GRAVITATION

Challenging **MCQ** questions by The Physics Cafe

Compiled and selected by The Physics Cafe

1 The Earth has approximately 81 times the mass of the Moon. There is a point between the Earth and the Moon where the resultant gravitational force on a mass m is zero. If the distance to this point from the centre of the Earth is *y* and from the centre of the Moon it is *x*, the ratio *y* / *x*

A $(81)^{\frac{1}{4}}$ **B** $(81)^{\frac{1}{2}}$ **C** 81 **D** $(81)^{2}$

2 **Fig. 16** shows the gravitational equipotentials near a certain non-spherical body.

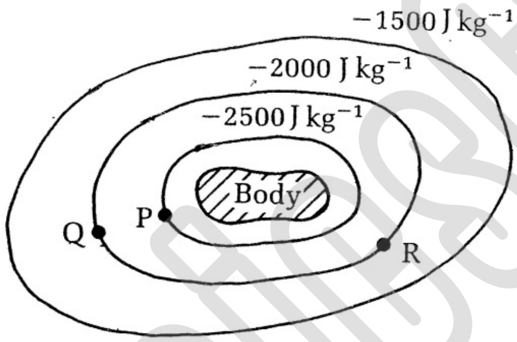
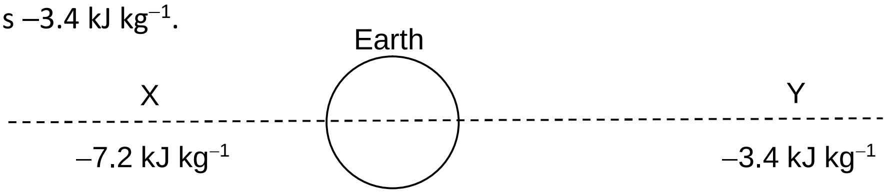


Fig. 16

What is the work that must be done on 100 g mass to move it from P to Q

A 50 J **B** - 50 J **C** 5000 J **D** -5000 J

3 The gravitational potential at point X due to the Earth is –7.2 kJ kg^{-1}. At point Y, the gravitational potential is –3.4 kJ kg^{-1}.



The change in gravitational potential energy of a 4.0 kg mass when it is moved from X to Y is

A –42.4 kJ **B** –10.6 kJ **C** +3.8 kJ **D** +15.2 kJ

4 Two satellites, A and B, orbiting around Earth have the same kinetic energy. Satellite A has a larger mass than satellite B. Which of the following statements is correct?

A Satellite A has the same total energy as satellite B.

B Satellite A has a smaller orbital radius than satellite B.

C Satellite A has a smaller period than satellite B.

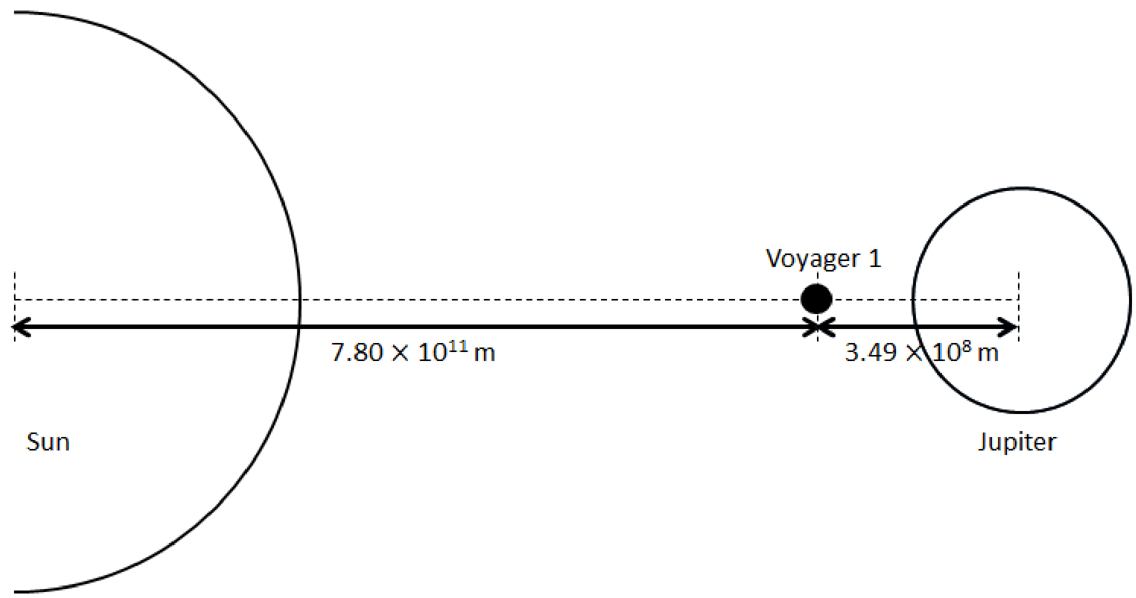
D Satellite A has a larger angular velocity than satellite B.

