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Living Science
Physics

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- ✓ Assertion-Reasoning
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CBSE
Living Science
Physics

Class 9

Chapter- 5 Work and Energy

LEARNING OBJECTIVES

Concept of Work

- ❖Essential conditions for work to be done
- ❖Factors on which the amount of work done depends
- ❖Unit of work
- ❖Work done by the force of gravity
- ❖Measurement of work done

Energy

- ❖ Different forms of energy
- ❖Kinetic energy
- ❖Potential energy

Transformation of Energy

Law of Conservation of Energy

Power

Why no work is said to be done in the following cases ?

1. A man trying to push a wall
2. A man holding a bucket of water
3. A porter carrying a heavy load
4. Reading books, drawing diagrams, watching TV, etc.

It is because work is said to be done only when a force acting on a body produces motion in it in the direction of the force applied.

Essential Conditions for Work to be Done

Two conditions need to be satisfied for work to be done:

1. A force should act on an object.

2. The object must be displaced in the direction of the force.

If any one of the above conditions is not met, work is not done. This is the concept of work in physics**.** So work is said to be done only when a force acting on a body produces motion in it in the direction of the force applied.

Factors on which the amount of work done depends

The amount of work done depends upon the following two factors:

1. Magnitude of the force applied: Work done by a force is directly proportional to its (force) magnitude, i.e. more the force applied, more is the work done provided the body is displaced.

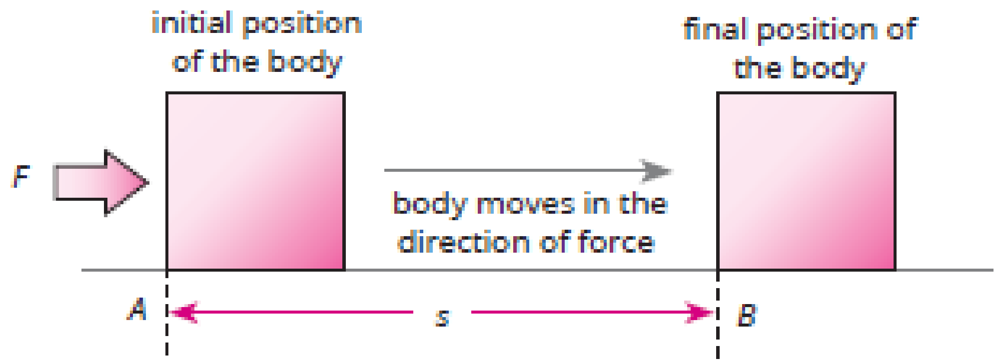
Work done ∝ Force applied (provided the body is displaced)

$$W \propto F$$

2. Displacement of the body: Work done by a force on a body is directly proportional to the displacement of the body in the direction of force applied.

Work done ∝ Displacement of the body in the direction of the force applied.

Measurement of work done by a constant force when the body moves in the direction of the applied force



When a force *F* acting on a body produces displacement *s* in it in the direction of the force, the work done *W* by this force is the product of the force and the displacement, i.e.

Work done = Force × Displacement (in the direction of force)

$$W = F \times s$$

T**he unit of work is newton metre (written as N m)**. The **SI unit of work is joule** which is denoted by the letter J.

Work done by the force of gravity

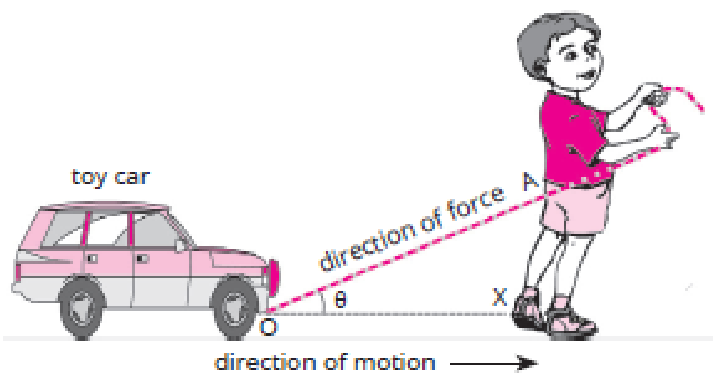
Suppose a body of mass *m* is lifted vertically upwards through a distance *h*. In this case, the force required to lift the body will be equal to the weight of the body, i.e. $m \times g$.

