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Where Minds Pollinate

Class 12
Physics

Chapter 15

Exercise Solution

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Short Questions

1) Why can gravitation not account for the formation of molecules?

Gravitation cannot account for the formation of molecules because it is an extremely weak force compared to the electromagnetic force, which governs the attraction and bonding between atoms. Molecular formation depends on the interaction between electrons and nuclei, which is controlled by electromagnetic forces, not gravitational ones. Hence grvitation cannot account for the formation of molecules.

2) Why dont two books on your desk attract each other gravitationally, despite Newton's law of gravitation?

Two books on your desk do attract each other gravitationally, as per Newton's law. However, the gravitational force is directly propotional to the product of their mases, and books have very small masses. Furthermore, the value of gravitational constant (G) is very small, making the force negligible. This incredibly weak attraction is then completly overshadowed by stronger forces like friction and air resistance, preventing any observable movement.

3) Why does an apple fall towards the Earth due to gravity, while the Earth doesnt move towards the apple?

An apple falls due to Earth's gravity pulling it downward. According to Newton's third law, the apple also pulls the earth upward with equal force. However, the Earth's mass is millions of times greater than the apple's. This means its acceleration is extremely small and unnoticeable. So, only the apple appears to move, while the Earth stays effectively still.

4) Can gravitational field strength be negative?

Yes, gravitational field strength can be negative. Gravitational field strength is a vector quantity, and its direction is defiened as force per unit mass acting toward the attracting body. If you choose a direction away from the mass as positive, then the field pointing towards the mass is considered negative. So, the negative sign indicates the direction of field, not that the strength is less than zero.

5) What factors determine the strength of the gravitational field strength around a planet?

The strength of the gravitational field ($g = GM/r^2$) around a planet is primarily determined by two factors:

1. Mass of the planet (M). The more massive a planet, the stronger its gravitational field. Gravity is directly propotional to the mass. $g \propto M$.
2. Distance from the center of the planet (r). The further you are from the center, the weaker the gravitational field. Gravity is inversly propotional to the square of the distance. $g \propto 1/r^2$.

6) If two planets have the same mass but different radii. How would their gravitational field strengths compare?

Gravitational field strength at a planet's surface is $g = GM/r^2$. Since mass M is the same for both planets, the difference comes down to the radius r. As gravitational field strength (g) is inversely propotional to radius (r) so the planet having small radii will have larger gravitational field strength and planet with large radii will have smaller gravitational field strength.

7) Why satellites in higher orbits have lower orbital velocities?

The formula for orbital velocity is given by $v = \sqrt{GM/r}$. Equation shows that orbital velocity (v) is inversely propotional to the square root of the orbital radius (r). Therefore, a satellite in a higher orbit (larger r) have lower orbital velocity (v).

8) How does the mass of earth affect the orbital velocity required for a satellite to stay in orbit?

The mass of the earth plays a crucial role in determining the orbital velocity required for a satellite to stay in orbit. The orbital velocity formula for a stable circular orbit is: $v = \sqrt{GM/r}$. From this equation, its clear that the orbital velocity (v) is directly propotional to the square root of the mass of earth (M). Hence, the greater the mass of earth, the higher the orbital velocity required for a satellite to stay in orbit.

9) What are primary benefits of using geostationary satellites for communication purposes compared to other types of satellite orbits?

Following are the primary benefits of using geostationary satellites for communication purposes:

1. Fixed Position: They stay above the same point on Earth, simplyfying ground antenna alignment.
2. Continuous Coverage: Provide unintrepted service to the same area—ideal for TV, radio and internet.
3. Wide Coverage: Each satellite covers about one-third of Earth's surface.
4. Fewer Satellites needed: Just three can offer near-global coverage (excluding poles).
5. Established Technology: Widely used with mature infrastructure and long operational life.

10) There are limited number of stable geostationary orbits available. So, what measures do we take to handle the possible rise in the number of satellites? Do we have any international rules or agreements to adress this?