5 A piece of a decommissioned satellite is initially at rest 620 km above the surface of the Earth, and begins falling towards the Earth's surface.

Given that Earth's radius and mass are 6400 km and 6.0×10^{24} kg respectively, what is the velocity of the object when it hits the surface of Earth? You may assume that air resistance is negligible.

A 3.3×10^3 m s^{-1} **B** 4.5×10^3 m s^{-1} **C** 3.6×10^4 m s^{-1} **D** 1.1×10^7 m s^{-1}

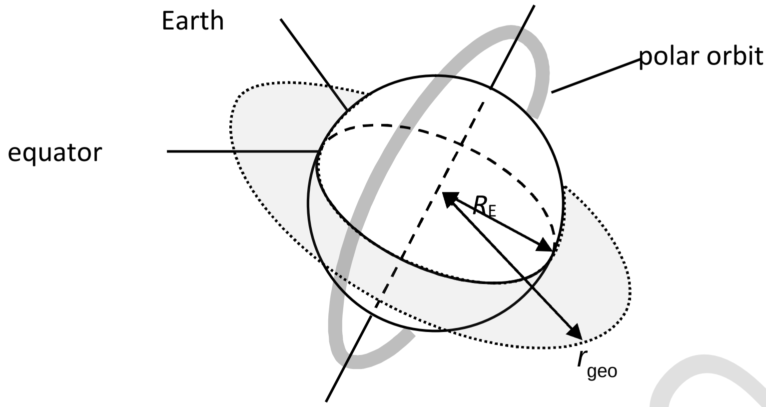
6 In 1979, the space probe Voyager 1 was sent to capture images of Jupiter. At the point of closest approach to Jupiter, it was 3.49×10^8 m from the centre of Jupiter and 7.80×10^{11} m from the Sun as shown in the figure below (not drawn to scale).



Given that the mass of Jupiter is 1.90×10^{27} kg and the mass of the Sun is 1.99×10^{30} kg, what was the escape velocity of the Voyager 1 at the point of closest approach to Jupiter? The gravitational forces due to other objects are assumed to be negligible.

A 18.4 km s^{-1} **B** 19.6 km s^{-1} **C** 26.9 km s^{-1} **D** 32.6 km s^{-1}

7 Geostationary satellites remain above fixed points on the Earth's surface along the equator as the Earth rotates about its axis. They orbit with a fixed radius of r_{geo} around the Earth, which has a radius of R_E.



In comparison, polar-orbiting satellites pass above the North and South poles of the Earth on each revolution. A polar orbit is illustrated in the figure above.

What will be the ratio $\frac{\text{angular velocity of polar-orbiting satellite}}{\text{angular velocity of geostationary satellite}}$ if the polar orbit is 16 times lower in **altitude** as that of a geostationary orbit?

A 4

B $4\left(\frac{1}{1-\frac{R_E}{r_{geo}}}\right)^{1/2}$

C 64

D $64\left(\frac{1}{1+15\frac{R_E}{r_{geo}}}\right)^{3/2}$

8 A satellite of mass 50 kg moves from a point where the gravitational potential due to the Earth is -20 MJ k g^{-1}, to another point where the gravitational potential is -60 MJ kg^{-1}.

In which direction does the satellite move and what is its change in potential energy?

