Today 13.3, 13.4

$\boxed{L36}$

Today $\underbrace{13.3}_{}$, 13.4

L36

Gravitational potential energy

Today 13.3, 13.4 L36

Gravitational potential energy

Motion of satellites

Today 13.3, 13.4

L36

SI session

Today 13.3, 13.4

L36

SI session

* 5pm to 6pm

Today 13.3, 13.4

L36

SI session

* 5pm to 6pm
* §13.1 Newton's law of gravitation

Today 13.3, 13.4

$\boxed{\text{L36}}$

SI session

* 5pm to 6pm
* §13.1 Newton's law of gravitation
* §13.2 Weight

L36

Today 13.3, 13.4

Wednesday 13.5, 13.8

Today 13.3, 13.4

L36

Wednesday $\underbrace{13.5}_{\text{Kepler's laws}}$, 13.8

L36

Today 13.3, 13.4

Wednesday 13.5, 13.8

Kepler's laws

Black holes

Today 13.3, 13.4

Wednesday 13.5, 13.8

Friday Holiday

$\boxed{L36}$

Today 13.3, 13.4

Wednesday 13.5, 13.8

Friday Holiday

Monday Nov. 30th Exam #4

L36

L36

Today 13.3, 13.4

Wednesday 13.5, 13.8

Friday Holiday

Monday Nov. 30th Exam #4

Wednesday Dec. 2nd Day of Reckoning

L36

Today 13.3, 13.4

Wednesday 13.5, 13.8

Friday Holiday

Monday Nov. 30th Exam #4

Wednesday Dec. 2nd Day of Reckoning

Friday Dec. 4th Final exam

Warning:

In these notes I mix some notation ☹

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Sometimes I use

$U \to$ Potential energy

<u>Warning:</u>

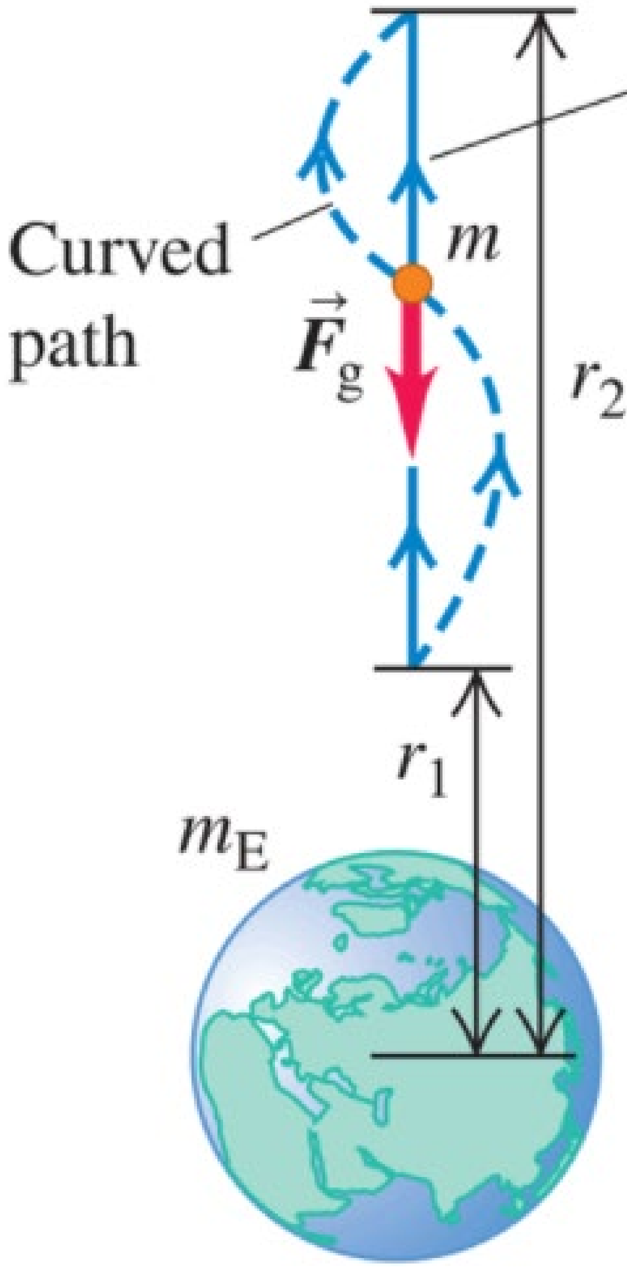
In these notes I mix some notation ☹

Sometimes I use

$U \to$ Potential energy

& Sometimes I use

$V \to$ Potential energy



The gravitational force is conservative: The work done by $\vec{F}_g$ does not depend on the path taken from r_1 to r_2.

$$W_{grav} = \int_{r_1}^{r_2} F_r \, dr$$

$$W_{grav} = \int_{r_1}^{r_2} F_r \, dr \quad , \quad F_r = -\frac{G M_E m}{r^2}$$