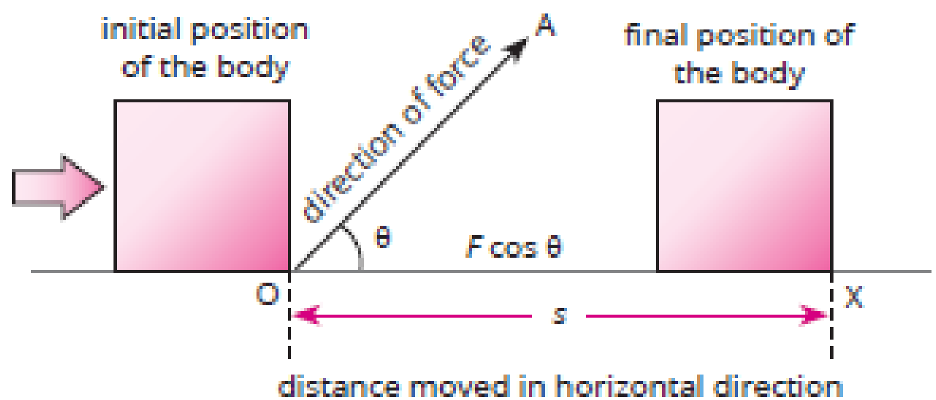
Now, work done in lifting a body = Weight of the body × Vertical distance moved

$$W = m \times g \times h$$

Measurement of work done by a constant force when the body moves at an angle to the direction of force

When a child pulls a toy car, the toy car moves on the horizontal ground OX but the force applied is along the string OA, at an angle θ to the direction of motion.





The horizontal component of force is the effective force which is pulling the body along the ground whereas the vertical component of the force balances the weight of the body.

Thus, work done is $W = F \cos\theta \times s$

where W = Work done, F = Force applied, θ = Angle between the direction of force and direction of motion and s = Displacement

Nature of Work Done

1. Positive work [When θ is acute ($\theta < 90^\circ$)]

As $W = F s \cos\theta$

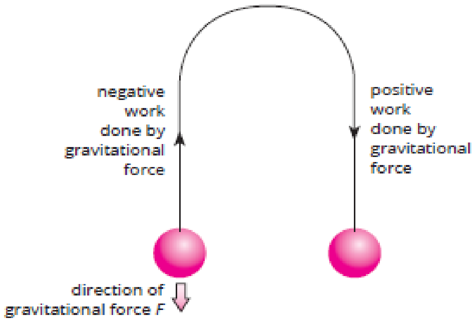
When the angle between the direction of force and direction of displacement is acute ($\theta < 90^\circ$), then **cos θ is positive** (i.e. the value of cos θ for θ less than 90° is positive). Hence, work done is positive. So, **work done when body moves in the direction of the applied force is positive.**

a. When a lawnmower is pushed by applying a force along the handle at an acute angle, work done by the applied force is positive.

b. When a body falls freely under the action of gravity, $\theta = 0^\circ$, so $\cos\theta = \cos 0^\circ = +1$. Therefore, work done by gravity on a body falling freely is positive.

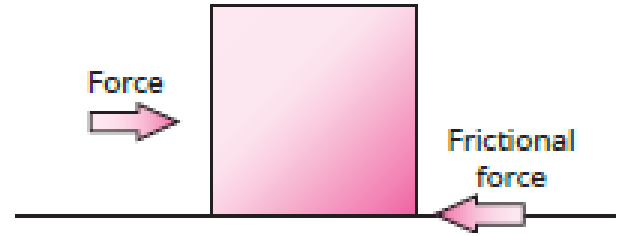
c. When a spring is stretched, work done by the stretching force is positive.

2. Negative work [When θ is obtuse ($\theta > 90^\circ$)] As $W = F s \cos\theta$ When the angle between the direction of force and the direction of displacement is obtuse ($\theta > 90^\circ$), then **cos θ is negative** (i.e. value of cos θ for θ more than 90° is negative). Hence, work done is negative.



a. When a stone is thrown up, its motion is opposed by gravity. The angle θ between gravitational force *F* and the displacement *s* is 180° . As cos θ = cos 180° = –1, work done by the gravity on a body moving upwards is negative.

b. When a body is moved over a rough horizontal surface, its motion is opposed by the force of friction. Hence, work done by the frictional force is negative .



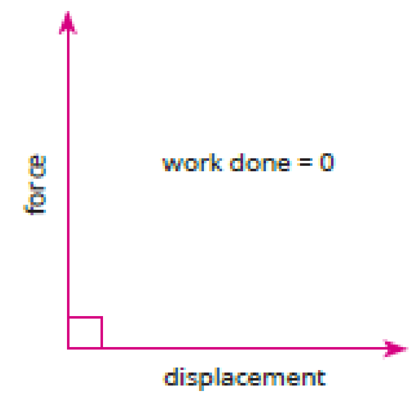
c. When brakes are applied on a moving vehicle, work done by the braking force is negative.

3. Zero work [When θ is a right angle]

As $W = F s \cos\theta$

when the angle between the direction of force and direction of displacement is 90° , then cos θ = cos 90° = 0.

