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Where Minds Pollinate

Class 12

Physics

Chapter 15

Handwritten Notes

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GRAVITATION

Law of Gravitation

~~Cons~~ Every object in the universe attracts every other object with a force which is directly propotional to the product of their masses and propotional to square of distance between their centers.

Mathematicaly: Consider two spherical bodies "m_1" and "m_2", separated by "r" distance.

$F_g \propto m_1 m_2$ — (i)

$F_g \propto 1/r^2$ — (ii)

Combining both relations

$F_g \propto m_1 m_2/r^2$

$F_g = G m_1 m_2/r^2$

Where G is constant of propotionality and its value is $6.67 \times 10^{-11}\ Nm^2 kg^{-2}$

Properties: **1. Mutual Force:** Gravitational force is a mutual force. Mass "m_1" and "m_2" apply equal and opposite force on each other.

2. Nature of Force: Gravitational force is only attractive in nature.

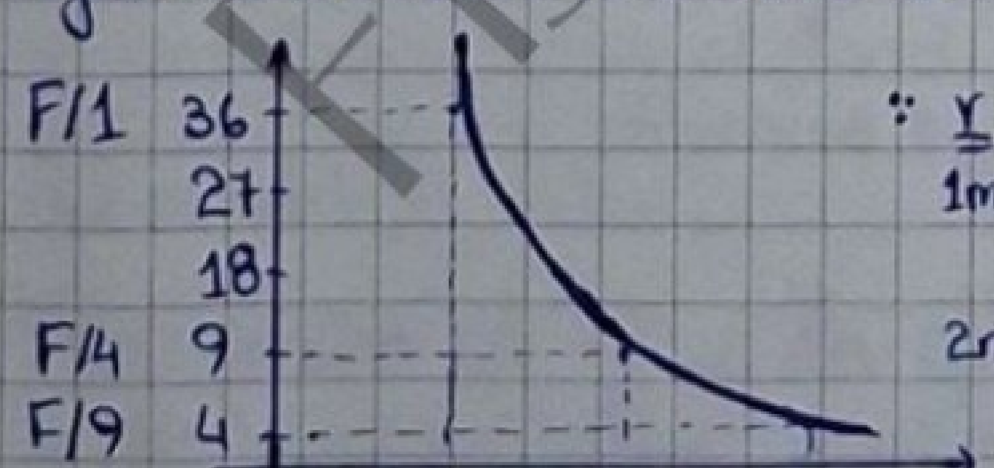
3. Effect of Medium: Gravitational force is independent of medium.

4. Line of action: Gravitational force act along line joining centers of spheres.

5. Validity: It is only valid for point masses.

6. Significance for masses: It is more significant for massive bodies as compared to lighter bodies. Because $F \propto m_1 m_2$.

7. Inverse square force: It is an inverse square force. It decreases four times when we double the distance. It decrease 9 times when we triple the distance. The graph between magnitude of gravitational force and distance:



$\because$ r	F
1m	$36 = 1/1^2 \times 36 = 36$
2m	$1/4 \times 36 = 1/2^2 \times 36 = 9$

Newton's 3rd Law and Law of Gravitation:

Newton's 3rd law is consistant with law of gravitation. According to 3rd law "To every action there is equal and opposite reaction". In gravitational law m_1 applys a force on m_2, this is action, m_2 also apply equal but opposite force which is reaction. Action and reaction are equal and opposite.

Gravitational Field

Gravitational field is a region around a mass where any other mass experiances a force of gravitation.

Gravitational feild strength: The gravitational force experianced per unit mass by a small test mass placed in gravitational field. Gravitational feild strength and acceleration due to gravity are equivalent.