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$$\Rightarrow \quad W_{grav} = -GM_E m \left(-\frac{1}{r}\right)\Bigg|_{r_1}^{r_2} = GM_E m \left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

$$W_{grav} = \int_{r_1}^{r_2} F_r \, dr \quad , \quad F_r = -\frac{G M_E m}{r^2}$$

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ASU

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Since $W = U_1 - U_2$

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Let $U_2 = 0 \Rightarrow$ reference point is $r_2 \to \infty$

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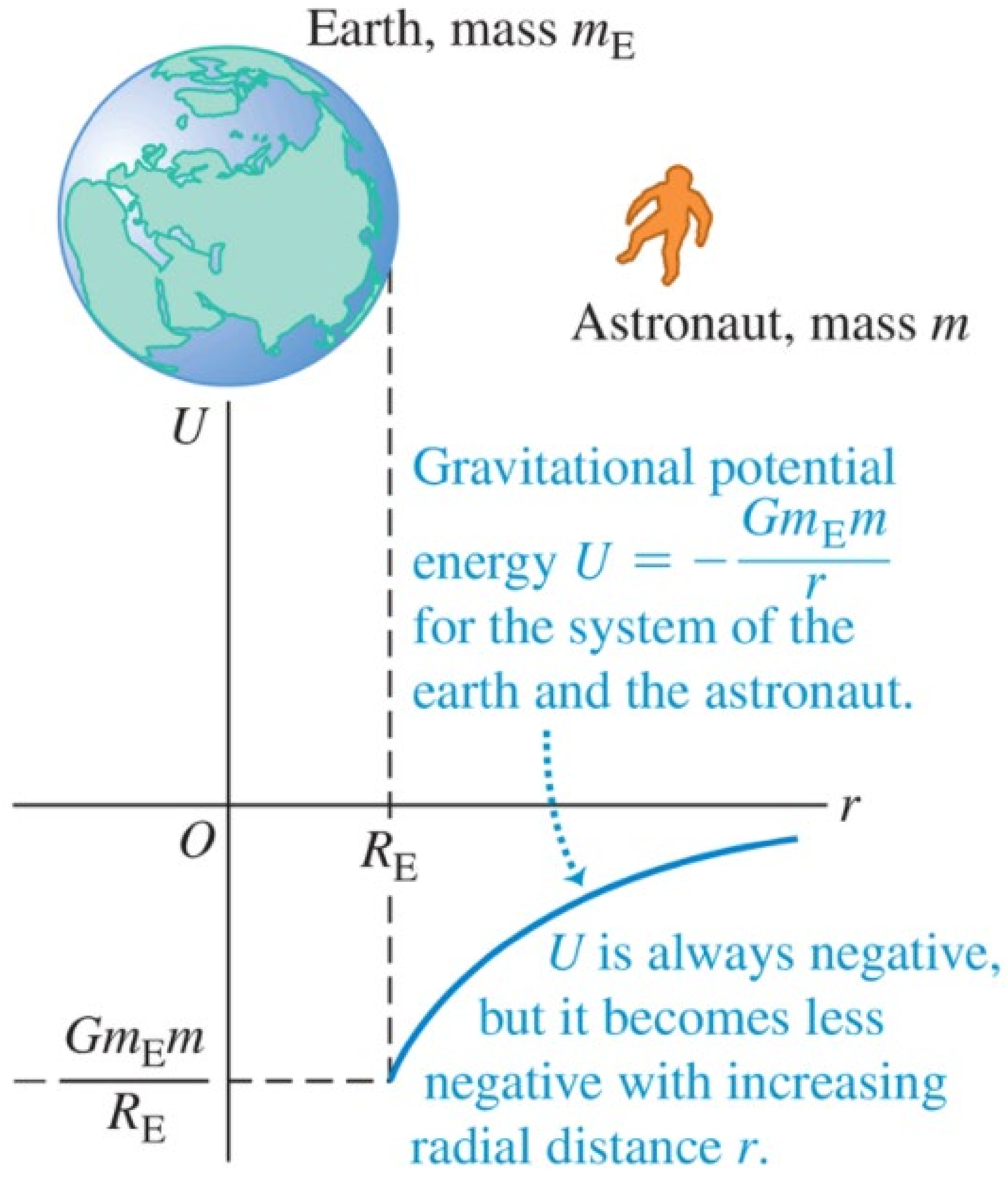
Let $U_2 = 0 \Rightarrow$ reference point is

$r_2 \to \infty$ Now $U = -GM_E m / r$



Earth, mass m_E
Astronaut, mass m
U
Gravitational potential energy $U = -\frac{Gm_E m}{r}$ for the system of the earth and the astronaut.
r
O
R_E
$-\frac{Gm_E m}{R_E}$
U is always negative, but it becomes less negative with increasing radial distance r.

In Jules Verne's 1865 story with this title, three men went to the moon in a shell fired from a giant cannon sunk in the earth in Florida. (a) Find the minimum muzzle speed needed to shoot a shell straight up to a height above the earth equal to the earth's radius R_{E}. (b) Find the minimum muzzle speed that would allow a shell to escape from the earth completely (the *escape speed*). Neglect air resistance, the earth's rotation, and the gravitational pull of the moon. The earth's radius and mass are $R_{\mathrm{E}} = 6.37 \times 10^6$ m and $m_{\mathrm{E}} = 5.97 \times 10^{24}$ kg.