Hence, work done is zero

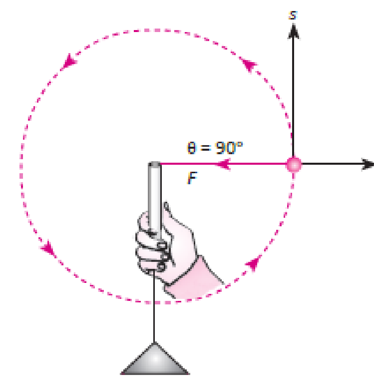


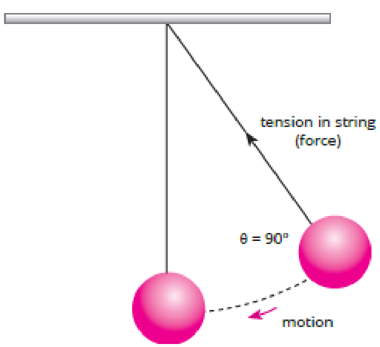
So, when force is perpendicular to displacement, work done is zero.

a. When a porter carrying some load on his head moves on a horizontal platform, then in order to balance the load on his head, he applies a force on the load in the upward direction, equal to its weight. His displacement is along the horizontal direction. Thus, the angle between force *F* and the direction of displacement is 90°.

Therefore, work done $W = F\,s \cos\theta = F\,s \cos 90^\circ = 0$ ($\cos 90^\circ = 0$)
Therefore, work done by the porter is zero. Similarly, when a person carrying a briefcase moves on a horizontal road, work done by him is zero.

b. When a body tied to one end of a string is rotated in a circle, work done by the centripetal force applied along the string is zero. This is because at every instant, force is perpendicular to the displacement, i.e. $\theta = 90^\circ$ and $W = F\,s \cos 90^\circ = 0$. Similarly, no work is done when a satellite revolves in a circular orbit around a planet.

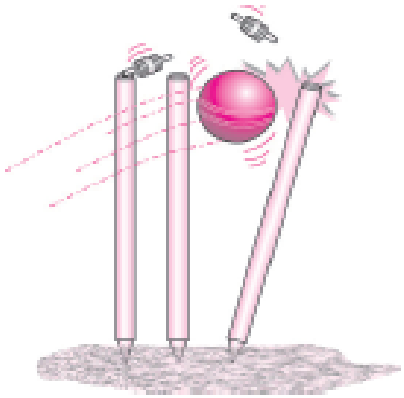




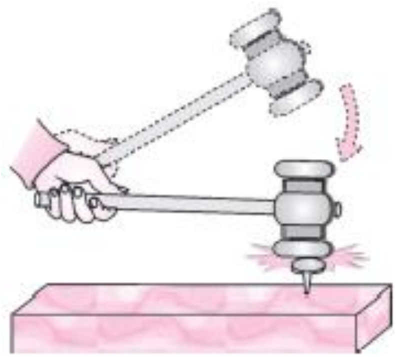
c. Tension in the string of a simple pendulum is always perpendicular to the displacement of the body. Therefore, work done by tension is always zero. Hence, the work done is zero if either displacement is zero, or force and displacement are perpendicular to each other.

Energy

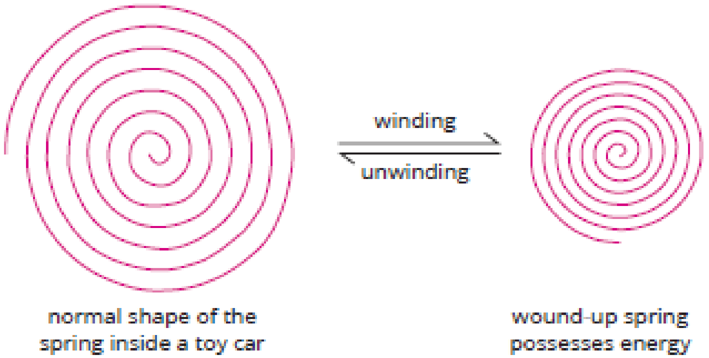
Energy of a body is defined as the capacity or ability of the body to do work. Also, the amount of energy possessed by a body is equal to the amount of work it can do when its energy is released.



A moving cricket ball possesses energy to blow the stumps away.



A moving hammer possesses energy to drive the nail into the wood.



Winding and unwinding of a spring

Unit of energy

The energy possessed by an object is measured in terms of capability or ability of an object to do work. The unit of energy is, therefore, the same as that of work, i.e. joule (J). So, the SI unit of energy is joule (J). 1 J is the energy required or consumed to do 1 joule of work.