As gravitational field strength:

$GFS = F_g/m$ — (i)

Acceleration $= a = F/m$ — (ii)

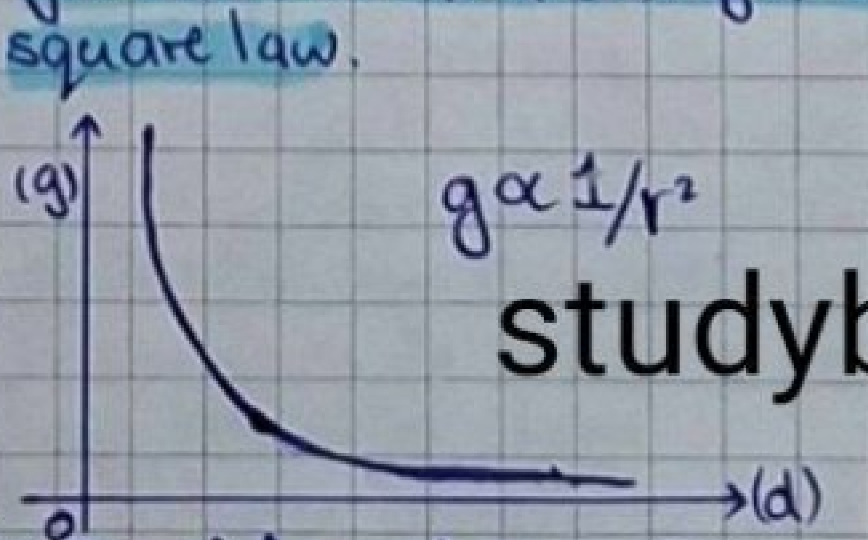
$g = F_g/m$

Where "F_g" is gravitational force, "m" is test mass, "g" is acceleration due to gravity.

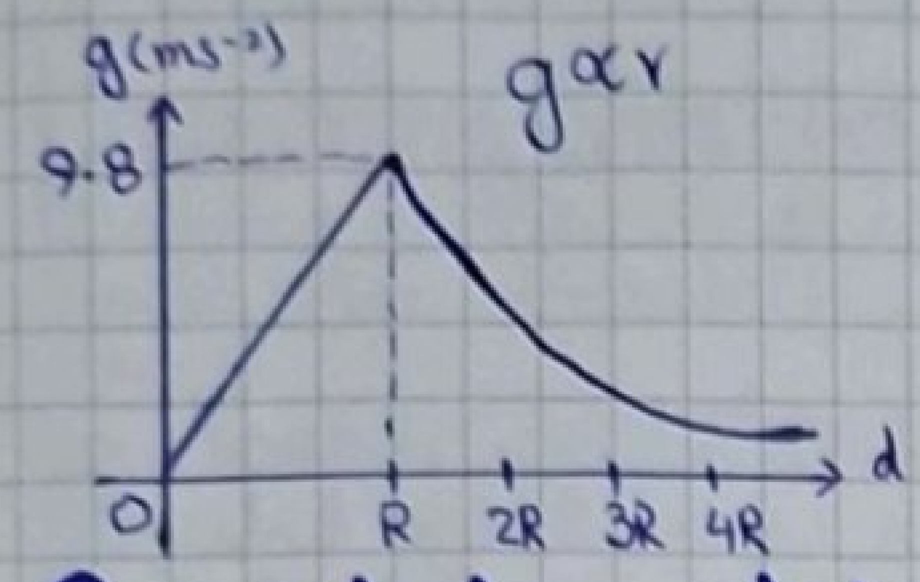
Gravitational feild lines: Gravitational feild lines are imaginary lines used to represent the direction and strength. Direction of field lines are radially inward. Feild is stronger where field lines are close. Field is weaker where field lines are further apart.

Concept of uniform sphere: A uniform sphere have a constant density throughout. It helps to calculate gravitational force for stars and planets. Gravitational field behave as:

1. Outside sphere: When you are outside a sphere gravitational field act as if all mass is concentrated in the center of sphere. Gravitational field decreases as you move away from center of sphere. Outside, gravitational field changes according to inverse square law.