Limited geostationary orbital slots are managed by the International Telecommunication Union (ITU). Measures include precise slot allocation and rigorous frequency coordination to prevent interference among satellites. Efficient spectrum use and technological advancements also maximize capacity with the orbital arc. International rules and agreements, primarily ITU Radio Regulations, mandate registration and ensure equitable access. Additionally, guidelines for post-mission disposal into "graveyard orbits" mitigate space debris.

11) Is it possible for an object's gravitational potential energy to become negative? So, what does this mean for the object's motion?

Yes, gravitational potential energy (GPE) can be negative. Near a planet, where gravity is stronger, the GPE becomes negative: $U = -\frac{GMm}{r}$

What it means for motion: If total energy $< 0 \rightarrow$ object stays in orbit or falls back. If total energy $\geq 0 \rightarrow$ object can escape the gravity (e.g. reaches escape velocity).

12) How the gravitational potential energy of two point masses is related to concept of gravitational potential?

The gravitational potential energy (U) of two point masses is the product of one mass (m) and the gravitational potential (V) created by the other mass (M) at the location of m. $V = -GM/r$. So the potential energy is $U = -\frac{GMm}{r}$

Conceptual Questions

Why doesn't a satellite fall back to the earth?

A satellite doesnt fall back to earth because its moving forward fast enough that as it falls due to gravity, the earth curves away beneath it, so it stays in orbit.

Does orbital velocity increase or decrease with altitude?

Orbital velocity decreases with altitude. At higher altitudes, earth's gravity is weaker, so a satellite doesn't need to move as fast to stay in orbit. That's why satellites closer to earth orbit faster than those far away.

What happens if the satellite moves slower than orbital velocity?

If a satellite moves slower than the required orbital velocity, gravity will pull it downward. As it loses height, it will enter dense layers of the atmosphere, experiance drag and, eventually burn up or fall back to the earth.

What happens if the satellite moves faster than orbital velocity?

If a satellite moves faster than the required orbital velocity at a given altitude, gravity wont be able to keep it in that orbit. It will move in a higher orbit if only slightly faster. If its much faster, it can escape earth's gravity completly and travel into space.

Why do satellites not need fuel to keep moving?

Satellites dont need fuel to keep moving because there is almost no air (no friction) in space to slow them down. Once launched at the right speed, they keep moving due to inertia (Newton's first law of motion). Fuel is only needed for small adjustments not for continous motion.

Why geostationary satellite appear stationary?

A geostationary satellite appears stationary because it orbits the earth once every 24 hours, the same time earth takes to rotate. Since it moves at the same speed and in the same direction as earth's rotation, it always stays above the same point on the equator.

Why a geostationary satellite placed very high?

A geostationary satellite is placed very high so that its orbital period matches earth's rotation (24 hours). This allows it to stay fixed over the same spot on earth.

What is difference between geostationary and polar satellites?

Geostationary satellite orbits above the equator, stays fixed over one point, good for communication and weather monitoring. Polar satellite orbits over the poles at low altitude, covers the whole earth as it passes, good for mapping, spying and earth observation.

Numericals

1) Find the mass of the earth by considering a scenario where a small object is placed on the earth's surface such that distance between their centers is equal to the earth's radius i.e., 6.4×10^6 m.

Data:

$M_E = ?$

$R = 6.4 \times 10^6$ m

Solution:

$F = GmM_E/R^2$ $\quad \because F = W$

$W = GmM_E/R^2$ $\quad \because W = mg$

$mg = GmM_E/R^2$

$g = GM_E/R^2$

$M_E = gR^2/G$

$M_E = \frac{(9.8)(6.4 \times 10^6)^2}{6.67 \times 10^{-11}}$

$M_E = 60.1 \times 10^{23}$

$M_E = 6.01 \times 10^{24}$ kg

2) Alpha Centuri is a binary star system with two stars: Alpha Centuari A and Alpha Centuri B. The mass of Alpha Centuri A is 2.19×10^{30} kg and Alpha centuri B is 1.80×10^{30} kg, they attract each other with a force of 2.24×10^{25} N. What is the distance between them?

