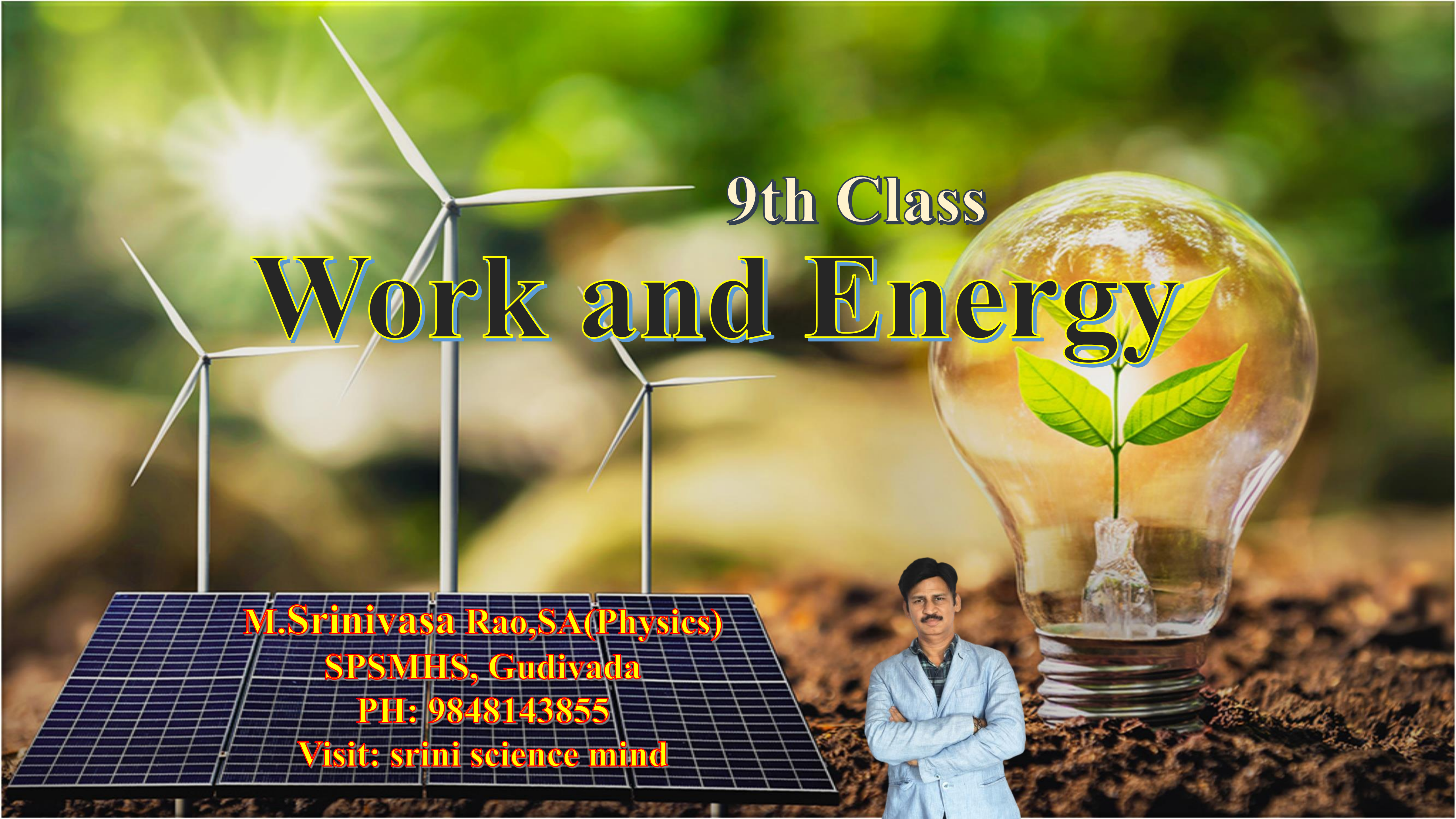

9th Class

Work and Energy

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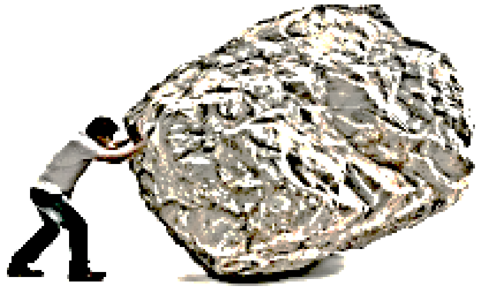
WORK

NOT MUCH 'WORK' IN SPITE OF WORKING HARD!

In science, **work is done** only when **a force causes displacement.** Other activities do not involve work. E.g.,

- Studying, reading, drawing and doing experiments expend energy, but little 'work' is done.
- Pushing a rock without moving it involves no work.
- Standing still with a load on the head involves no work.