2. Inside sphere: Behaviour of gravitational field is inside spherical mass is different from outside. Gravitational field increase as you move away from center of sphere but inside the sphere. It changes linearly in the sphere. Reason is that only the mass enclosed with a radius "r" contributes to gravitational field at point inside a sphere. (Newton's Shell Theorem)



Gravitational Accelaration

Gravitational accelaration is the accelratin experianced by a body when it is allowed to freely fall under action of earth's gravity. It is denoted by "g". It's direction is towards the center of earth.

Formula: Consider an object of mass "mo" placed on surface of earth having mass "ME". "R" is radius of earth. "r" is radis of object which is very small so, it is ignored.

From law of gravitation:

$F = GM_E m_o / R^2$ —— (i)

From Newton's 2nd law

$F = W = mg$ $\because F = ma$

Putting value in equation (i)

$mg = GM_E m_o / R^2$

$g = GM_E / R^2$ —— (ii)

$\because R = 6.4 \times 10^6 m$

$\because$ ~~ME~~ $G = 6.673 \times 10^{-11} Nm^2 kg^{-2}$

$\because M_E = 6 \times 10^{24} kg$

Putting the values in the equation

$g = \frac{6.673 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^6)^2}$

$g = 9.8 ms^{-2}$

Concept of freefall: It is clear from above relation that value of "g" is independent of mass of the object that means heavy and light object should fall at the same rate.

Dependence: It dependence upon mass of planet and radius of planet. Value of "g" and our weight is influenced by mass of planet and it's radius.

Variation of "g" with altitude: Value of "g" decreases with increase in height above surface of earth and therefore our weight also decreases.

Mathematically: When the object of mass "mo" is at height "h" from surface of earth then it is represented by "gh".

$g_h = GM_E / (R+h)^2$ —— (iii)

from equation (ii)

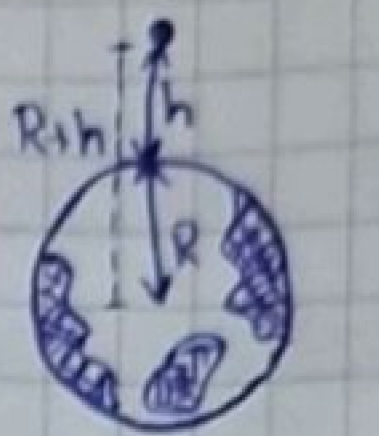
$gR^2 = GM_E$

Put in equation (iii)

$g_h = gR^2 / (R+h)^2$

$\because R^2/(R+h)^2 < 1$

So, $g_h < g$



To conclude, as we move away from surface of the earth, value of "g" will decrease.

Satellite

A satellite is any object that orbits the planet due to force of gravity, maintaining a stable path around it. There are two types of satellites, natural and artificial satellite.

Natural Satellite: A natural body orbiting a planet, minor planet or dwarf planet, where the larger body's gravity dominates the system is called natural satellite.

Artificial Satellite: Artificial satellites are man-made objects launched into orbit around earth or other celestial body for specific purposes.

Characteristics: These satellites orbit around the earth without need of any engine. They remains in orbit due to gravitational pull of earth.

Types of Satellites: There are different types of satellites for different purposes.

Communication Satellite: These satellites are used for long distance communication via radio signals. Most of these are geostationary. They enable unintrupted contact with ground station.

Weather Satellite: It is used for weather forecasting. It is equiped with cameras and instruments directed at earth's atmosphere. It helps to provide advance warning of severe weather.

Navigation Satellite: Navigation satellites help in determining the position of ground based objects. For example, spacecraft, ships, cars etc. US air force operates "NAVSTAR" global positioning system which consists of 24 satellites. It can provide accurate position information from 100m to <1cm.

Millitary Satellite: These are similar to communication satellite. It transmit encrypted data decoded by special receiver. Survallience satellites have high resolution cameras for imaging.

Scientific Satellite: These are used to study map of earth, ocean, atmosphere and distant space. For example, Hubble space telescope which cant be affected by atmosphere. It provides clear images of deep space.

Launching Satellites:
Satellites are launched to high altitude using spacecraft (rocket). Then accelerated to sufficient tangential speed.