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$$K_1 + V_1 = K_2 + V_2$$

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But $g = \dfrac{G M_E}{R_E^2}$

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$$K_1 + V_1 = \cancelto{0}{K_2} + \cancelto{0}{V_2} \Rightarrow \quad K_1 = -V_1 \Rightarrow$$

$$\frac{1}{2} m v_1^2 = \frac{G M_E m}{R_E} \Rightarrow \quad \frac{1}{2} \cancel{m} v_1^2 = \cancel{m} g R_E$$

In Jules Verne's 1865 story with this title, three men went to the moon in a shell fired from a giant cannon sunk in the earth in Florida. (a) Find the minimum muzzle speed needed to shoot a shell straight up to a height above the earth equal to the earth's radius R_E. (b) Find the minimum muzzle speed that would allow a shell to escape from the earth completely (the *escape speed*). Neglect air resistance, the earth's rotation, and the gravitational pull of the moon. The earth's radius and mass are $R_E = 6.37 \times 10^6$ m and $m_E = 5.97 \times 10^{24}$ kg.

$$K_1 + V_1 = \overset{0}{\cancel{K_2}} + \overset{0}{\cancel{V_2}} \Rightarrow K_1 = -V_1 \Rightarrow$$

$$\frac{1}{2} m v_1^2 = \frac{G M_E m}{R_E} \Rightarrow \frac{1}{2} \cancel{m} v_1^2 = \cancel{m} g R_E \Rightarrow$$

$$v_1 = \sqrt{2 g R_E}$$

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$$K_1 + V_1 = \cancel{K_2}^{\,0} + \cancel{V_2}^{\,0} \Rightarrow K_1 = -V_1 \Rightarrow$$

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$$v_1 = \sqrt{2 g R_E} = [2 * 9.8 * 6.37]^{1/2} * 10^3 \text{ m/s}$$

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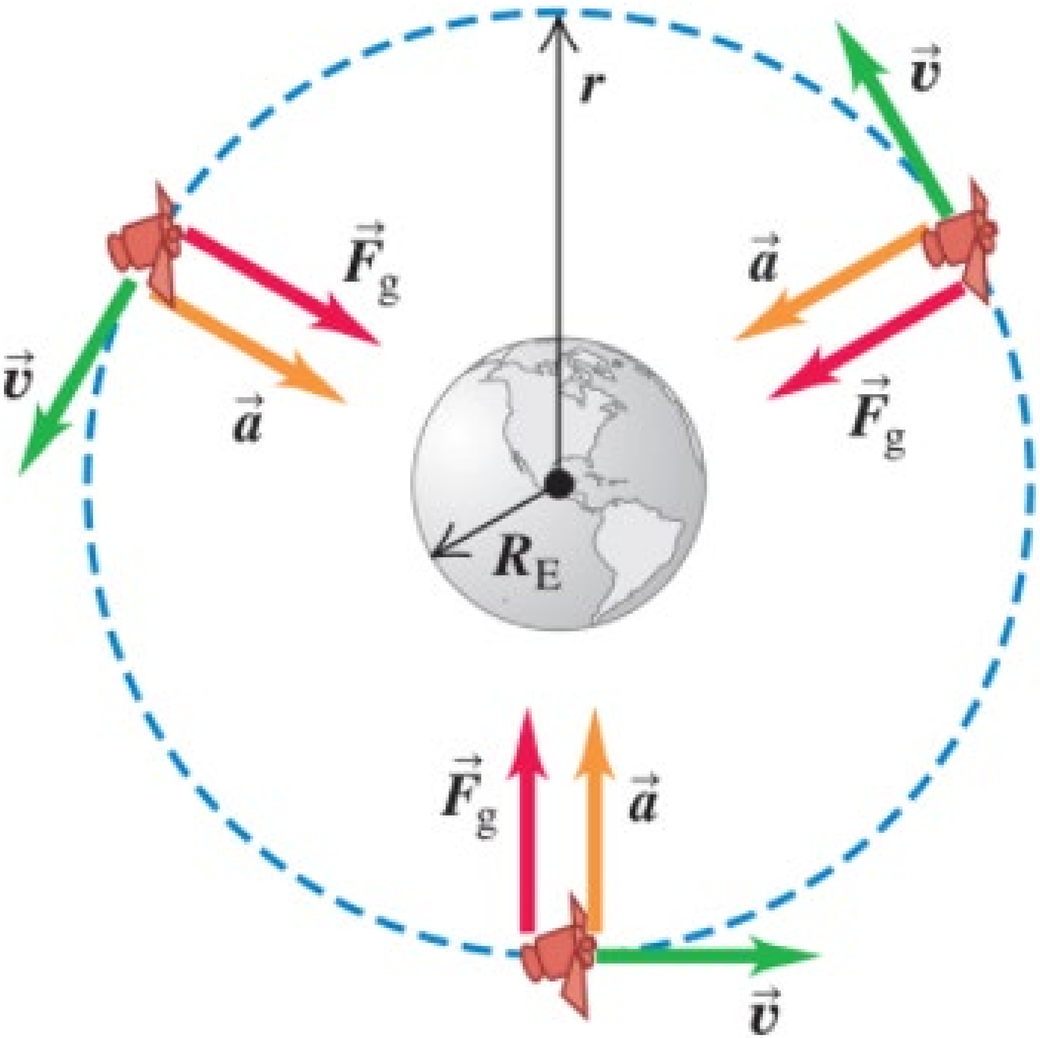
$$v_1 = \sqrt{2 g R_E} = [2 * 9.8 * 6.37]^{1/2} * 10^3 \, m/s$$