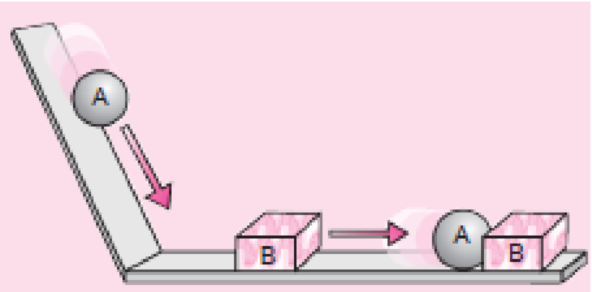
1 kilojoule = 1000 joules

Different Forms of Energy

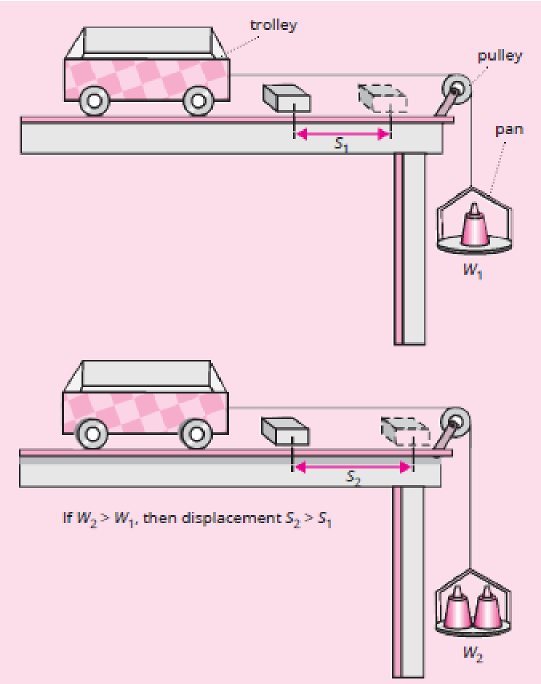
1. Chemical energy 2. Sound energy 3. Light energy 4. Heat energy
5.Electrical energy 6.Nuclear energy 7.Magnetic energy
8. Mechanical energy: It is of two types: a. Kinetic energy b. Potential energy

Kinetic Energy

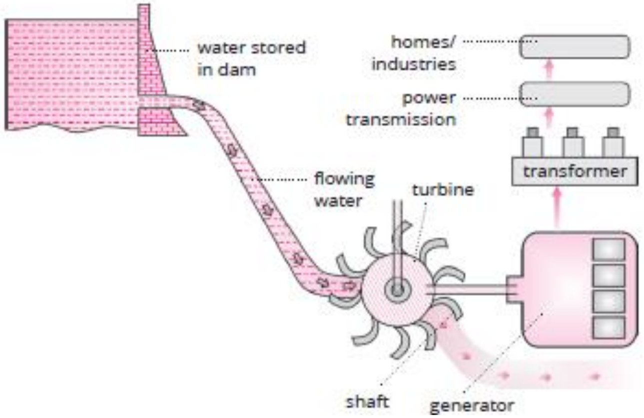
The energy possessed by a body by virtue of its motion is called kinetic energy. Thus, an object in motion has the ability to do work and hence possesses kinetic energy.



A moving steel ball displaces a wooden block.

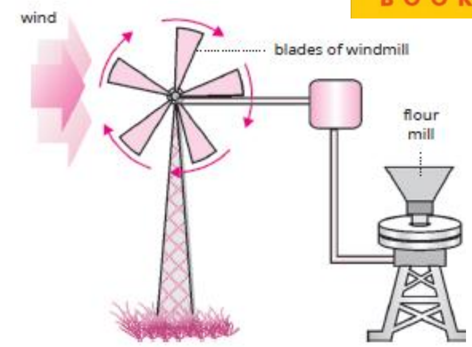


A fast moving object possesses more energy and can do more work.



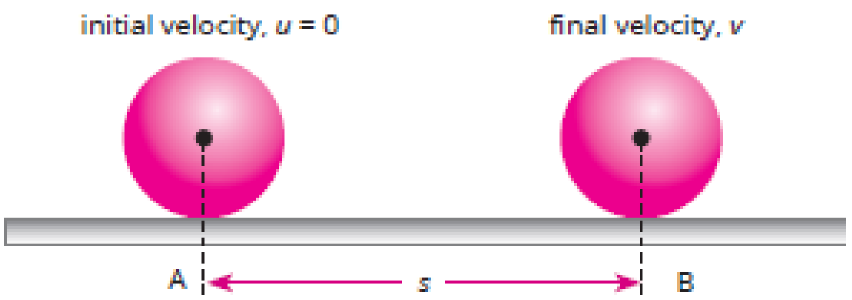
Energy of flowing water is used in generating hydroelectricity.

- A windmill works on the kinetic energy of moving air.
- A bullet fired from a gun possesses kinetic energy and can pierce a target.



Derivation of the formula for kinetic energy

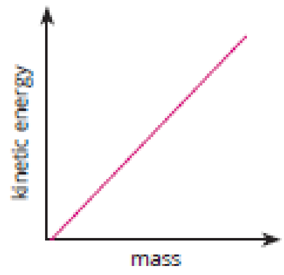
Energy spent in doing this work of moving the body from rest to attain a velocity *v* is stored in the body as its kinetic energy, or Work = Kinetic energy gained by the body.



Therefore, the kinetic energy of the body = $1/2\ mv^2$

The kinetic energy of a moving body is directly proportional to the mass of the body and to the square of velocity of the body.