Low speed: Satellites fall back on earth.
Adjusted speed: moves in circular orbit.
High speed: Satellite moves in elliptical or escape from gravity.

Orbital Velocity:

Orbital velocity is the minimum velocity required by a satellite to stay in a circular orbit around a planet.

Derivation: Consider a satellite of mass "m" ~~with~~ revolving with orbital velocity "Vo" around earth of mass "M". Let "r" be the distance between center of earth and center of the satellite. The centripetal force is provided by gravitational force.

$F_c = F_g$

$\because F_c = mv^2/r$

$\because F_g = Gm_1m_2/r^2$

$mV_o^2/r = GMm/r^2$

$V_o^2 = GM/r$

Taking square root on both sides

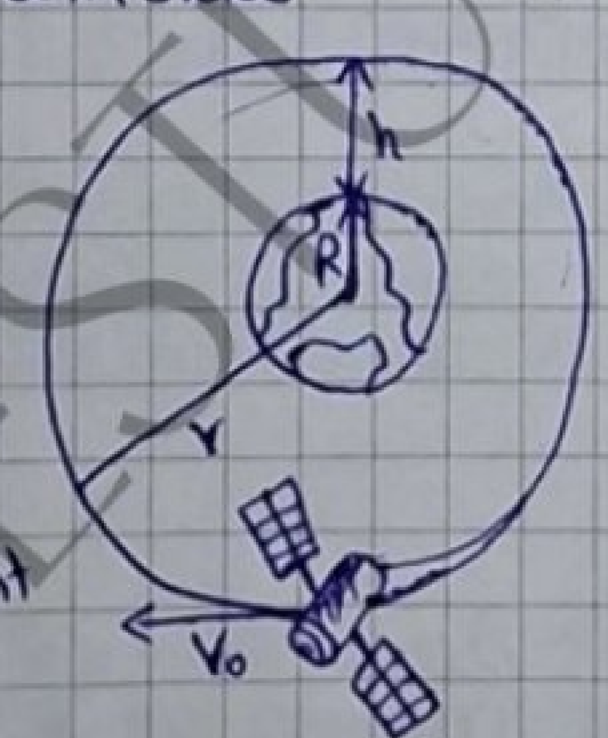
$\sqrt{V_o^2} = \sqrt{GM/r}$

$V_o = \sqrt{GM/r}$

$\because$ as, $r = R+h$

So,

$$V_o = \sqrt{\frac{GM}{(R+h)}}$$



Where,
G = Gravitational constant
M = Mass of earth
r = radius of orbit
Vo = Orbital velocity
R = Radius of earth
h = Altitude of satellite

For close to earth: $h \ll R$, $h = 0$

So, $V_o = \sqrt{GM/R}$

$$V_o = \sqrt{\frac{(6.67\times10^{-11})(6\times10^{24})}{6.4\times10^{6}}}$$

$V_o = 7.9\,kms^{-1}$

Dependence: Orbital velocity depends upon mass of large body and orbital radius $r = (R+h)$. Satellite moves faster when it is close to the earth. Orbital velocity is independent of satellite mass.

Geostationary Satellites:

A geostationary satellite is a satellite that remains fixed above a point on earth's equater, appearing stationary to an observer on earth.

Why appears stationary: Earth completes one rotation in 24 hours, geo-stationary satellite complete one revolution in 24 hours, that is why it appears stationary.

Conditions:
- Must orbit in a circle.
- Must rotate in equatorial plane.
- Must rotate in same direction as earth.
- Time period of satellite should be 24 hours.

Velocity: Consider a satellite of mass "m" revolving with velocity "Vo" around earth of mass "M". Let "r" be the distance between the centers of earth and satellite. Earth's gravitational force acts as centripetal force.

$F_c = F_g$

$mV_o^2/r = GMm/r^2$

$V_o^2 = GM/r$

$V_o = \sqrt{GM/r}$ —(i)

Geostationary orbit: The circular orbit in which a satellite remains fixed over one point on earth called geostationary orbit.