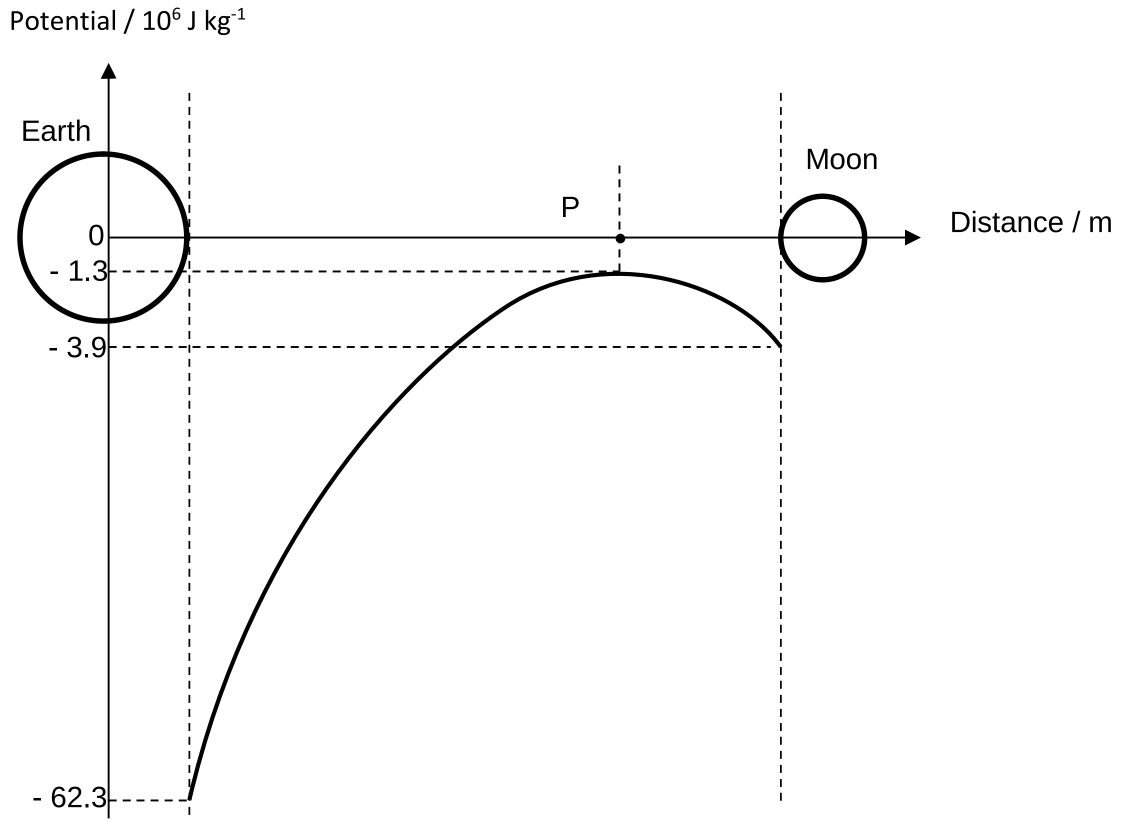
A closer to the Earth and a loss of 2000 MJ of potential energy.

B closer to the Earth and a loss of 40 MJ of potential energy.

C further from the Earth and a gain of 2000 MJ of potential energy.

D further from the Earth and a gain of 40 MJ of potential energy.

9 The figure below shows the variation of the gravitational potential between the surface of Earth and the surface of the Moon along the line joining their centres. The gravitational potential is maximum at point P.



What is the minimum speed for a projectile to be launched from the surface of the earth to reach the surface of the moon? (Ignore air resistance)

A 11.2 km s^{-1} **B** 11.0 km s^{-1} **C** 10.8 km s^{-1} **D** 2.8 km s^{-1}

10 A satellite of mass m is in circular orbit with radius r around the Earth with a period of T. The satellite is moved to a new orbit with radius $4r$ around the Earth. What is the new period in terms of T?