$$\Rightarrow \boxed{v_1 = 11 * 10^3 \, m/s}$$

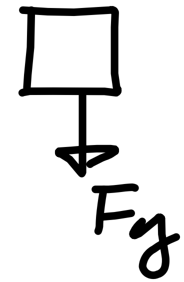
§13.4

Motion of Satellites



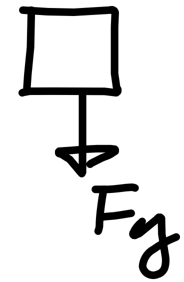
The satellite is in a circular orbit: Its acceleration $\vec{a}$ is always perpendicular to its velocity $\vec{v}$, so its speed v is constant.

$$\sum F_{rad} = m\,a_{rad}$$



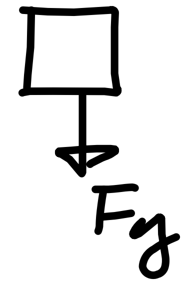
$$\sum F_{rad} = m\, a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r}$$



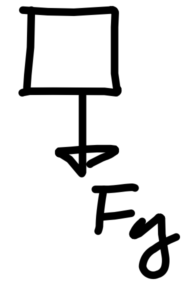
$$\sum F_{rad} = m\, a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E m}{r^2} = m\frac{v^2}{r}$$



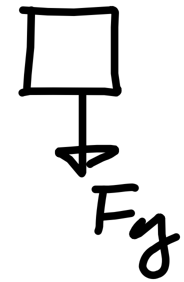
$$\sum F_{rad} = m\, a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^2} = \cancel{m}\frac{v^2}{r}$$



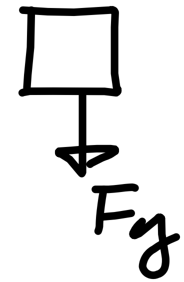
$$\sum F_{rad} = m\,a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$



$$\Sigma F_{rad} = m\, a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$

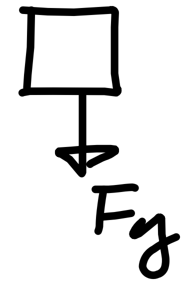


$$\Rightarrow \quad v^2 = \frac{G M_E}{r}$$

$$\sum F_{rad} = m\, a_{rad}$$

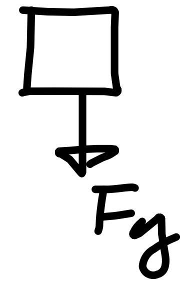
$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$

$$\Rightarrow \quad v^2 = \frac{G M_E}{r} \Rightarrow \quad v = \sqrt{\frac{G M_E}{r}}$$



$$\Sigma F_{rad} = m a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$

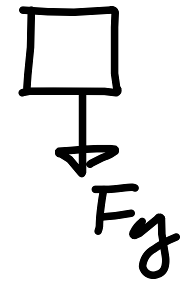


$$\Rightarrow \quad v^2 = \frac{G M_E}{r} \Rightarrow \quad v = \sqrt{\frac{G M_E}{r}}$$

Since $\quad v = \dfrac{2\pi r}{T}$

$$\sum F_{rad} = m\, a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$



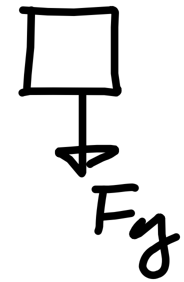
$$\Rightarrow \quad v^2 = \frac{G M_E}{r} \Rightarrow \quad v = \sqrt{\frac{G M_E}{r}}$$

Since $\quad v = \dfrac{2\pi r}{T}$, then

$$T = \frac{2\pi r}{v}$$

$$\Sigma F_{rad} = m\, a_{rad}$$

$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$

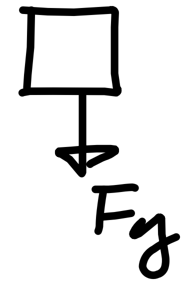


$$\Rightarrow \quad v^2 = \frac{G M_E}{r} \Rightarrow \quad v = \sqrt{\frac{G M_E}{r}}$$

