WORK, ENERGY AND POWER

WORK

Work is the product of the force applied and the distance moved by the point of application of the force in the direction of the force.

Work done (W) = Force (F) × Displacement (S)

W = FS

The S.I unit of work done is a **joule** (J).

Note that the distance moved has to be in the direction of the applied force. If the force or displacement is opposite, then work done is negative and we say work is done against the force e.g. the case of friction and gravity.

Work is a scalar quantity since it has magnitude only without direction.

Definition:

A joule is the work done by a force of 1 N when the point of application of the force moves through a distance of 1 m in the direction of the force.

Example: 1

1. Calculate the work done when a force of 9000N acts on a body and makes it move through a distance of 6m.

Solution

Force, F= 9000N

Distance, s = 6m

Work done = Force (F) × Displacement (S)

W= F×S

W= 9000×6 W= 54000J

Note:

If an object is raised vertically or falling freely, then the force causing work to be done is weight.

Force = Weight = mass (m) × acceleration due to gravity (g)

Force = Weight= mg

Thus, the work done against gravity is given by; **Work done = Weight × height = mgh**

Where m is mass in kg, h is distance in metres.

Example:2

A block of mass 3kg held at a height of 5m above the ground is allowed to fall freely to the ground. Calculate the workdone.

Solution

Given, mass, m = 3Kg, Distance, s = 5m Force F= Weight, W =mass × g F= mg = 3×10 F = 30N Work done = Force, F × Displacement, S **W= F×S** W= 30×5 W= 150J

Example: 3

A man of mass 80kg runs up a staircase of 10 stairs, each of vertical height 25cm. Find the work done against gravity.

Solution:

Given, mass m = 80 kg,

Distance (height covered) $= nh = 10 \times 25$cm $= 250$cm

= 2.5m

Then; Work done = Weight × height

Work done = mgh = 80×10×2.5

Work done = 2000J

Example: 4

A crane is used to raise 20 tonnes of concrete to the top floor of a building 30m high. Calculate the total work done by the crane.

Solution:

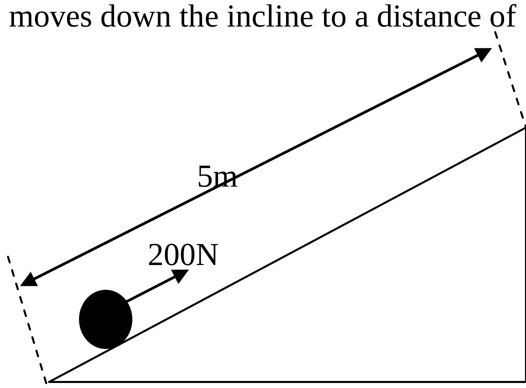
Given, mass m = 20tonnes=20×1000=20,000 kg, Distance, h= 30m

Then; Work done = Weight × height = mgh = 20,000×10×30

Work done = 6,000,000J

Example: 5

The figure below shows a bale of hay being pulled up an inclined plane with a force of 200N. The bale moves down the incline to a distance of 5m.



(i) Calculate the work done by the force.

Solution: Work done = Force (F) × Displacement (S) = 200N×(-5m) Work done = -1000J

(ii) Explain your answer.

The distance moved by the bale, was in a direction opposite to that of the force applied hence a negative displacement.

The negative in the answer therefore means that the bale did the work instead of the force applied.

ENERGY

Energy is the ability or capacity to do work. Energy is also a scalar quantity.

The S.I unit of energy is a joule (J).

Sources of energy:

The raw material for the production of energy is called the energy source.

There are two types of energy sources.

(a) Non-renewable sources of energy

These are energy sources, which cannot be replaced when they get used up.

Examples of non- renewable sources of energy

(i) Fossil fuels; these are formed from plant remains that died million years ago. They include; coal, petroleum oil, natural gas, e.t.c.

(ii) Nuclear fuels; these are fuels found in radioactive elements which may be occurring naturally such as Uranium.

These fuels can be used in nuclear reactions to produce electricity.

Advantages of non-renewable source of energy.

- They have high energy density. i.e a lot of energy can be produced from a small quantity.
- They are readily available as demand increases.

