AS Level Physics

Chapter 4 – Work, Energy and Power

4.2.1 Kinetic and Potential Energies

Notes

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KINETIC ENERGY

Kinetic energy is energy possessed by **anything moving**.

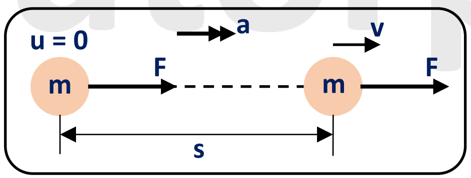
$$\boldsymbol{E_K = \frac{1}{2}mv^2}$$

Where:

- $E_K = Kinetic\ energy\ measured\ in\ \boldsymbol{joules\ (J)}$
- $m = mass\ measured\ in\ \boldsymbol{kg}$
- $v = velocity\ measured\ in\ \boldsymbol{ms^{-1}}$

Deriving Kinetic Energy:

An object with mass (m) is acted on by a constant force (F) which in turn gives the object a constant acceleration (a), and increases its velocity from rest to a final value (v) over a distance (s).



KE gained by the object is equal to the work done by the force, so

$$\boldsymbol{E_K = work\ done\ by\ force\ F}$$

$$E_K = force \times distance\ moved\ in\ the\ direction\ of\ the\ force$$

$$E_K = F \times s$$

But since F = ma:

$$E_K = mas$$

$$\boldsymbol{But\ v^2 = u^2 + 2as\ where\ u = 0}$$

$$\therefore\ as = \frac{1}{2}v^2$$

$$\boldsymbol{Thus{:}\ E_K = \frac{1}{2}mv^2}$$

KINETIC ENERGY

Worked Example 1:

A car of mass 950 kg is moving at $19\ ms^{-1}$. What is its KE?

$$Use{:}\ E_K = \frac{1}{2}mv^2$$

Its very easy to forget to square the velocity so always double check the calculation.

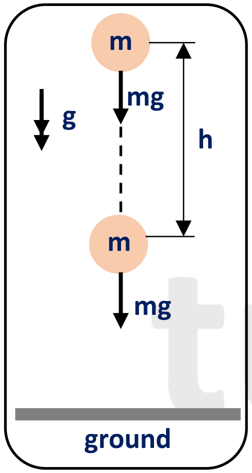
$$E_K = \frac{1}{2}(950\ kg)(19\ ms^{-1})^2$$

$$\boldsymbol{E_K = 171475\ J = 1.71 \times 10^5\ J\ (2\ d.p.)}$$

GRAVITATIONAL POTENTIAL ENERGY

Gravitation potential energy is when an object with weight, mg has to do work against gravity to be able to raise to a higher position above the ground.

Gravitational potential energy (E_P) is the energy an object gains when it is lifted.



$$\boldsymbol{E_P \text{ gained by the object} = \text{work done in lifting}}$$

$$E_P = force \times distance\ moved$$

$$E_P = objects\ weight \times height\ lifted$$

$$E_P = mg \times h$$

$$\boldsymbol{Therefore: E_P = mgh}$$

$$\boldsymbol{E_P = mgh}$$

Where:

- $E_P = Gravitational\ potential\ energy\ measured\ in\ \boldsymbol{J}$
- $m = mass\ measured\ in\ \boldsymbol{kg}$
- $g = gravitational\ field\ strength\ (\boldsymbol{9.81\ Nkg^{-1}})$
- $h = height\ object\ has\ been\ lifted\ measured\ in\ \boldsymbol{m}$

GRAVITATIONAL POTENTIAL ENERGY

Worked Example 1:

A crane lifts a 80 kg mass a height of 7 m. Calculate the GPE gained by the mass.

$$Use: E_P = mgh$$

$$E_P = (80\ kg)(9.81\ Nkg^{-1})(7\ m)$$

$$\boldsymbol{E_P = 5493.6\ J}$$

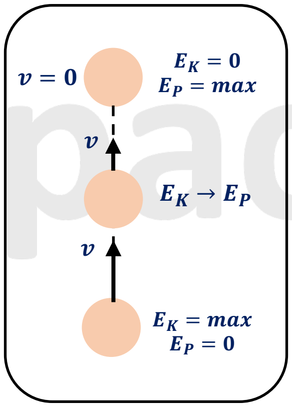
KE AND GPE EXCHANGE

In situations where an object is moving up and down, there is an interchange between kinetic energy (KE) and gravitational potential energy (GPE). If no energy is lost as heat and energy is conserved, we can assume that the change in KE is equal to the change in GPE.