Since $v = \dfrac{2\pi r}{T}$, then

$$T = \frac{2\pi r}{v} = 2\pi r\sqrt{\frac{r}{G M_E}}$$

$$\Sigma F_{rad} = m a_{rad}$$



$$\Rightarrow \quad F_g = m\frac{v^2}{r} \Rightarrow \frac{G M_E \cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$

$$\Rightarrow \quad v^2 = \frac{G M_E}{r} \Rightarrow \quad v = \sqrt{\frac{G M_E}{r}}$$

Since $\quad v = \dfrac{2\pi r}{T}$, then

$$T = \frac{2\pi r}{v} = 2\pi r\sqrt{\frac{r}{G M_E}} \Rightarrow \quad T = \frac{2\pi r^{3/2}}{\sqrt{G M_E}}$$

Energy = K + U

$$\mathcal{E}\text{nergy} = K + U \Rightarrow$$

$$\mathcal{E} = \frac{1}{2} m \left(\frac{G M_E}{r} \right) + \left(- \frac{G M_E m}{r} \right)$$

$$\mathcal{E}nergy = K + U \Rightarrow$$

$$\mathcal{E} = \frac{1}{2} m \left(\frac{GM_E}{r}\right) + \left(-\frac{GM_E m}{r}\right) \Rightarrow$$

$$\mathcal{E} = \left(\frac{GM_E m}{r}\right)\left(\frac{1}{2} - 1\right)$$

$$\mathcal{E}nergy = K + U \Rightarrow$$

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$$\mathcal{E} = \left(\frac{GM_E m}{r} \right) \left(\frac{1}{2} - 1 \right) \Rightarrow$$

$$\mathcal{E} = -\frac{GM_E m}{2r}$$

$$\mathcal{E}\text{nergy} = K + U \Rightarrow$$

$$\mathcal{E} = \frac{1}{2} m \left(\frac{GM_E}{r}\right) + \left(-\frac{GM_E m}{r}\right) \Rightarrow$$

$$\mathcal{E} = \left(\frac{GM_E m}{r}\right)\left(\frac{1}{2} - 1\right) \Rightarrow$$

$$\mathcal{E} = -\frac{GM_E m}{2r}$$

for circular orbit

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3).

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$m = 1000 kg$

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$m = 1000\,kg$, $R = R_E + 340\,km$

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$M = 1000\,\text{kg}$, $R = R_E + 340\,\text{km}$,

Find v, T, a_{rad}:

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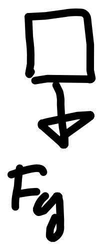
Find v, T, a_{rad}: $\Sigma F = ma$



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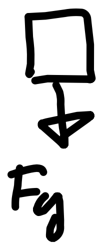
$M = 1000\,kg$, $R = R_E + 340\,km$,

<u>Find v, T, a_{rad}</u>: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$



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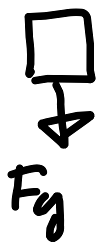
$m = 1000\,\text{kg}$, $R = R_E + 340\,\text{km}$,

<u>Find v, T, a_{rad}:</u> $\Sigma F = ma \Rightarrow F_g = m\dfrac{v^2}{R}$

$\Rightarrow \quad v^2 = \dfrac{RF_g}{m}$



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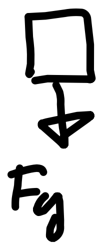
Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$

$$\Rightarrow \quad v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{R}{m}\right)\left(\frac{GM_E m}{R^2}\right)$$



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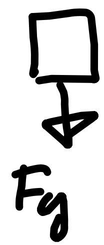
$$\Rightarrow v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{m}\right)\left(\frac{GM_E m}{R^{\cancel{2}}}\right)$$



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$M = 1000\,\text{kg}$, $R = R_E + 340\,\text{km}$,

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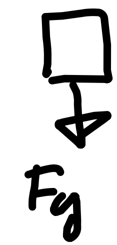

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Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$

$$\Rightarrow \quad v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{GM_E/R}$$

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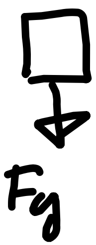

$$\Rightarrow \quad v^2 = \frac{R F_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{G M_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{G M_E / R} = \left[\frac{(6.67 * 10^{-11})(5.97 * 10^{24})}{(6370 + 340) * 10^3}\right]^{1/2} \frac{m}{s}$$

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3).

$m = 1000\,\text{kg}$, $R = R_E + 340\,\text{km}$,

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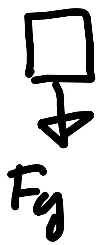


$$\Rightarrow \quad v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

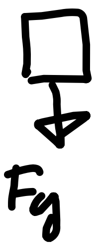
$$v = \sqrt{GM_E/R} = \left[\frac{(6.67 * 10^{-11})(5.97 * 10^{24})}{(6370 + 340) * 10^3}\right]^{1/2} \frac{m}{s}$$

$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} * 10^{(24-11-3)/2} \frac{m}{s}$$

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3).