Disadvantages of non-renewable source of energy.
 They are highly polluting.

(b) Renewable sources of energy
These are energy sources which can be replaced when they get used up. They can never get exhausted.
Advantage:
They are non-polluting.
Examples of renewable sources of energy.
(i) Solar energy: This is the form of energy which reaches the earth in form of heat and light.

It can be harvested using solar panels and transformed into electrical energy, which is used for many purposes.
It is also used in direct low temperature heating.
(ii) Wind: Wind can be harvested using giant windmills, which can turn electrical generators to produce electrical energy, which is a more useful form.
(iii) Running water: Running water is used in hydro- electricity plants to turn giant turbines, which produce electrical energy.

The water will always flow hence a renewable source. Tides can also be used to generate electricity in this way.
(iv) Geothermal energy: Water is pumped to hot under ground rocks where it's heated and then forced out through another shaft where it can turbines.

Forms of energy
Energy can exist in the following forms;
a) Chemical energy:

Chemical energy is the form of energy a body has due to the nature of its atoms and molecules and the way they are arranged.
In the combination of atoms to form compounds, there is gain or loss of energy. This energy is stored in the compound as chemical energy.
If the atoms in such compounds are rearranged to form a new compound, this energy is released.
E.g If sugars in the human body are burnt, a lot of chemical energy is released.
b) Nuclear energy:

This is the energy released when atomic nuclei disintegrate during nuclear reactions.
In nuclear reactions, the energy, which holds the nuclear particles together (Binding energy), is released.
There are two types of nuclear reactions i.e. fission (Where large nuclei break to form smaller ones) and fusion (Where smaller nuclei combine to form larger ones). In both cases, large amounts of energy are released.
c) Electrical energy (Electricity):

This is the form of energy which is due to electric charges moving from one point of a conductor to another.
This form of energy is most easily converted to other forms, making it the most useful form.
d) Light energy:

This is the form of energy which enables us to see. Light is part of a wider spectrum of energy called the electromagnetic spectrum. Light consists of seven visible colours, of red, orange, yellow, green, blue, indigo and violet. We are able to see because the eye is sensitive to the colours.
e) Heat energy:

Heat is a form of energy, which results from random movement of the molecules in the body.
It is responsible for changes in temperature.
When a body is heated or when heat energy of the body increases;
(i) The internal kinetic energy of the molecules increases leading to a rise in temperature.
(ii) The internal potential energy of molecules increases leading to expansion and change of state of the body.

f) Sound energy:

This is the energy which enables us to hear.
Like light, sound is also a form of wave motion, which makes particles to vibrate. Our ears are able to detect sound because it produces vibrations in the ear.
g) Mechanical energy:

This is the energy of motion. **Mechanical energy = kinetic energy + Potential energy**
There are two forms of mechanical energy.

(i) Kinetic energy:- This is the energy possessed by a body due to its velocity or motion.

Kinetic energy (K.E) $= \frac{1}{2} m V^2$

Where m is the mass of the body and V is velocity of the body.
(ii) Potential energy:- This is the energy possessed by a body due to its position or condition.
It is equal to the work done in putting the body in that position or condition.
A body above the earth's surface has an amount of gravitational potential energy equal to the work done against gravity.
Weight is the force of gravity acting on a body.
Weight = mg.
Gravitational Potential energy (P.E)**=** (**mass**)×(**acceleration due to gravity**) ×(**Height above the ground**)
P.E = mgh
Conservation of Energy
The principle of conservation of energy:
It states that 'energy is neither created nor destroyed' but can be changed from one form to another.

In any system, the total original energy is equal to the total final energy. For example, electrical energy is changed to light energy in the bulb. However, the bulb also feels hot because some of the energy is changed to heat.
Therefore, light energy plus the heat energy is equal to the electrical energy supplied.
Thus from this principle, we conclude that;

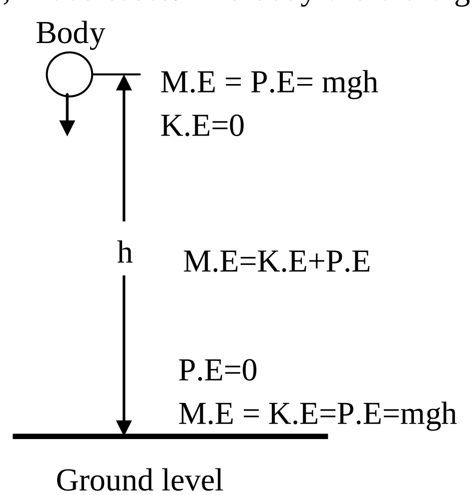
- No new energy is created
- Total existing energy is not destroyed
- Energy is only changed from one form to another.