$\because$ Radius $= r$

$\because$ Circumference $= 2\pi r$

$\because$ Velocity $= V_o = d/t$

for one complete cycle,

$V_o = 2\pi r/T$ —(ii)

Comparing equation (i) and (ii)

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

Squaring both sides

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

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

Taking cube root on both sides,

$r = [T^2GM/4\pi^2]^{1/3}$ —(iii)

$\because T$ = time period for one rotation $= 24hr = 86400s$

Putting the values in equation (iii)

$$r = \left[\frac{(86400)^2\times(6.67\times10^{-11})\times(6\times10^{24})}{4(3.14)^2}\right]^{1/3}$$

$r = 4.23\times10^7 m$

putting the value in equation (i)

$$V_o = \sqrt{\frac{(6.67\times10^{-11})(6\times10^{24})}{4.23\times10^{7}}}$$

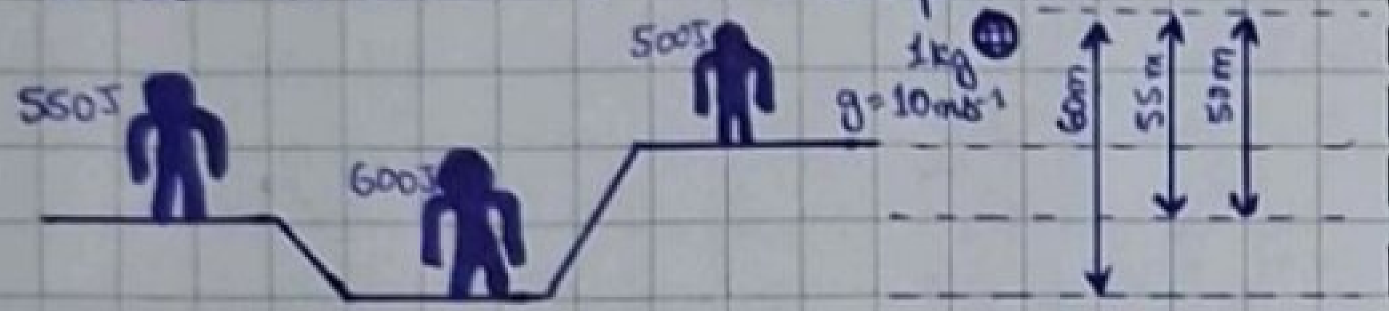
$V_o = 3.07\times10^3 ms^{-1}$

Gravitational Potential

Gravitational potential energy is the energy stored in a object due to it's position above the earth surface.

$\Delta P.E = mgh$ —(i)

This formula is valid only when "g" is constant i.e. near the surface of earth.
P.E is measured w.r.t some refrence point. For example, we measure P.E w.r.t ground. Different observers can measure different P.E due to different refrence point.



So we choose infinity as refrence point to measure exact amount of P.E. P.E at $r=\infty$ is zero. This choice results "-ve" P.E because as we move closer to earth P.E decreases.

Absolute Gravitational Potential Energy (U):

Amount of work done in moving a body from earth's surface to a point at infinity distance where the value of "g" is negligible is called absolute potential energy (U).

Absolute Gravitational Potential (V):

Graitational potential (V) is the work done per unit mass in bringing a small mass from infinity to that point inside the gravitational field.

$V = U/m$

Derivation:

G.P.E = Work from $(0 \to \infty)$

During this work force is not constant so, we have to divide the path into small parts in which force is constant.