$M = 1000\,\text{kg}, \quad R = R_E + 340\,\text{km},$

$\underline{\text{Find } v,\ T,\ a_{rad}}: \quad \Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$



$$\Rightarrow \quad v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E\cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{GM_E/R} = \left[\frac{(6.67*10^{-11})(5.97*10^{24})}{(6370+340)*10^3}\right]^{1/2}\frac{m}{s}$$

$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} * 10^{(24-11-3)/2}\,\frac{m}{s} = 0.077*10^5\,\frac{m}{s}$$

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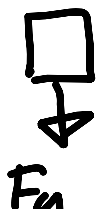
Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$



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$$= \boxed{7.7*10^3\,m/s}$$

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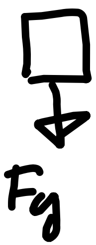
$m = 1000\,\text{kg}$, $R = R_E + 340\,\text{km}$,

Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$



$$\Rightarrow v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E\cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{GM_E/R} = \left[\frac{(6.67*10^{-11})(5.97*10^{24})}{(6370+340)*10^3}\right]^{1/2}\frac{m}{s}$$

$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} *10^{(24-11-3)/2}\frac{m}{s} = 0.077*10^5\frac{m}{s}$$

$$= \boxed{7.7*10^3\,m/s}$$

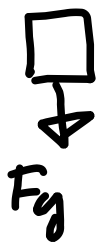
$$v = \frac{2\pi R}{T}$$

ASU

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3).

$M = 1000\,kg$, $R = R_E + 340\,km$,

Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$



$$\Rightarrow \quad v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E\cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{GM_E/R} = \left[\frac{(6.67*10^{-11})(5.97*10^{24})}{(6370+340)*10^3}\right]^{1/2} \frac{m}{s}$$

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$$= \boxed{7.7*10^3\ m/s} \qquad v = \frac{2\pi R}{T} \Rightarrow T = \frac{2\pi R}{v}$$

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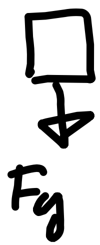

$$\Rightarrow v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{GM_E/R} = \left[\frac{(6.67*10^{-11})(5.97*10^{24})}{(6370+340)*10^3}\right]^{1/2} \frac{m}{s}$$

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$$= \boxed{7.7*10^3\, m/s}$$

$$v = \frac{2\pi R}{T} \Rightarrow T = \frac{2\pi R}{v} \Rightarrow$$

$$T = \left(\frac{2*3.14*6710*10^3}{7.7*10^3}\right)\frac{m}{s}$$

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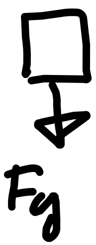
Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$



$$\Rightarrow \quad v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{GM_E/R} = \left[\frac{(6.67*10^{-11})(5.97*10^{24})}{(6370+340)*10^3}\right]^{1/2}\frac{m}{s}$$

$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} *10^{(24-11-3)/2}\,\frac{m}{s} = 0.077*10^5\,\frac{m}{s}$$

$$= \boxed{7.7*10^3\, m/s} \qquad v = \frac{2\pi R}{T} \Rightarrow T = \frac{2\pi R}{v} \Rightarrow$$

$$T = \left(\frac{2*3.14*6710*\cancel{10^3}}{7.7*\cancel{10^3}}\right)\frac{m}{s}$$

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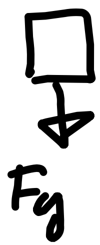
$M = 1000\,\text{kg}, \quad R = R_E + 340\,\text{Km},$

Find v, T, a_{rad}: $\quad \Sigma F = ma \Rightarrow F_g = m\dfrac{v^2}{R}$



$$\Rightarrow \quad v^2 = \frac{R F_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{G M_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$v = \sqrt{G M_E / R} = \left[\frac{(6.67 * 10^{-11})(5.97 * 10^{24})}{(6370 + 340) * 10^3}\right]^{1/2} \frac{m}{s}$$

$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} * 10^{(24-11-3)/2} \frac{m}{s} = 0.077 * 10^5 \frac{m}{s}$$

$$= \boxed{7.7 * 10^3\, m/s} \qquad v = \frac{2\pi R}{T} \Rightarrow T = \frac{2\pi R}{v} \Rightarrow$$

$$T = \left(\frac{2 * 3.14 * 6710 * \cancel{10^3}}{7.7 * \cancel{10^3}}\right) \frac{m}{s} = 5470\,s$$

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3).

$m = 1000\,kg$, $R = R_E + 340\,Km$,

Find v, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{v^2}{R}$

$$\Rightarrow v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

F_g

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$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} * 10^{(24-11-3)/2} \frac{m}{s} = 0.077 * 10^5 \frac{m}{s}$$

$$= \boxed{7.7 * 10^3\, m/s}$$

$$v = \frac{2\pi R}{T} \Rightarrow T = \frac{2\pi R}{v} \Rightarrow$$

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ASU

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3). $m = 1000\,kg$, $R = R_E + 340\,Km$,

