(b)** The Earth and Mars move in elliptical orbits around the Sun. In July 2018, the closest distance between the centre of Mars and the centre of Earth will be 5.8×10^{10} m.

Fig. 1.2 shows the variation of the resultant gravitational field strength g between the two planets with distance r from the centre of the Earth.

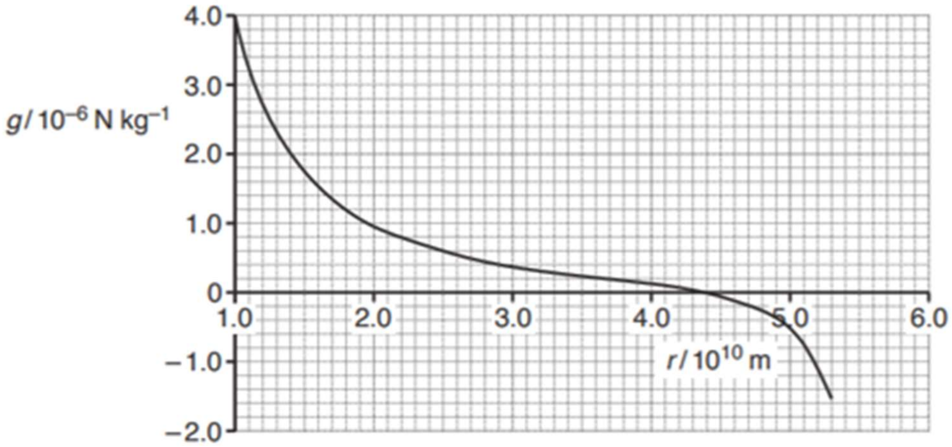


Fig. 1.2

(i) Explain briefly the overall shape of the graph in Fig. 1.2.

....

....

....

.... [2]

(ii) Determine the ratio $\dfrac{\text{mass of Earth}}{\text{mass of Mars}}$.

$\dfrac{\text{mass of Earth}}{\text{mass of Mars}}$ = ... [2]

9

(iii) After successfully collected some geological samples on the surface of Mars, a space rover with a total mass of 200 kg, wants to return to Earth.

Estimate the minimum energy required to return to Earth, assuming that it starts from the distance of 5.3×10^{10}m from the centre of the Earth.

minimum energy = ... J [3]

10 A research institute in Singapore sends nanosatellites into space. The mass of each nanosatellite is 100 kg. The nanosatellites are launched near Earth's equator to a low Earth orbit of 1.5×10^3 km above Earth.

The radius of Earth is 6.4×10^3 km and the mass of Earth is 6.0×10^{24} kg.

(a) A nanosatellite is launched in the same direction as Earth rotation, with a propulsion system that supplies 1.5×10^9 J of energy to the nanosatellite. Assume negligible air resistance and no loss in mass, calculate the kinetic energy of the nanosatellite when it just reaches the low Earth orbit.

kinetic energy = ... J [3]

(b) In Fig. 5.1, the dashed lines enclosing Earth represent gravitational equipotential lines. The equipotential lines for low Earth orbits with potentials ϕ_1 and ϕ_2 are shown.

On Fig. 5.1, draw the equipotential line for potential $\frac{\phi_2 - \phi_1}{2}$. [1]

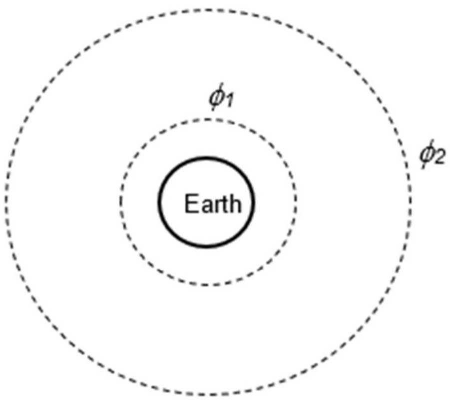


Fig. 5.1

10 **(c)** Fig. 5.2 shows the variation of the gravitational potential energy of a nanosatellite with distance from centre of Earth, *r*. At a certain distance *R* from the centre of the Earth, the total energy of the nanosatellite may be represented by a point on the line XY.
Five points, A, B, C, D, E have been marked on this line.

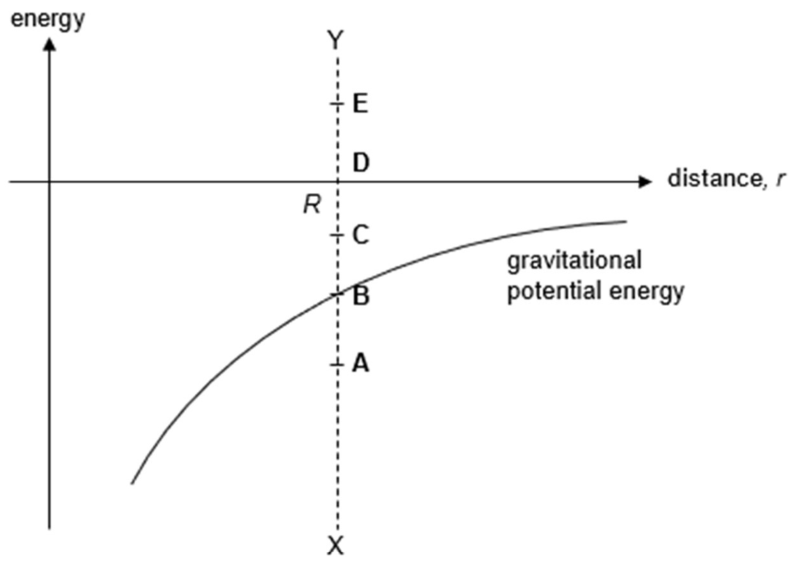


Fig. 5.2

(i) State what the gradient of the graph represents.