In all the examples we assume that no energy is lost (e.g. as heat or sound) and air resistance is negligible.

Example 1: Ball thrown vertically upwards

- If you throw an object upwards, KE (E_K) is converted into GPE (E_P) as it rises and the ball slows down (decelerate).
- At the maximum height, all KE is converted into GPE and velocity (v) is zero.
- Then the ball travels back downwards, converting GPE into KE as it falls and the ball starts to speed up (accelerate).
- As the ball is coming down all the GPE is converted to KE and velocity (v) is at its maximum and GPE = 0.



Note: this example assumes air resistance to be zero.

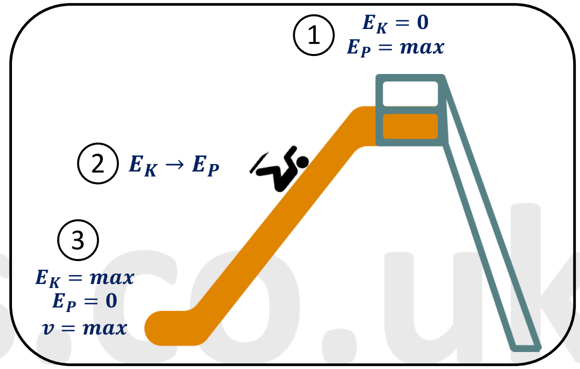
KE AND GPE EXCHANGE

Example 2: Slide

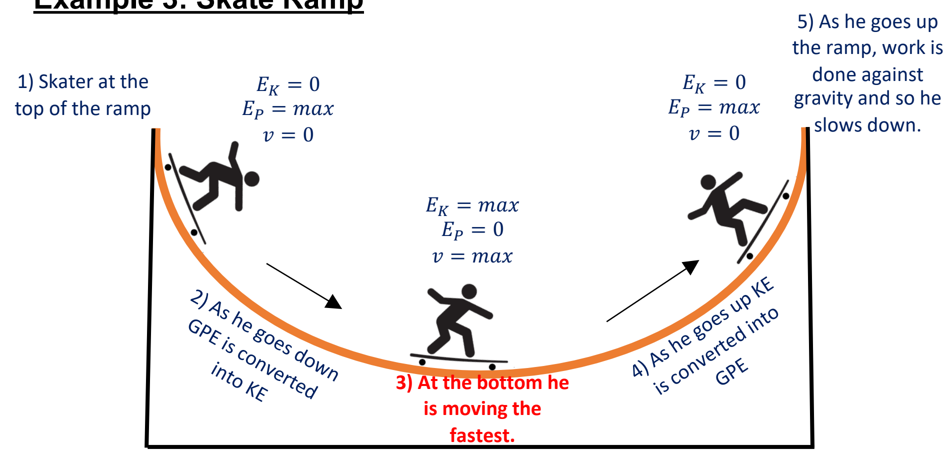
1) At the top of the slide GPE is at its maximum, KE is zero and velocity (v) is zero

2) As you go down the slide GPE is converted into KE.

3) At the bottom of the slide GPE is zero, KE is max and velocity (v) is at its maximum.