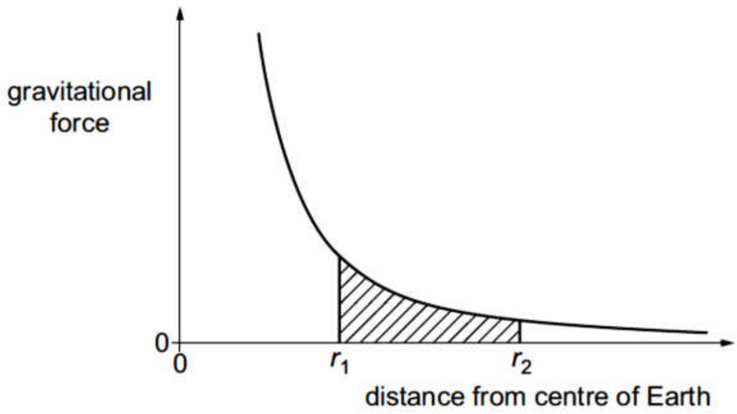
A ¼ T **B** $2T$ **C** $4T$ **D** $8T$

11 A satellite is in a circular orbit of radius r around the Earth. The orbital period of the satellite is T.

A second satellite, in a different circular orbit, has an orbital period $64T$. What is the radius of the orbit of the second satellite?

A 8 r **B** 16 r **C** 64 r **D** 512 r

12 A satellite above the Earth in a circular orbit of radius r_1 is moved to a higher circular orbit of radius r_2. The gravitational force-distance graph is shown for the satellite.



What does the shaded area on the graph represent?

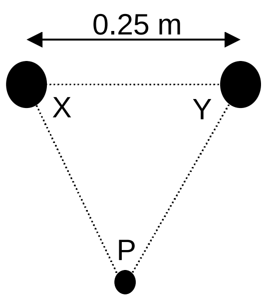
A The change in gravitational potential energy of the satellite

B The change in kinetic energy of the satellite

C The final gravitational potential energy of the satellite

D The final kinetic energy of the satellite

13 Two objects, each of mass 8000 kg and 0.25 m apart are placed at points X and Y as shown below. XYP forms an equilateral triangle.



Determine the gravitational potential energy of a mass of 5.0 kg placed at point P.

A -1.1×10^{-5} J

B -2.1×10^{-5} J

C -4.3×10^{-5} J

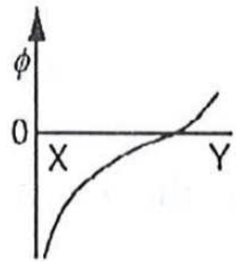
D -8.5×10^{-5} J

14 The diagram below (not to scale) represents the relative positions of the Earth and the Moon.

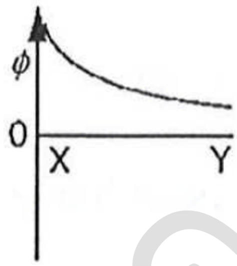
The line XY joins the surface of the Earth to the surface of the Moon.

Which graph represents the variation of gravitational potential ϕ along the line XY?

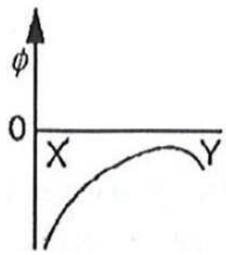
A



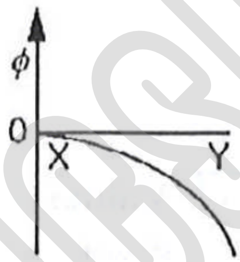
B



C



D



15 An astronaut goes out for a "space-walk" at a distance above the earth equal to the radius of the earth. If the gravitational field strength at the surface of the earth is g, what is the astronaut's acceleration due to gravity?

A zero **B** g / 4 **C** g / 2 **D** g

GRAVITATION WORKED SOLUTIONS

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1 Ans: **B**

At the point where gravitational force on mass m is zero the gravitational force on the mass m exerted by earth is equal and opposite to that exerted by moon on mass m . Applying Newton's law of gravitation to determine magnitude of these two forces

2 Ans: **A**

Work done by external agent on mass = change in GPE of the 100g mass

$\Delta U = m(\phi f - \phi i) = 0.100(-2000-(-2500)) = 50$ J

3 Ans: **D**

There is work done on mass to move it from X to Y. Hence, a gain in its GPE.