....

.... [1]

(ii) Explain which point(s) can represent the total energy of the nanosatellite, if the nanosatellite is at distance *R* and is moving away from the Earth with sufficient energy to reach infinite distance.

....

....

....

....

.... [2]

11 The planet Mars has a radius of 3390 km. **Fig. 2.1** below shows the variation with the distance r from the centre of this planet, of the gravitational potential ϕ near it.

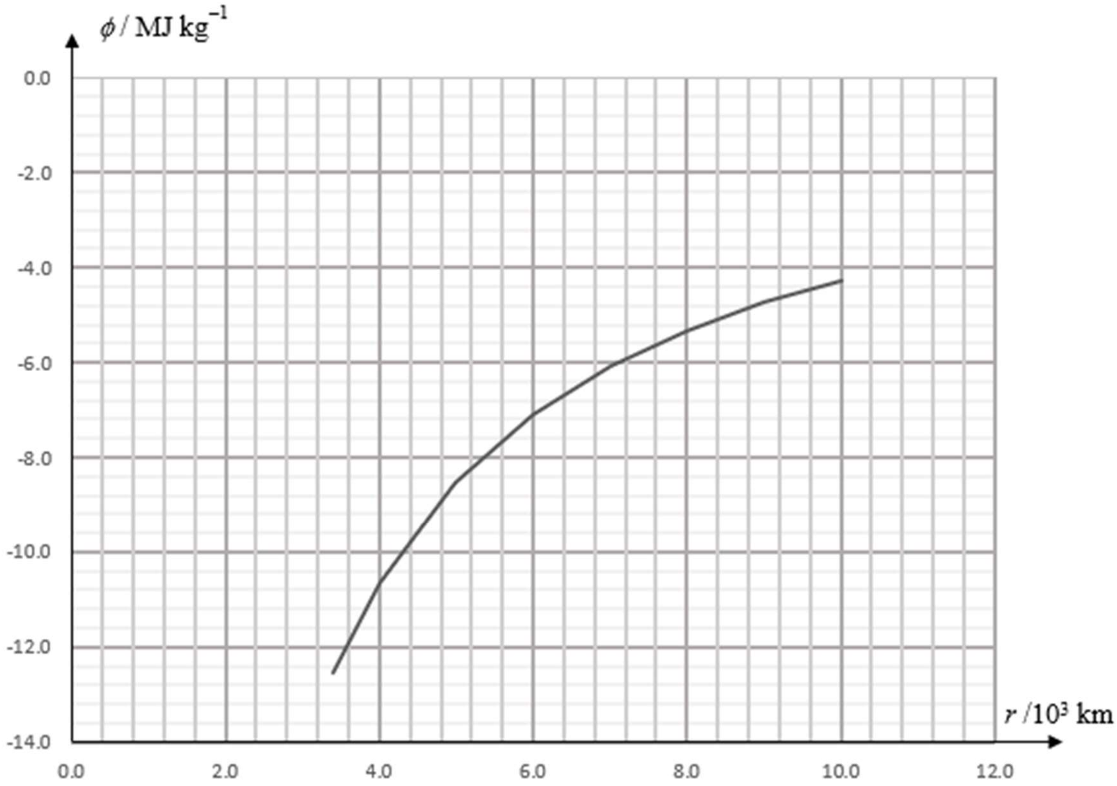


Fig 2.1

(a) Explain why gravitational potential has a negative value.

....

....

....

.... [2]

(b) **(i)** On **Fig. 2.1** draw a tangent to the graph at r = 6000 km.

The gradient of this tangent is the magnitude of a vector quantity. State what this physical quantity is.

.... [1]

11 **(ii)** Calculate the gradient of this tangent and hence state the magnitude of the physical quantity that you have identified in **(b)(i)**, together with its S.I. unit.

Magnitude and unit =……… ……………………[3]

(c) The Perseverance rover is a car sized Mars rover designed to explore the Jezero crater on Mars as part of NASA's Mars 2020 mission. The landing craft, initially at rest 6000 km from the centre of the planet, is released and accelerates towards the surface. Use **Fig. 2.1** to estimate the magnitude of the velocity of the landing just as it impacts the surface. Disregard atmospheric friction.

Magnitude of velocity = ……………………… m s^{-1} [3]

(d) In order to safely land the rover without damage, suggest a mechanism/method that the landing craft can use to reduce the damage of impact.

…………………………………………………………………………………..

……………………………………………………………………………… [1]