Some important conclusions from the equation K.E. = $1/2\ mv^2$

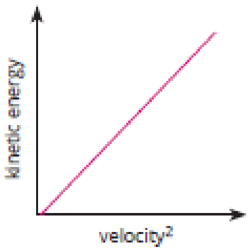


1. The kinetic energy of a moving body is directly proportional to its mass when the velocity of the body is kept constant, i.e. K.E. $\propto m$

a. If the velocity of the moving body is doubled (*m* remaining constant), the kinetic energy of the body increases by four times.

b. If the velocity of the moving body is halved (*m* remaining constant), the kinetic energy becomes one-fourth (of the original value).

2. The kinetic energy of a body is directly proportional to the square of its velocity when the mass of the body is kept constant, i.e. $\text{K.E.} \propto v2$



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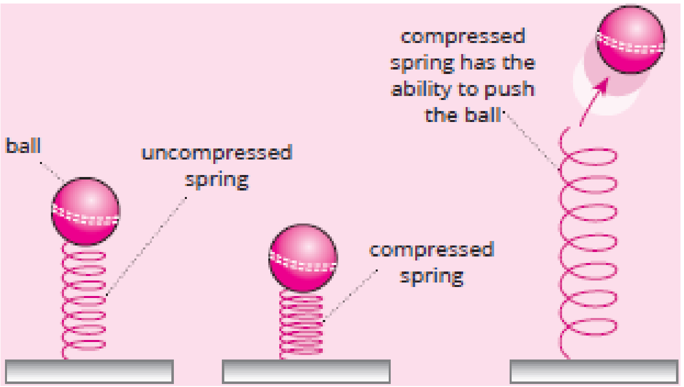
Potential Energy

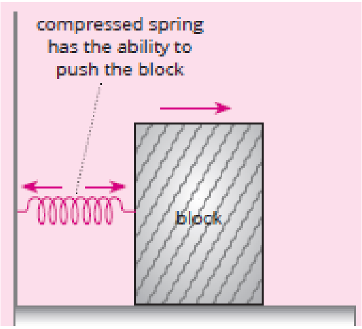
An object can have energy not only by virtue of its motion, but also by virtue of its raised position or change in configuration. This energy is called its potential energy.

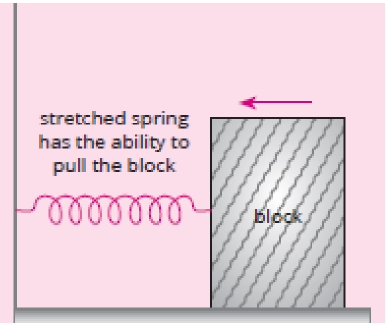
When the compressed spring is released, it does the work of pushing the ball. The compressed spring has the ability to do work.



Work done by a compressed spring

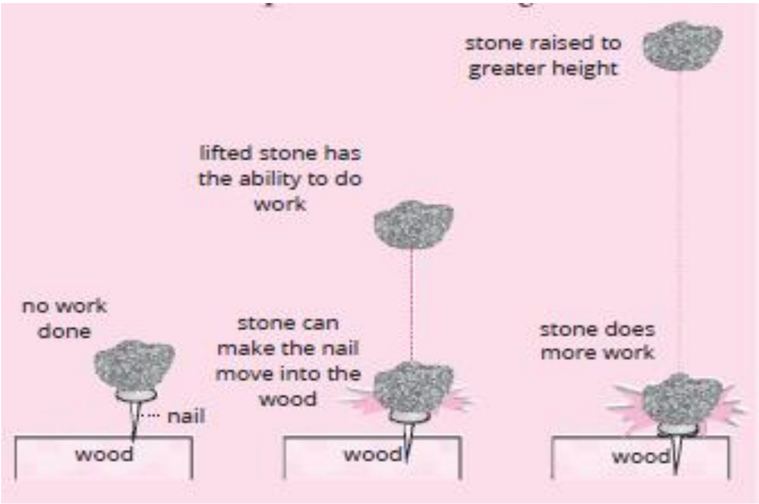
The stretched/ compressed spring has energy in it because of its configuration. This energy gets stored in the spring due to the work done on stretching or compressing it.





The energy transferred to the stretched or the compressed spring is stored as potential energy. This form of potential energy is the **elastic potential energy** and it is equal to the amount of work done in compressing or stretching the spring against its elasticity.

Potential energy stored in a stone raised to a height



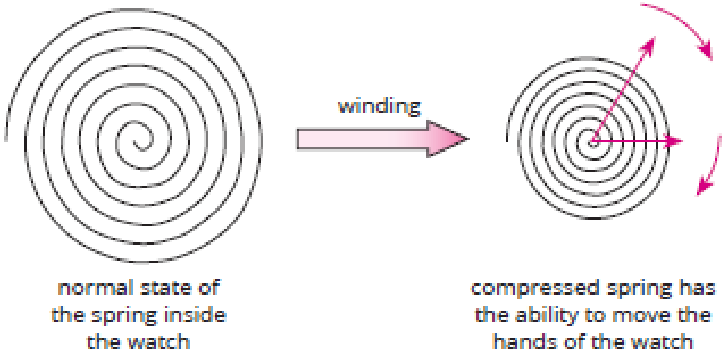
The stone placed at a height has energy in it because of its position at that height. The stone has potential energy. This form of potential energy is called **gravitational potential energy** and it is equal to the amount of work done in lifting the stone to that height against the force due to gravity.