As energy is changed from one form or state to another, an energy converter (Device) is required to ease the conversion. Examples of such devices are shown in the table below.

Energy Change	
Chemical to electrical	Cells or Batteries
Light to Electrical	Solar panels
Electrical to light	Electric lamps e.g bulbs
Electrical to heat	Cooker or flat iron, etc.
Heat to Electrical	Thermocouple
Electrical to sound	Loud speakers
Sound to Electrical	Microphones
Electrical to Kinetic	Electric motors
Kinetic to Electrical	Electric generators

Conservation of mechanical energy

A body of mass m at a height h above the ground, has a potential energy, P.E = mgh. At this point, the velocity of the body is $0ms^{-1}$ hence it has no kinetic energy. (K.E. = 0J).
When the body is released, it begins to fall with an acceleration g. The velocity of the body thus increases as the height, h decreases. The body therefore gains kinetic energy at the expense of potential energy.



When the body is just reaching the ground, the height, h is zero (h = 0m) while its velocity is given by;

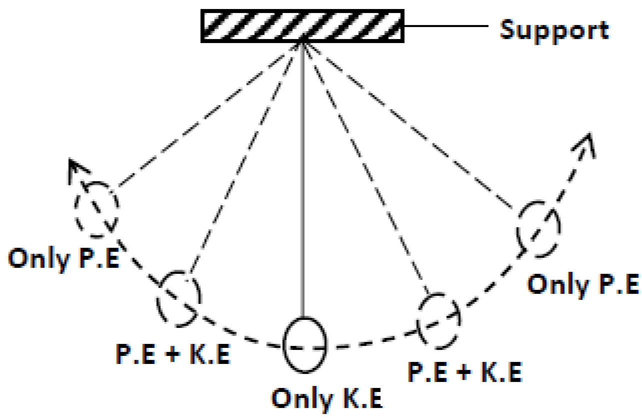
$$K.E = P.E = mgh$$

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

$$V^2 = 2gh \rightarrow V = \sqrt{2gh}$$

Therefore; **Gain in K.E=Loss in P.E**.

A swinging pendulum



Mechanical energy = P.E + K.E

The transformation of energy between kinetic and potential energy can be seen in a swinging pendulum.

At the end (extremes) of the swing, the energy of the pendulum bob is only potential.

As it passes the central position, it has only kinetic energy.

In other positions between the extreme ends and the central position, it has both potential and kinetic energies.

Example:

A ball of mass 200g falls freely from a height of 20m above the ground and hits a concrete floor and rebounds to a height of 5m. Given that g = $10ms^{-2}$, find the;

i) P.E of the ball before it fell.

ii) Its K.E. as it hits the concrete.

iii) Velocity with which it hits the concrete.

iv) K.E as it rebounds.

v) Velocity with which it rebounds.

vi) Velocity when it has fallen through a height of 15m.

Solution:

(i) P.E=mgh (h=height from which the ball is dropped) P.E=0.2×10×20

P.E=40J

(ii) As it hits the concrete, P.E is converted to K.E

$$K.E = P.E = mgh = 0.2 \times 10 \times 20 = 40J$$

iii) Velocity with which it hits the concrete.

$$K.E = P.E = mgh$$

$$\frac{1}{2}mV^2 = mgh \rightarrow V^2 = 2gh$$

$$\therefore V = \sqrt{2gh}$$

$$= \sqrt{2 \times 10 \times 20} = \sqrt{400} = 20 \text{ ms}^{-1}$$

Thus velocity of the ball as it hits the concrete is 20 ms^{-1}

(iv) As the bounces from the concrete, the K.E used to move the ball from the bottom to the height h1 is converted to P.E at h1and it is momentarily at rest. K.E1=12mv12= mgh1 (h1=height to which the ball bounces).