$W_{0\to\infty} = W_1 + W_2 + W_3 + \dots + W_n$

$\because W = Fd\cos\theta$

$W_1 = F_{AV} \cdot \Delta r$

$W_1 = F_{AV}\Delta r \cos 180$

$W_1 = F_{AV}\Delta r(-1)$

$W_1 = -F_{AV}(r_1 - R_E)$ $\because \Delta r = r_1 - R_E$

$W_1 = \dfrac{-GMm}{r_{AV}^2}(r_1 - R_E)$ $\because F_{AV} = F_g$

Now, to make the calculation easier, we do some steps,

$\Delta r = r_1 - R_E$ —(i)

$r_{AV} = r_1 + R_E/2$ —(ii)

$\Delta r + R_E = r_1$ $\because$ From eq (i)

Put the value of r_1 in equation (ii)

$r_{AV} = \Delta r + R_E + R_E/2$

$r_{AV} = 2R_E/2 + \Delta r/2$

$r_{AV} = R_E + \Delta r/2$

Taking square on both sides

$(r_{AV})^2 = (R_E + \Delta r/2)^2$

$r_{AV}^2 = R_E^2 + (\Delta r/2)^2 + \cancel{2}R_E\,\Delta r/\cancel{2}$ $\because a^2+b^2+2ab$

$(\Delta r)^2$ is a very small value so its $= 0$.

$r_{AV}^2 = R_E^2 + R_E\Delta r$

$r_{AV}^2 = R_E^2 + R_E(r_1 - R_E)$

$r_{AV}^2 = \cancel{R_E^2} + R_E r_1 - \cancel{R_E^2}$

$r_{AV}^2 = R_E r_1$

So,

$W_1 = \dfrac{-GMm}{R_E r_1}(r_1 - R_E)$

$W_1 = -GMm\left[\dfrac{\cancel{r_1}}{\cancel{r_1}R_E} - \dfrac{\cancel{R_E}}{r_1\cancel{R_E}}\right]$

$W_1 = -GMm\left[\dfrac{1}{R_E} - \dfrac{1}{r_1}\right]$

$W_2 = \dfrac{-GMm}{r_1 r_2}(r_2 - r_1)$

$W_2 = -GMm\left[\dfrac{\cancel{r_2}}{r_1\cancel{r_2}} - \dfrac{\cancel{r_1}}{\cancel{r_1}r_2}\right]$

$W_2 = -GMm\left[\dfrac{1}{r_1} - \dfrac{1}{r_2}\right]$

$W_3 = -GMm\left[\dfrac{1}{r_2} - \dfrac{1}{r_3}\right]$

$W_4 = -GMm\left[\dfrac{1}{r_3} - \dfrac{1}{r_4}\right]$

$W_n = -GMm\left[\dfrac{1}{r_{n-1}} - \dfrac{1}{r_n}\right]$

$W = -GMm\left[\dfrac{1}{R_E} - \dfrac{1}{r_1}\right] - GMm\left[\dfrac{1}{r_1} - \dfrac{1}{r_2}\right] - GMm\left[\dfrac{1}{r_2} - \dfrac{1}{r_3}\right] - GMm\left[\dfrac{1}{r_3} - \dfrac{1}{r_4}\right] - \dots\dots - GMm\left[\dfrac{1}{r_{n-1}} - \dfrac{1}{r_n}\right]$

$W = -GMm\left\{\dfrac{1}{R_E} - \cancel{\dfrac{1}{r_1}} + \cancel{\dfrac{1}{r_1}} - \cancel{\dfrac{1}{r_2}} + \cancel{\dfrac{1}{r_2}} - \cancel{\dfrac{1}{r_3}} + \cancel{\dfrac{1}{r_3}} - \dfrac{1}{r_4} \dots\dots + \dfrac{1}{r_{n-1}} - \dfrac{1}{r_n}\right\}$

$W = -GMm\left\{\dfrac{1}{R_E} - \dfrac{1}{r_n}\right\}$ $\because r_n = \infty$

$W = -GMm\left\{\dfrac{1}{R_E} - \dfrac{1}{\infty}\right\}$ $\because 1/\infty = 0$