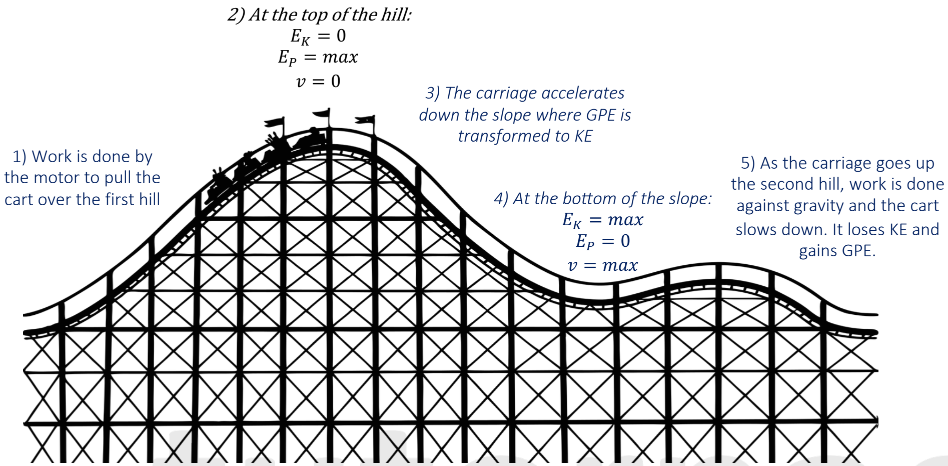


Example 3: Skate Ramp

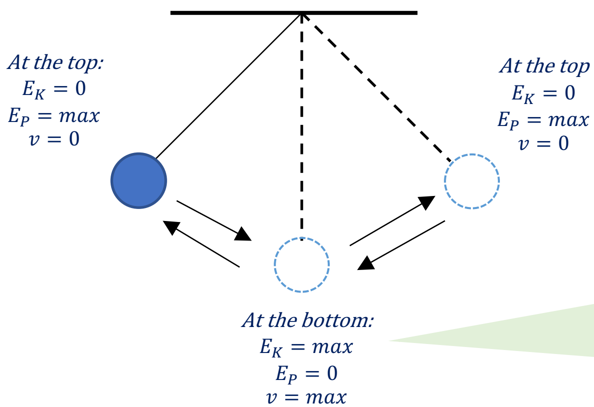


KE AND GPE EXCHANGE

Example 4: Roller Coaster



Example 5: Simple Pendulum



A simple pendulum has a continuous interchange of KE and GPE.
At the bottom of the pendulum the bob is the fastest.

KE AND GPE EXCHANGE

To summarise, when an object falls its GPE decreases and its KE increases. Assuming no energy is lost in process:

$$GPE\ Lost = KE\ Gained$$

Knowing this information we can solve a variety of problems, such as the velocity attained by an object when it falls from a given height.

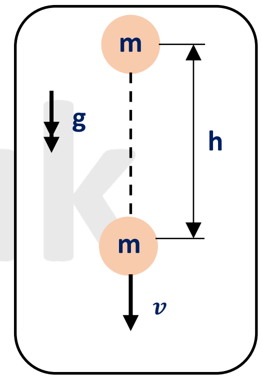
Consider an object of mass (m) which falls from a height (h) above the ground. We can calculate the velocity of this object as it falls by doing the below:

$$KE\ gained = GPE\ lost$$

$$\frac{1}{2}mv^2 = mgh$$

Cancel out the masses (m)

$$\textbf{Therefore:}\ v = \sqrt{(2gh)}$$



KE AND GPE EXCHANGE WORKED EXAMPLES

Example 1:

A ball falls from a height of 6 m. How fast is it moving when it reaches the ground?

1) The decrease in the ball's GPE as it falls is equal to its gain in KE.

$$GPE\ lost = KE\ gained$$

$$mgh = \frac{1}{2}mv^2$$

2) Cancel out the m from both sides:

$$gh = \frac{1}{2}v^2$$

3) Substitute values and solve for v:

$$9.81\ ms^{-2} \times 6\ m = 0.5\ v^2$$

$$v^2 = \frac{9.81 \times 6}{0.5}$$

$$v^2 = 117.72$$

$$\mathbf{v = 10.8\ ms^{-1}\ (1\ d.p.)}$$

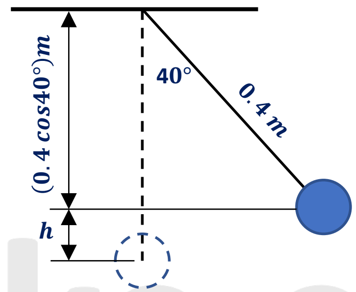
Note: mass (m) cancels out so we would get the same answer for any value of m, i.e. all balls of all masses would fall at the same rate (neglecting air resistance).