$$K.E_1 = P.E_1 = mgh_1 = 0.2 \times 10 \times 5 = 10 \text{ J}$$

v) Velocity with which it rebounds.

$$K.E_1 = P.E_1 = mgh_1$$

$$\frac{1}{2}mV_1^2 = mgh_1 \rightarrow V_1^2 = 2gh_1$$

$$\therefore V_1 = \sqrt{2gh_1} = \sqrt{2 \times 10 \times 5}$$

$$\therefore V_1 = \sqrt{2gh_1} = \sqrt{2 \times 10 \times 5} = \sqrt{100} = 10 \text{ ms}^{-1}$$

Ball rebounds with velocity of 10 ms^{-1}.

vi) Velocity when it has fallen through a height of 15m.

$V^2 = u^2 + 2as$ where u=0, a=g=10 ms^{-2} and s=h=15m

$$V^2 = u^2 + 2as$$

$$= 0^2 + 2 \times 10 \times 15$$

$$= 300$$

$$V = \sqrt{300}$$

$$V = \sqrt{300} = 17.32 \text{ ms}^{-1}.$$

Exercise

1.Calculate the kinetic energy of a 2kg mass trolley traveling at 400m per second.

2. A 5kg mass falls from a height of 20m. Calculate the potential energy lost.

3. A 200g ball falls from a height of 50m. Calculate its kinetic energy just before hitting the ground and the velocity with which it hits the ground.

4. A block of mass 2 kg falls freely from rest through a distance of 3m.

i) Find the K.E of the block. (Ans: =60J)

ii) Potential energy (Ans: =60J)

iii) The velocity with which the block hits the ground. (K.E gained = P.E lost).

5. A body falls freely through 3m. Calculate the velocity with which it hits the ground. (Ans: = 7.75ms^{-1})

6. A 100g steel ball falls from a height of 1.9m on a plate and rebounds to a height of 1.25m. Find the;

(i) P.E of the ball before the fall. (Ans: =1.8J)

(ii) Its K.E. as it hits the plate. (Ans: =1.8J)

(iii) Its velocity on the plate. (Ans: =6ms^{-1})
(iv) Its K.E as it leaves the plate on rebound. (Ans: =1.25J)
(v) Its velocity of rebound. (Ans: =5ms^{-1})

POWER

Power is the rate of doing work. Or
Power is the rate of transfer of energy.

Note: Work done is the same as energy transferred. **Power**=**Work done**/**Time taken**= Energy transferred/Time taken

Where work done=Force × Distance

Power $=\frac{F\times d}{t}=F\times\frac{d}{t}=F\times V$=FV

Where V is the velocity of the body.

Also **Power** $=\frac{mgh}{t}$

Where mg is the weight of the body and h the height.

The S.I unit of power is **watt** (W). **1watt=1Js^{-1}**

Definition:

A watt is the rate of transfer of energy of one joule per second.
Or It is the rate of doing work of 1joule per second.

Example/Exercise:

1.An engine raises 20kg of water through a height of 50m in 10 seconds. Calculate the power of the engine.

Solution: Power $=\frac{mgh}{t}=\frac{20\times10\times50}{10}=1000$ W

2.A girl of mass 40kg runs up a stair case in 16 seconds. If each stair case is 20 cm high and she uses 100 Js^{-1} . Find the number of stairs. [Ans: 20]

3.A man of mass 80kg runs up a stair case in 100 seconds. If each stair case is 20 cm high and there are 50 stairs, find the power developed.

Check the following in the question bank of ORDINARY physics

1994 Qn. 17
1989 Qn. 29
2007 Qn.33
1987 Qn.3 and Qn.24
1993 Qn.4 and 18
1997 Qn.10
1999 Qn.2 and Qn.8
2000 Qn.23
2001 Qn.26

2006 Qn.7
1997 Qn.5
1995 Qn.9
1991 Qn.11
1992 Qn.11
2003 Qn.15
2007 Qn.6
1993 Qn.4
2005 Qn.45

END

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