The stone raised to a greater height can do more work and hence possesses greater gravitational potential energy. So potential energy of a body is defined as the energy possessed by the body by virtue of its position or configuration (change in shape or size).

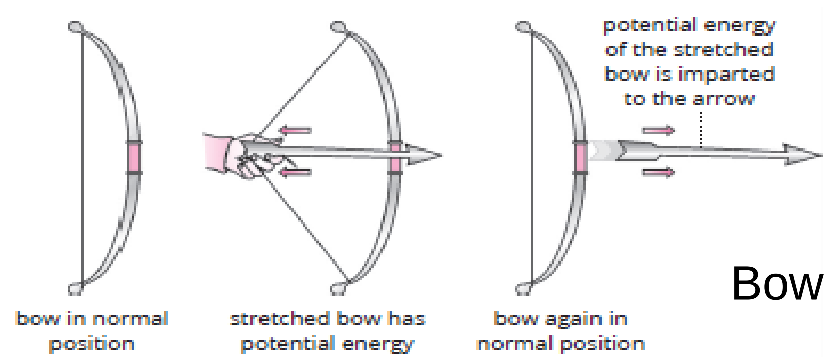
Examples of Potential Energy

1. The water stored at a height in a dam has **gravitational potential energy** stored in it. If it is allowed to fall, the falling water can do work by turning a turbine to generate electricity.

2. When we wind the spring of our watch, some work is done on the spring and it gets coiled more tightly. This work gets stored up in the compressed spring in the form of **elastic potential energy** (change in shape of the body due to compression). As the spring unwinds, it works to move the hands of the watch.



(Watch spring)



Bow and arrow

Examples of elastic potential energy

Types of Potential energy

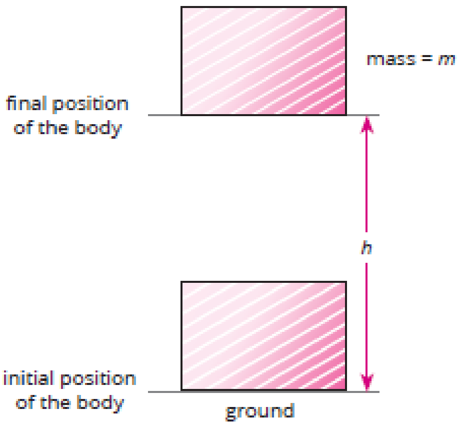
Gravitational potential energy: The gravitational potential energy of an object at a point above the ground is defined as the work done in raising it from the ground to that point against gravity.

Elastic potential energy: Elastic potential energy of a body is the energy possessed by the body by virtue of its configuration.

Derivation of formula for gravitational potential energy

Suppose a body of mass m is raised to a height h above the surface of the ground. The force applied just to overcome the gravitational attraction is

$F = m \times g$ where g = acceleration due to gravity



As distance moved is in the direction of force applied, work is said to be done. The object gains energy equal to the work done on it. Let the work done on the object against gravity be W, so Work done = Force $\times$ Displacement

$$W = F \times h$$

So we get $W = m \times g \times h$

Thus, Work done on the object against gravity = Gravitational potential energy

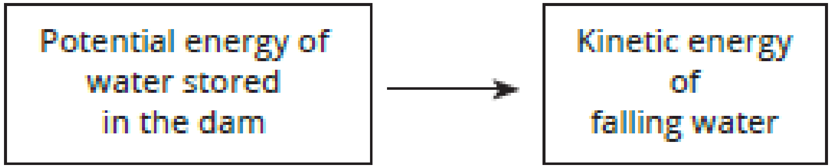
Gravitational potential energy (P.E.) = $m \times g \times h$

Some important conclusions from the formula P.E. = *mgh*

1. The potential energy of a body is directly proportional to the mass m of the body when acceleration due to gravity g and height h are kept constant, i.e. P.E. $\propto m$
2. The potential energy of a body is directly proportional to the height h to which it is raised when mass m and acceleration due to gravity g remain constant.
3. The potential energy of a body is directly proportional to acceleration due to gravity g when mass m and height h remain constant .

Transformation of Energy

In hydroelectric power plants, water is stored at a certain height in large reservoirs and it possesses potential energy. The stored water is made to fall, converting its potential energy into the kinetic energy of falling water.



The flowing water is made to turn a turbine. Thus, the kinetic energy of falling water is transferred to the turbine and reappears in the form of kinetic energy of blades of the turbine (as these blades rotate when water falls on them).

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Kinetic energy of falling water → Kinetic energy of blades of turbine

This kinetic energy gained by the turbine drives an electric generator generating electrical energy.

