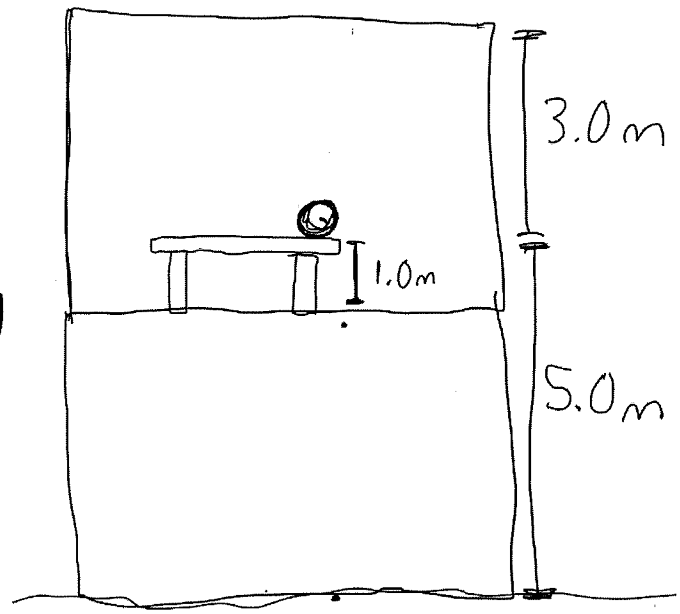
Gravitational Potential Energy:

$E_p = mgh$

A 2.0 kg ball is placed on a table which is on the second floor of a building as shown.



What is the gravitational energy of the ball with respect to:

a) the floor of the room it is in?

$E_p = mgh$

$= 2\,kg \times 9.8\,\frac{m}{s^2} \times 1\,m = 19.6\,J$

b) the ground?

$E_p = mgh$

$= 2 \times 9.8\,\frac{m}{s^2} \times 5\,m = 98\,J$

c)the roof?

$= 2 \times 9.8\,\frac{m}{s^2} \times (-3) = -58.8\,J$

Recall how we derived the potential energy formula. It is the Work needed to lift an object a certain height

Work = $Fd = F_g d = mgd$ or mgh

This works when the force is constant. If an object is lifted a long ways from Earth the force required to lift it the first 1000 m will be more than the force required to lift it the next 1000 m because the gravitational field strength decreases with distance. Since force is not constant, we will need to use a different formula.

Universal Gravitational Potential Energy

$$E_p = -\frac{G m_1 m_2}{r}$$

Where m_1 and m_2 are the masses

G is $6.674 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$

r is the distance between the centers of the masses

Why is it negative?

We set the point where potential energy is zero to be when the objects are infinitely far apart. This means the value we get will always be negative. This turns out to be a reasonable choice for many problems.

Example: A 2500 kg satellite is in orbit 3.6×10^7 m above the Earth's surface. What is the gravitational potential energy of the satellite due to the gravitational field of Earth? (Earth has radius 6.38×10^6 m and mass 5.98×10^{24} kg.)

$$E_p = \frac{-6.674\times10^{-11} \times 2500\,kg \times 5.98\times10^{24}}{(3.6\times10^7\,m + 6.38\times10^6\,m)} = -2.3\times10^{10}\ J$$

What is the gravitational potential energy of the satellite on the surface of Earth?

$$E_p = \frac{-6.674\times10^{-11} \times 2500 \times 5.98\times10^{24}}{6.38\times10^6} = -1.56\times10^{11}\ J$$

How much more potential energy does the satellite have when it is in orbit?

$$E_{pf} - E_{pi} = -2.3\times10^{10} - (-1.56\times10^{11})$$
$$= 1.33\times10^{11}\ J$$

If the satellite were pulled directly into Earth, with no friction, how fast would it be moving when it hit the surface of the planet?

$$E_k = 1.33\times10^{11}\ J$$

$$v = \sqrt{\frac{2E_k}{m}} = 10315\ m/s$$

Escape Velocity

If you throw an object up it will come back down, unless you throw it VERY hard.

Escape velocity is the velocity which an object must be moving such that it will never be pulled back by gravity.

As the object goes further from its launch site the gravitational pull will decrease but will never be fully eliminated so we must consider the velocity required to get the object infinitely far from its starting point.

This is the point we set as the zero for our universal potential energy.

Recall energy is conserved so:

$$\begin{aligned} E_K \text{ at start} &= \Delta E_p \text{ from start to end} \\ &= E_{pf} - E_{pi} \\ &= 0 - E_{pi} \end{aligned}$$

$$\frac{1}{2}\cancel{m}v^2 = +\frac{G\cancel{m_1}m_2}{r}$$

$$v = \sqrt{\frac{2GM}{r}}$$

escape velocity formula

Example: What is escape velocity on Earth? (m =5.98 × $10^{24}kg$, r= 6.36 × $10^{6}m$)

$$V = \sqrt{\frac{2 \times 6.674\times10^{-11} \times 5.98\times10^{24}}{6.36\times10^{6}}}$$

$$= \cancel{11288\,m/s}$$

$$11203\,m/s$$