KE AND GPE EXCHANGE WORKED EXAMPLES

Example 2:

A simple pendulum has a mass of 600 g and a length of 40 cm. It is pulled out to an angle of 40° from the vertical.

(a) Find the GPE stored in the pendulum bob:



You can work out the increase in height, h, of the end of the pendulum using trig.

$$GPE = mgh$$

$$GPE = 0.6kg \times 9.81ms^{-2} \times (0.4 - 0.4cos40°)$$

$$\mathbf{GPE = 0.55\ J}$$

b) The pendulum is released. Find the maximum speed of the pendulum bob as it passes the vertical position:

To find the maximum speed, assume no air resistance.

The maximum speed of the pendulum is when the pendulum is at the centre of its swing. At that point the GPE lost is equal to the KE gained therefore:

$$mgh = \frac{1}{2}mv^2$$

$$0.55\ J = \frac{1}{2}(0.6\ kg)v^2$$

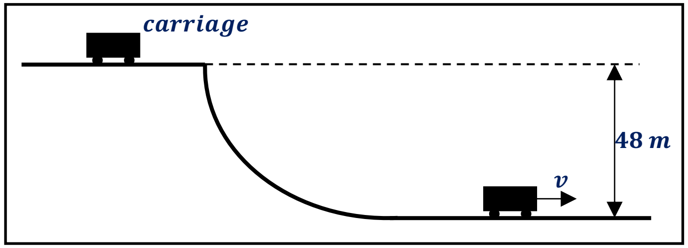
$$v = \sqrt{\frac{2 \times 0.55}{0.6}}$$

$$\mathbf{Max\ speed, v = 1.35\ ms^{-1}}$$

KE AND GPE EXCHANGE WORKED EXAMPLES

Example 3:

In a fairground ride, a 300 kg carriage runs downhill through a vertical distance of 48 m. The final KE of the carriage is 40% of the decrease in its GPE. Determine the final speed, v, of the carriage.



1) Calculate the GPE first:

$$GPE = mgh$$
$$GPE = 300\ kg \times 9.81\ ms^{-2} \times 48\ m$$
$$GPE = 141{,}264\ J$$

2) We know that at the bottom of the ramp all the GPE is converted into KE (GPE lost = KE gained) but there is going to be a 40% decrease. Therefore:

$$40\%\ decrease\ in\ KE = 141264 \times \frac{40}{100}$$
$$KE = 5.65 \times 10^4\ J$$

3) Now that we know the KE we can use it to calculate the velocity:

$$KE = \frac{1}{2}mv^2$$
$$5.65 \times 10^4 J = \frac{1}{2}(300\ kg)v^2$$
$$v = \sqrt{\frac{5.64 \times 10^4}{300}}$$
$$\mathbf{v = 19.4\ ms^{-1}}$$

KE AND GPE EXCHANGE WORKED EXAMPLES

Example 3: Alternative Method

1) We know:

$$KE\ Gained = GPE\ lost$$

2) Also the final KE of the carriage is 40% of the decrease in its GPE therefore:

$$KE = 40\%\ GPE$$
$$\frac{1}{2}mv^2 = (0.40)\ mgh$$
$$Cancel\ the\ m$$
$$\frac{1}{2}v^2 = (0.4)gh$$
$$v = \sqrt{(0.40)(2)(9.81)(48)}$$
$$\mathbf{v = 19.4\ ms^{-1}}$$

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Please see *'4.2.2 Kinetic and Potential Energies Worked Examples'* pack for exam style questions.

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