Find V, T, a_{rad}: $\Sigma F = ma \Rightarrow F_g = m\frac{V^2}{R}$

F_g

$$\Rightarrow V^2 = \frac{RF_g}{m} \Rightarrow V^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

$$V = \sqrt{GM_E/R} = \left[\frac{(6.67 * 10^{-11})(5.97 * 10^{24})}{(6370 + 340) * 10^3}\right]^{1/2} \frac{m}{s}$$

$$= \left[\frac{(6.67)(5.97)}{6710}\right]^{1/2} * 10^{(24-11-3)/2} \frac{m}{s} = 0.077 * 10^5 \frac{m}{s}$$

$$= \boxed{7.7 * 10^3\, m/s} \qquad V = \frac{2\pi R}{T} \Rightarrow T = \frac{2\pi R}{V} \Rightarrow$$

$$T = \left(\frac{2 * 3.14 * 6710 * \cancel{10^3}}{7.7 * \cancel{10^3}}\right)\frac{m}{s} = \boxed{5470s} \qquad a_{rad} = \frac{V^2}{R}$$

ASU

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F_g

$$\Rightarrow v^2 = \frac{RF_g}{m} \Rightarrow v^2 = \left(\frac{\cancel{R}}{\cancel{m}}\right)\left(\frac{GM_E \cancel{m}}{R^{\cancel{2}}}\right) \Rightarrow$$

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$$a_{rad} = \frac{v^2}{R}$$

$$a_{rad} = \frac{v^2}{R} \Rightarrow$$

$$a_{rad} = \frac{V^2}{R} \Rightarrow \quad a_{rad} = \frac{[7.7 * 10^3]^2}{6710 * 10^3} \left(\frac{m}{s^2}\right)$$

$$a_{rad} = \frac{v^2}{R} \Rightarrow a_{rad} = \frac{[7.7*10^3]^2}{6710*10^3}\left(\frac{m}{s^2}\right)$$

$$\Rightarrow a_{rad} = \left(\frac{7.7^2}{6.71}\right)\frac{m}{s^2}$$

$$a_{rad} = \frac{v^2}{R} \Rightarrow a_{rad} = \frac{[7.7 * 10^3]^2}{6710 * 10^3}\left(\frac{m}{s^2}\right)$$

$$\Rightarrow a_{rad} = \left(\frac{7.7^2}{6.71}\right)\frac{m}{s^2}$$

$$\Rightarrow \boxed{a_{rad} = 8.84\,\frac{m}{s^2}}$$

ASU

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3).

$m = 1000\,kg$, $R = R_E + 340\,km$

$W = E_2 - E_1$

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$m = 1000\,kg$, $R = R_E + 340\,km$

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ASU

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$$W = E_2 - E_1 = (K_2 + V_2) - (\cancel{K_1}^{\,0} + V_1) = K_2 + V_2 - V_1$$

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$$K_2 = \frac{1}{2} m v_2^2, \quad V_2 = -\frac{G M_E m}{R}$$

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$m = 1000\,kg$, $R = R_E + 340\,km$

$$W = E_2 - E_1 = (K_2 + U_2) - (\cancel{K_1}^{\,0} + U_1) = K_2 + U_2 - U_1 \text{, where}$$

$$K_2 = \frac{1}{2} m v_2^2, \quad U_2 = -\frac{G M_E m}{R}, \quad U_1 = -\frac{G M_E m}{R_E}$$

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$F_g = m v_2^2 / R$

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$$K_2 = \frac{1}{2} m v_2^2, \quad V_2 = -\frac{G M_E m}{R}, \quad V_1 = -\frac{G M_E m}{R_E} \quad \text{But}$$

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$$K_2 = \frac{1}{2} m v_2^2, \quad V_2 = -\frac{G M_E m}{R}, \quad V_1 = -\frac{G M_E m}{R_E} \quad \text{But}$$

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$$W = E_2 - E_1 = (K_2 + V_2) - (\cancel{K_1}^{\,0} + V_1) = K_2 + V_2 - V_1 \text{, where}$$

$$K_2 = \frac{1}{2} m v_2^2 \text{, } V_2 = -\frac{G M_E m}{R} \text{, } V_1 = -\frac{G M_E m}{R_E} \quad \text{But}$$

$$F_g = m v_2^2 / R \Rightarrow m v_2^2 = R F_g = \frac{G M_E m}{R} \Rightarrow K_2 = \frac{G M_E m}{2R}$$

Now $W = K_2 + V_2 - V_1 =$

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$$K_2 = \frac{1}{2} m v_2^2, \quad V_2 = -\frac{G M_E m}{R}, \quad V_1 = -\frac{G M_E m}{R_E} \quad \text{But}$$

$$F_g = m v_2^2 / R \Rightarrow m v_2^2 = R F_g = \frac{G M_E m}{R} \Rightarrow K_2 = \frac{G M_E m}{2R}$$

$$\text{Now} \quad W = K_2 + V_2 - V_1 = (G M_E m)\left[\frac{1}{2R} + \left(-\frac{1}{R}\right) - \left(-\frac{1}{R_E}\right)\right]$$

$$\Rightarrow W = (G M_E m)\left[\frac{1}{R_E} - \frac{1}{2R}\right]$$

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$$\text{Now} \quad W = K_2 + V_2 - V_1 = (G M_E m)\left[\frac{1}{2R} + \left(-\frac{1}{R}\right) - \left(-\frac{1}{R_E}\right)\right]$$

$$\Rightarrow W = (G M_E m)\left[\frac{1}{R_E} - \frac{1}{2R}\right] = (g m R_E^2)\left(\frac{1}{R_E} - \frac{1}{2R}\right)$$