Kinetic energy of blades of the turbine → Electrical energy produced by electric generator

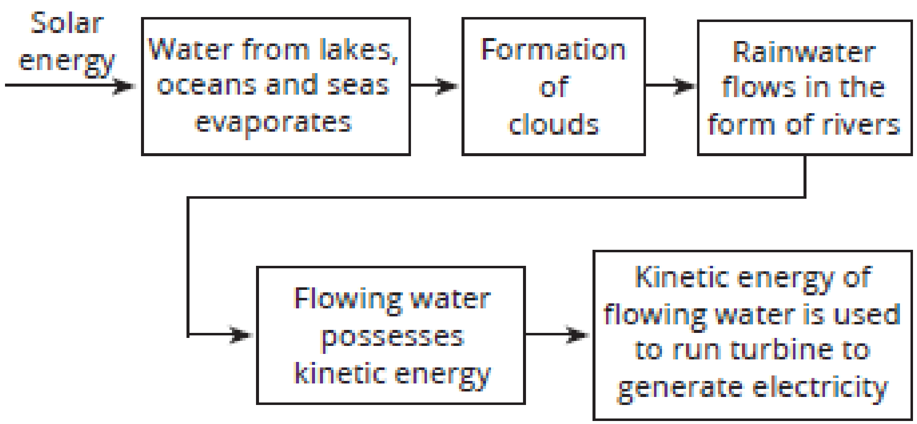
Energy can be changed from one form to another. Every time it is used, it is converted. The change of one form of energy into another is known as the transformation of energy.

Conversion of energy of food in nature

Plants absorb solar energy and carry out the process of photosynthesis → Chemical energy of the food → Muscular energy stored in humans and animals → Mechanical work done by humans and animals

Energy of flowing water

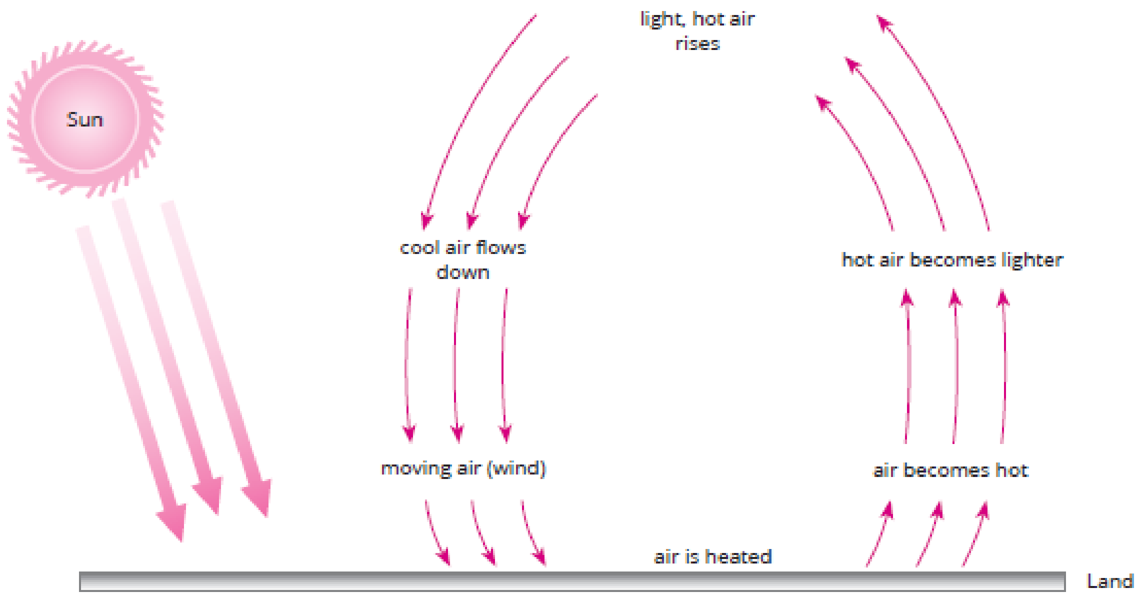
The sun's heat energy causes water from lakes, rivers and oceans to evaporate. The water vapour rises in the air to form clouds. On cooling, clouds give rain. Rainwater falling on mountains, hills and other high places flows down in the form of rivers. This flowing water has kinetic energy, which can be used to turn turbines in dams to generate electricity.



Energy of wind

The heat energy of the sun heats the air near the surface of the earth. The hot air spreads and becomes lighter. The light, hot air rises up creating a vacuum below. At the same time, cooler air flows in to take its place. The cooler air flowing in from the sides is the wind . This **wind possesses kinetic energy** and can turn the windmills.