$W = -GMm\left\{\dfrac{1}{R_E}\right\}$

For general relation,

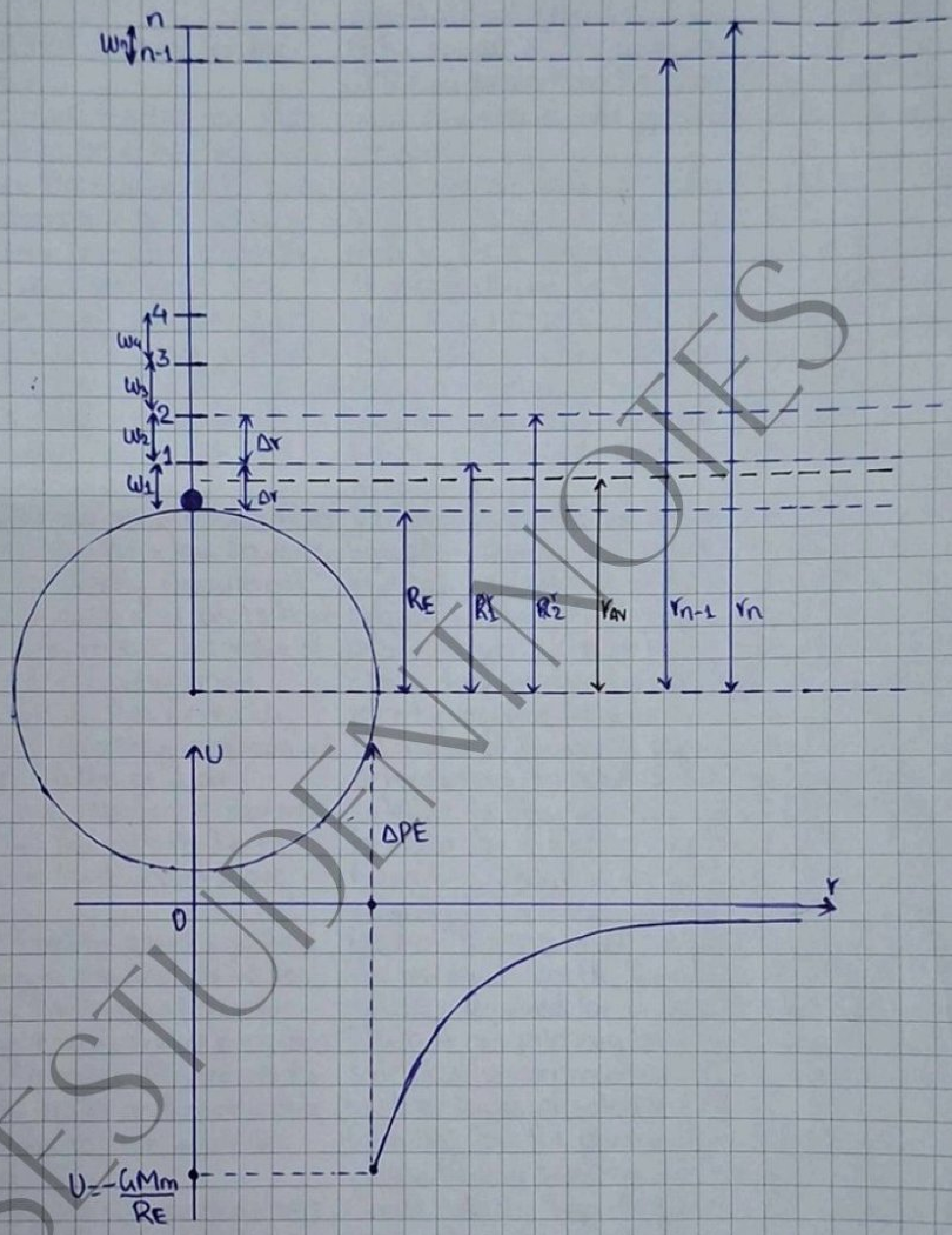
$W = \dfrac{-GMm}{r}$ $\because GPE = U = W$

$U = \dfrac{-GMm}{r}$

For gravitational potential (V),

$\dfrac{U}{m} = \dfrac{-GM\cancel{m}}{r\cancel{m}}$ $\because V = U/m$

$V = \dfrac{-GM}{r}$



Gravitational Potential