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$m = 1000\,\text{kg}$, $R = R_E + 340\,\text{km}$

$$W = E_2 - E_1 = (K_2 + V_2) - (\cancel{K_1}^{\,0} + V_1) = K_2 + V_2 - V_1 \text{, where}$$

$$K_2 = \frac{1}{2} m v_2^2 \text{, } V_2 = -\frac{G M_E m}{R} \text{, } V_1 = -\frac{G M_E m}{R_E} \quad \text{But}$$

$$F_g = m v_2^2 / R \Rightarrow m v_2^2 = R F_g = \frac{G M_E m}{R} \Rightarrow K_2 = \frac{G M_E m}{2R}$$

$$\text{Now} \quad W = K_2 + V_2 - V_1 = (G M_E m)\left[\frac{1}{2R} + \left(-\frac{1}{R}\right) - \left(-\frac{1}{R_E}\right)\right]$$

$$\Rightarrow W = (G M_E m)\left[\frac{1}{R_E} - \frac{1}{2R}\right] = (g m R_E^2)\left(\frac{1}{R_E} - \frac{1}{2R}\right)$$

$$\Rightarrow W = 9.8 * 1000 * 6340^2 * 10^6 \left(\frac{1}{6340} - \frac{1}{2*6370}\right)\frac{J}{10^3}$$

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$$\Rightarrow W = 9.8 * 1000 * 6340^2 * 10^6 \left(\frac{1}{6340} - \frac{1}{2 * 6370}\right) \frac{J}{10^3}$$

$$\Rightarrow W = 3.28 * 10^7 * 10^3\,J$$

You wish to put a 1000 kg satellite into a circular orbit 340 km above the earth's surface. (a) What speed, period, and radial acceleration will it have? (b) How much work must be done to the satellite to put it in orbit? (c) How much additional work would have to be done to make the satellite escape the earth? The earth's radius and mass are given in Example 13.5 (Section 13.3). $m = 1000\,kg$, $R = R_E + 340\,Km$

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$$\text{Now } W = K_2 + V_2 - V_1 = (GM_E m)\left[\frac{1}{2R} + \left(-\frac{1}{R}\right) - \left(-\frac{1}{R_E}\right)\right]$$

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$M = 1000\,kg$, $R = R_E + 340\,Km$

$W = E_3 - E_2$

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$M = 1000\,kg$, $R = R_E + 340\,km$

$$W = E_3 - E_2 = (\cancel{K_3} + \cancel{V_3}) - (K_2 + V_2) \text{ from}$$

previous $\quad K_2 = \frac{G M_E m}{2R}$

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$m = 1000\,\text{kg}, \quad R = R_E + 340\,\text{km}$

$$W = E_3 - E_2 = (\cancel{K_3} + \cancel{V_3}) - (K_2 + V_2)$$

from previous

$$K_2 = \frac{G M_E m}{2R} \quad \text{so} \quad W = -\frac{G M_E m}{2R} - \left(-\frac{G M_E m}{R}\right)$$

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$M = 1000\,\mathrm{kg}$, $R = R_E + 340\,\mathrm{km}$

$$W = E_3 - E_2 = (\cancelto{0}{K_3} + \cancelto{0}{V_3}) - (K_2 + V_2)$$

from previous $K_2 = \frac{GM_E m}{2R}$ so $W = -\frac{GM_E m}{2R} - \left(-\frac{GM_E m}{R}\right)$

$$\Rightarrow \quad K_2 = \left(\frac{GM_E m}{R}\right)\left(-\frac{1}{2} + 1\right)$$

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$0 \quad 0$

From previous $\Rightarrow$

$$K_2 = \frac{GM_E m}{2R} \quad \text{so} \quad W = -\frac{GM_E m}{2R} - \left(-\frac{GM_E m}{R}\right)$$

$$K_2 = \left(\frac{GM_E m}{R}\right)\left(-\frac{1}{2} + 1\right) = \frac{GM_E m}{2R}$$

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so $$W = -\frac{G M_E m}{2R} - \left(-\frac{G M_E m}{R}\right) = \frac{G M_E m}{2R} \Rightarrow$$

$$W = mg\frac{R_E^2}{2R}$$

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$$W = mg\frac{R_E^2}{2R} = \frac{1000 * 9.8 * 6370^2 * 10^6}{2 * 6710 * 10^3}\,J$$

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so $\quad W = -\frac{GM_E m}{2R} - \left(-\frac{GM_E m}{R}\right) = \frac{GM_E m}{2R} \Rightarrow$

$$W = mg\frac{R_E^2}{2R} = \frac{1000 * 9.8 * 6370^2 * 10^6}{2 * 6710 * 10^3}\,J = 2.96 * 10^{10}\,J$$