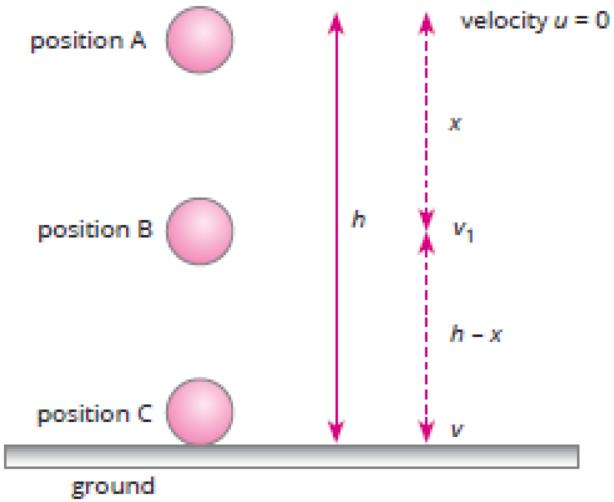
Thus, the sun rays cause uneven heating of land and produce different temperatures and pressures at different places. This causes the air to move from one place to another place.



Conservation of Energy

According to the law of conservation of energy, energy can neither be created nor destroyed. It can only be converted from one form to another. The total energy before and after transformation remains the same. The law of conservation of energy holds universally, i.e. it is valid in all situations and for all kinds of transformations.

Verification of law of conservation of energy



Let m be the mass of a body held at a position A and height h above the ground.

At position A

Kinetic energy of the body (K.E.) = 0

(Since the body is at rest at A)

Potential energy of the body (P.E.) = mgh

(Since the body is held at a height h)

∴ Total mechanical energy at A (E_1) = K.E. + P.E.

= 0 + mgh = mgh

∴ $E_1 = mgh$

Let the body be allowed to fall freely under the action of gravity. In the free fall, let the body reach position B with a velocity v_1, where AB = x.

At position B

From the equation of motion,

$v^2 - u^2 = 2as$

$v_1^2 - 0 = 2gx$

$v_1^2 = 2gx$ … (1)

Kinetic energy of the body (K.E.) = 1/2 mv^2_1 … (2)

Substituting the value of v_1^2 from Eq. (1) in Eq. (2), we get

$$\text{K.E.} = 1/2\, m(2gx) = mgx$$

Height of the body at B above the ground

$$= \text{CB} = (h - x)$$

∴ Potential energy of the body at B

$$\text{P.E.} = mg(h - x)$$

Total mechanical energy at B (E_2) = K.E. + P.E.

$$= mgx + mg(h - x)$$

$$= mgx + mgh - mgx = mgh$$

Let the body be allowed to fall freely under gravity, when it strikes the ground at C with a velocity v.

At position C

Using $v^2 - u^2 = 2as$

We get $v^2 - 0 = 2gh$ ∴ $v^2 = 2gh$ … (3)

Kinetic energy of the body (K.E.) = $1/2\, mv^2$ … (4)

Substituting the value of v^2 from Eq. (3) in Eq. (4), we get

K.E. = $1/2\, m(2gh) = mgh$

Potential energy of the body at C (P.E.) = $mgh = mg\,(0)$

(Since the body is on the ground, so $h = 0$)

Total mechanical energy (E_3) = K.E. + P.E.

$= mgh + 0 = mgh$

$\therefore \quad E_3 = mgh$

Thus, we find that $E_1 = E_2 = E_3 = mgh$

Thus, the total mechanical energy (i.e. the sum of kinetic energy and potential energy) always remains constant at each point of motion of a body falling freely under gravity and is equal to *mgh* (initial potential energy at height *h*). As the body falls, its potential energy decreases and kinetic energy increases. The potential energy changes into kinetic energy.

At A, the energy of the body is entirely potential energy and at C, it is entirely kinetic energy. At B, the energy is partly kinetic and partly potential. Total mechanical energy stays constant (i.e. *mgh*) throughout. This proves the law of conservation of mechanical energy.

Power

The rate of doing work by a body (man or machine) is called **power**. Thus, power of a body is also defined as the rate at which the body can do the work,

i.e. Power = Work done / Time taken

or $P = W/t$

Power in terms of energy

We know, energy is the ability of a body to do work. Power is the rate of doing work. Hence,

Work done = Energy supplied (transferred)

So, **the rate of energy supplied by a body is called its power,** i.e.

Power = Energy supplied /Time taken = $E/t = (F \times s) / t$

$$= F \times (s/t) = F \times v$$

where v is the velocity of the body.

Average Power

Average power is defined as the average amount of work done by a body per unit time, i.e.

Average power = Average amount of work/ done Time taken

In terms of energy,

Average power = Average amount of energy supplied /Time taken

Average Power

The SI unit of power is 'joule per second' or J/s. This unit is called watt (W).

Summary

1. Work: Work is said to be done when force acting on a body produces motion in the direction of force applied.

2. Positive work: When the body moves in the direction of force applied, work done is said to be positive.

3. Energy: Energy of a body is defined as the capacity or ability of the body to do work.

4. Kinetic energy: The energy possessed by a body by virtue of its motion is called kinetic energy.

5. Potential energy: The energy possessed by virtue of its position or configuration (change in shape or size) is called potential energy.

6. Law of conservation of energy: Energy can neither be created nor be destroyed. It can only be converted from one form to another. The total energy before and after the transformation remains the same.

7. Power: The rate of doing work is called power.