Climbing stairs or a tree involves work as there is **displacement** in the direction of the applied force.

WORK

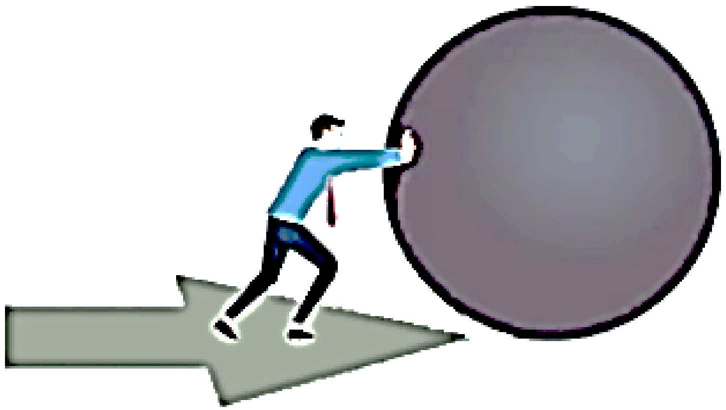
SCIENTIFIC CONCEPTION OF WORK

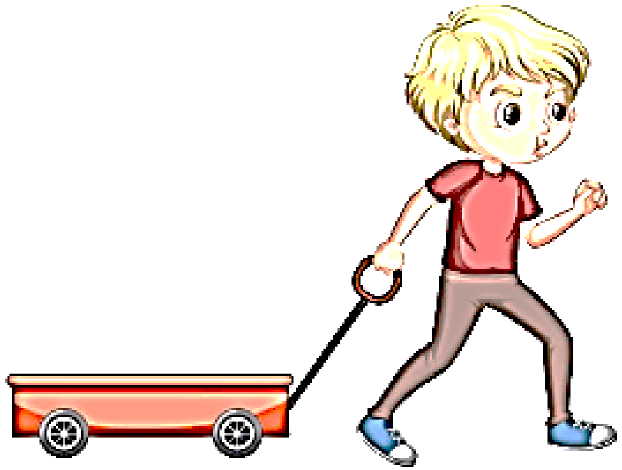
When a **force** is exerted on an object and the object **is displaced** (moved), **work is done.** E.g.,

- Pushing a pebble or pulling a trolley.
- Lifting a book.
- A bullock pulling a cart.