Data:

$m_A = 2.19 \times 10^{30}$ kg

$m_B = 1.80 \times 10^{30}$ kg

$F = 2.24 \times 10^{25}$ N

$d = ?$

Solution:

$F = Gm_1m_2/R^2$

$F = Gm_Am_B/d^2$

$d^2 = Gm_Am_B/F$

$d^2 = \frac{(6.67\times10^{-11})(2.19\times10^{30})(1.80\times10^{30})}{2.24\times10^{25}}$

$d^2 = 11.74\times10^{24}$

$d = 3.43\times10^{12}m$

3) What will be the value of "g" on an exoplanet (a planet outside the Solar System) whose mass is five times the mass of earth and its radius is twice the radius of earth?

Data:

$g = ?$

$M = 5M_E$

$R = 2R_E$

Solution:

$g = GM/R^2$

$g = G(5M_E)/(2R_E)^2$

$g = 5GM_E/4R_E^2$

$g = \frac{5(6.67\times10^{-11})(6\times10^{24})}{4(6.4\times10^6)^2}$

$g = 1.22\times10^1$

$g = 12.2ms^{-1}$

4) The Hubble Space telescope is in a circular orbit 613km above earth's surface. The average radius of the Earth is 6.4×10^6m and the mass of earth is 6×10^{24} kg. (a) What is the speed of the telescope in its orbit? (b) What is the period of the telescope's orbit?

Data:

$h = 613km = 0.613\times10^6m$

$R = 6.37\times10^6 = 6.4\times10^6m$

$M = 5.97\times10^{24} = 6\times10^{24}kg$

$v = ?$

$T = ?$

Solution:

(a) $v = \sqrt{GM/R+h}$

$v = \sqrt{\frac{(6.67\times10^{-11})(5.97\times10^{24})}{6.37\times10^6+0.613\times10^6}}$

$v = \sqrt{5.7\times10^7}$

$v = 7550ms^{-1}$

(b) $T = 2\pi r/v$

$T = 2\pi(R+h)/v$

$T = \frac{2(3.14)(6.37\times10^6)+(0.613\times10^6)}{7550}$

$T = 5807s$

5) To launch a satellite around planet Mars at an altitude of 300 km above its surface. Mars has a mass of 6.42×10^{23}kg and has a radius of 3.39×10^6m, calculate its orbital velocity?

Data:

$h = 300km = 3\times10^5m$

$M = 6.42\times10^{23}kg$

$R = 3.39\times10^6m$

$v = ?$

Solution:

$v = \sqrt{GM/R+h}$

$v = \sqrt{\frac{(6.67\times10^{-11})(6.42\times10^{23})}{3.39\times10^6+3\times10^5}}$

$v = \sqrt{11.6\times10^6}$

$v = 3.4\times10^3ms^{-1}$

$v = 3.4kms^{-1}$

(6) An asteriod orbits around the sun 8.35×10^{11}m from it. (a) How fast must the asteriod travel to maintain its circular orbit around the sun? (b) How long will it take the aestroid to orbit the sun?

Data:

$R = 8.35\times10^{11}m$

$v = ?$

$T = ?$

Solution:

$v = \sqrt{GM/R}$

$v = \sqrt{\frac{(6.67\times10^{-11})(1.99\times10^{30})}{8.35\times10^{11}}}$

$v = \sqrt{1.59\times10^8}$

$v = 1.26\times10^4ms^{-1}$

$T = 2\pi r/v$

$T = \frac{2(3.14)(8.35\times10^{11})}{1.26\times10^4}$

$T = 41.62\times10^7s$

$T = \frac{41.62\times10^7}{3.15\times10^7}$ years

$T = 13.2$ years

7) Mars has a mass of 6.42×10^{23}kg and has a period of 88,642s. What would be the radius of a stationary satellite for this planet?