Change in GPE = [–3.4 – (–7.2)]x4 = +15.2 kJ

4 Ans: **A**

Since $m_A v_A^2/r_A = GMm_A/r_A^2$, $m_A v_A^2 = GMm_A/r_A$

Similarly, $m_B v_B^2 = GMm_B/r_B$

Since $\frac{1}{2} m_A v_A^2 = \frac{1}{2} m_B v_B^2$, $GMm_A/r_A = GMm_B/r_B$, $m_A/r_A = m_B/r_B$,

Since $m_A > m_B$, $\mathbf{r_A > r_B}$, and $v_A^2 < v_B^2$, $v_A < v_B$,

Since $v = r\omega$, $r_A \omega_A < r_B \omega_B$, $\boldsymbol{\omega_A < \omega_B}$, as $T = 2\pi/\omega$, $\mathbf{T_A > T_B}$.

Total energy E = -1/2[GMm/r],

Since $GMm_A/r_A = GMm_B/r_B$, $\mathbf{E_A = E_B}$

5 Ans: **A**

$GPE_i + 0 = GPE_f + KE_f$

$KE_f = GPE_i - GPE_f = -(GPE_f - GPE_i)$

$$\frac{1}{2}mv^2 = -\left[\left(-\frac{GMm}{r_f}\right) - \left(-\frac{GMm}{r_i}\right)\right]$$

$$= GMm\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$$

$$v = \sqrt{2GM\left(\frac{1}{r_f} - \frac{1}{r_i}\right)}$$

$$= \sqrt{2(6.67\times10^{-11})(6.0\times10^{24})\left(\frac{1}{6400\times10^3} - \frac{1}{(6400+620)\times10^3}\right)}$$

$$= 3.3\times10^3 \text{ m s}^{-1}$$

6 Ans: **D**

Resultant potential at the point:

$$\begin{aligned}\phi_{res} &= \phi_S + \phi_J \\ &= -\frac{GM_S}{r_S} + \left(-\frac{GM_J}{r_J}\right) \\ &= -\left(\frac{6.67\times10^{-11}\times1.99\times10^{30}}{7.80\times10^{11}}\right) + \left(-\frac{6.67\times10^{-11}\times1.90\times10^{27}}{3.49\times10^{8}}\right) \\ &= -5.33\times10^{8}\ \text{J kg}^{-1}\end{aligned}$$

Escape velocity:

$$\begin{aligned}\frac{1}{2}mv_E^2 &= m\left|(\phi_S + \phi_J)\right| \\ v_E &= \sqrt{2\left|(\phi_S + \phi_J)\right|} \\ &= \sqrt{2(5.33\times10^{8})} \\ &= 32.6\ \text{km s}^{-1}\end{aligned}$$

7 Ans: **D**

8 Ans: **A**

9 Ans: **B**

10 Ans: **D**

11 Ans: **B**

$T^2 \propto r^3$

$$\left(\frac{T_2}{T_1}\right)^2 = \left(\frac{r_2}{r_1}\right)^3$$

$$\left(\frac{64T}{T}\right)^2 = \left(\frac{r_2}{r}\right)^3$$

$r_2 = 16r$

12 Ans : **A**

$$F = -\frac{\Delta U}{\Delta r}$$

$\Delta U = -F\Delta r$ (Area under F-r graph = change in GPE)

13 Ans: **B**

$$U = 2\frac{-GMm}{r} = 2\left(\frac{-(6.67\times10^{-11})(8000)(5)}{0.25}\right) = -2.1\times10^{-5}\ \text{J}$$

14 Ans: **C**

By definition, gravitational potential is **zero** at infinity and **negative** near the gravitational mass. As gravitational field strength is related to the gravitational potential by $g = -\frac{d\phi}{dr}$ (which is the negative of the gradient of the graph of gravitational potential against distance from the centre of the Earth/Moon), the gradient of this graph decreases as the gravitational field strength decreases when the distance from the centre of the Earth increases. At certain point between the Earth and the Moon, gradient of the graph is zero as the resultant gravitational field strength acting on a mass along XY is zero since the gravitational forces acting on a mass by the Earth and the Moon at that point are opposite in direction but have the same magnitude. Beyond this point in the direction of the Moon, the gradient of this graph decreases as gravitational force acting on it by the Moon increases as it moves towards the Moon.

15 Ans: **B**

Since $g = GM / r^2$, at a height of r above the earth surface, the new $g_1 = GM / (2r)^2$ hence new $g_1 = g / 4$