Data:

$M = 6.42\times10^{23}kg$

$T = 88642s = 8.86\times10^4s$

$r = ?$

Solution:

$T = 2\pi r/v$

$T = 2\pi r/\sqrt{GM/r}$

$T^2 = 4\pi^2r^2/GM/r$

$T^2 = 4\pi^2r^3/GM$

$r^3 = T^2GM/4\pi^2$

$r^3 = \frac{(8.86\times10^4)^2(6.67\times10^{-11})(6.42\times10^{23})}{4(3.14)^2}$

$r^3 = 85.2\times10^{20}$

$r = 2.0424\times10^7$

$r = 20424\times10^3m$

$r = 20424km$

8) Calculate the potential energy of the Moon having mass 7.35×10^{22}kg, relative to earth with mass 5.98×10^{24}kg if the distance between their centers is 3.94×10^5km

Data:

$U = ?$

$M_m = 7.35\times10^{22}kg$

$M_E = 5.98\times10^{24}kg$

$R = 3.94\times10^5km = 3.94\times10^8m$

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Solution:

$U = -GM_EM_m/R$

$$U = -\frac{(6.67\times10^{-11})(5.98\times10^{24})(7.35\times10^{22})}{3.94\times10^{8}}$$

$U = -74.4\times10^{27}$

$U = -7.44\times10^{28}J$

9) A 50kg weather satellite move in a circle orbit about the earth at an altitude of 1000km. A similar 50kg communication satellite is at an altitude of 37,000km in circular orbits about the earth. Calculate the difference in the gravitational potential energies of the two satellites in their respective orbits?

Data:

$m_1 = 50kg$

$h_1 = 1000km = 1\times10^6m$

$m_2 = 50kg$

$h_2 = 37000km = 37\times10^6m$

$\Delta U = ?$

Solution:

$U_1 = -GM_Em_1/R$

$U_1 = -GM_Em_1/R_E+h_1$

$$U_1 = -\frac{(6.67\times10^{-11})(6\times10^{24})(50)}{6.4\times10^6+1\times10^6}$$

$U_1 = -270.4\times10^7J$

$U_2 = -GM_Em_2/R$

$U_2 = -GM_Em_2/R_E+h_2$

$$U_2 = -\frac{(6.67\times10^{-11})(6\times10^{24})(50)}{6.4\times10^6+37\times10^6}$$

$U_2 = -46.1\times10^7J$

$\Delta U = U_2 - U_1$

$\Delta U = (-46.1\times10^7)-(-270.4\times10^7)$

$\Delta U = -46.1\times10^7+270.4\times10^7$

$\Delta U = 224.3\times10^7J$

$\Delta U = 2.243\times10^9J$

$\Delta U = 2.243\,GJ$

10) What is the change in gravitational potential energy of a 64.5kg astronaut, lifted from Earth's surface into a circular orbit of altitude 4.40×10^2 km?

Data:

$\Delta U = ?$

$m = 64.5kg$

$h = 4.4\times10^2km = 4.4\times10^5m = 0.44\times10^6m$

Solution:

$U_{surface} = -GM_Em/R_E$

$$U_{surface} = -\frac{(6.67\times10^{-11})(6\times10^{24})(64.5)}{6.4\times10^6}$$

$U_{surface} = -403.3\times10^7J$

$U_{orbit} = -GM_Em/R_E$

$U_{orbit} = -GM_Em/R_E+h$

$$U_{orbit} = -\frac{(6.67\times10^{-11})(6\times10^{24})(64.5)}{6.4\times10^6+0.44\times10^6}$$

$U_{orbit} = -377.4\times10^7J$

$\Delta U = U_{orbit} - U_{surface}$

$\Delta U = (-377.4\times10^7)-(-403.3\times10^7)$

$\Delta U = 2.59\times10^8J$

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