It means, **two conditions** must be met for **work:**

- A **force** should act on the object.
- The object must be **displaced.**





WORK

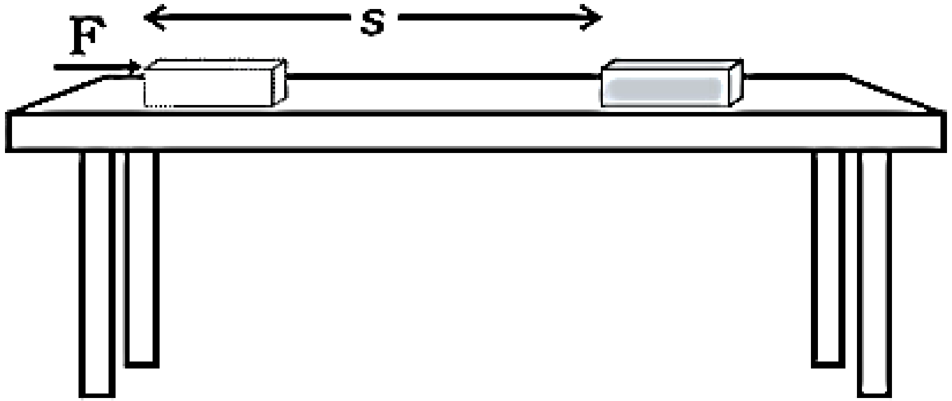
WORK DONE BY A CONSTANT FORCE

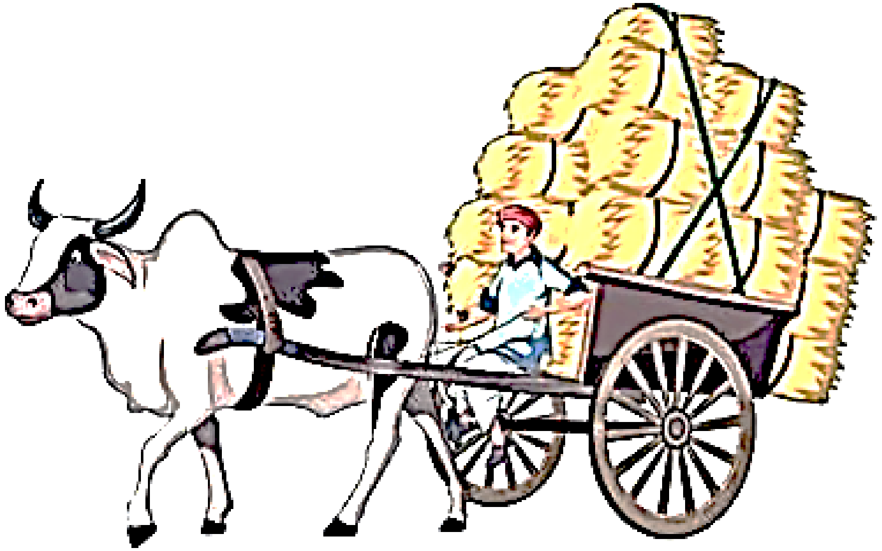
Work is defined as the **product of force and displacement.**

$$\text{Work done} = \text{force} \times \text{displacement}$$

$$W = F s$$

- W= the work done.
- F= a constant force acting on an object.
- s= displacement of the object in the direction of force.





WORK

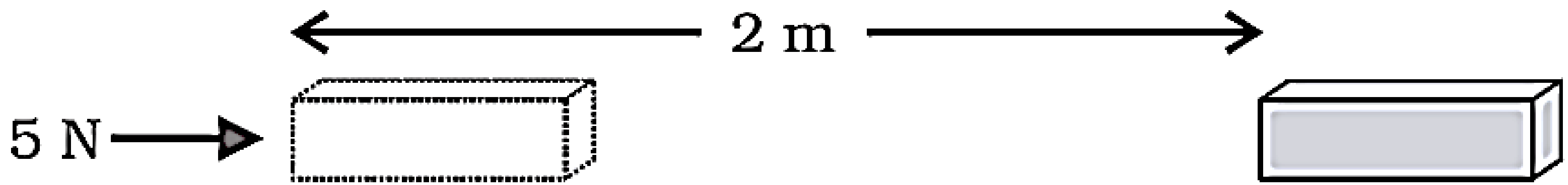
WORK DONE BY A CONSTANT FORCE

- Work has **only magnitude** and **no direction.**
- If $F = 1$ N and $s = 1$ m, the work done, $W = 1$ N m.
- The unit of work is **newton metre (N m)** or **joule (J).**
- Thus 1 J is the work done when a force of 1 N displaces an object by 1 m in the direction of the force.
- If the force is zero, the work done is also zero. Similarly, if the displacement is zero, no work is done.

Example

A **force of 5 N** is acting on an object. The object is **displaced** through **2 m** in the direction of the force.

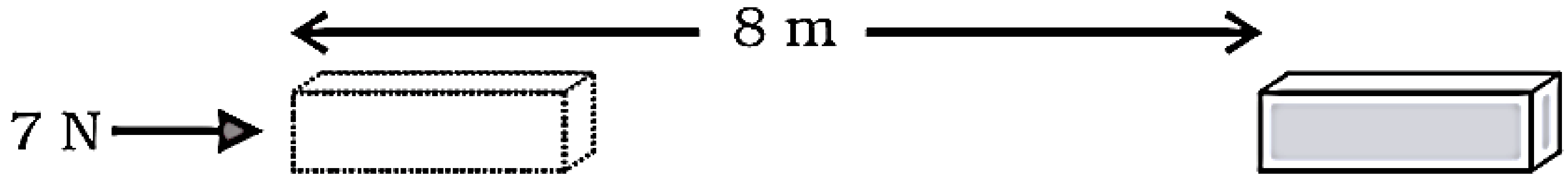
If the force acts on the object all through the displacement, **work done** is 5 N × 2 m =**10 N m** or **10 J.**



WORK — WORK DONE BY A CONSTANT FORCE

Question

A force of 7 N acts on an object. The displacement is, say 8 m, in the direction of the force. Let us take it that the force acts on the object through the displacement. What is the work done in this case?



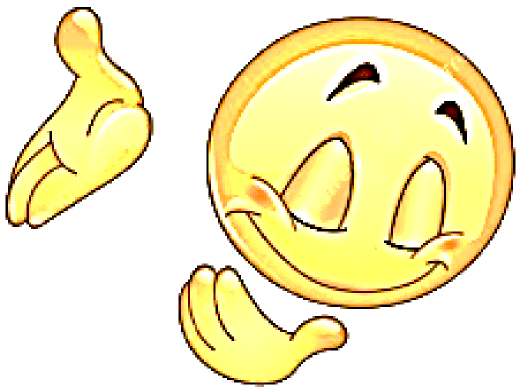
Answer

$W = F\,s$

Force (F) = 7 N

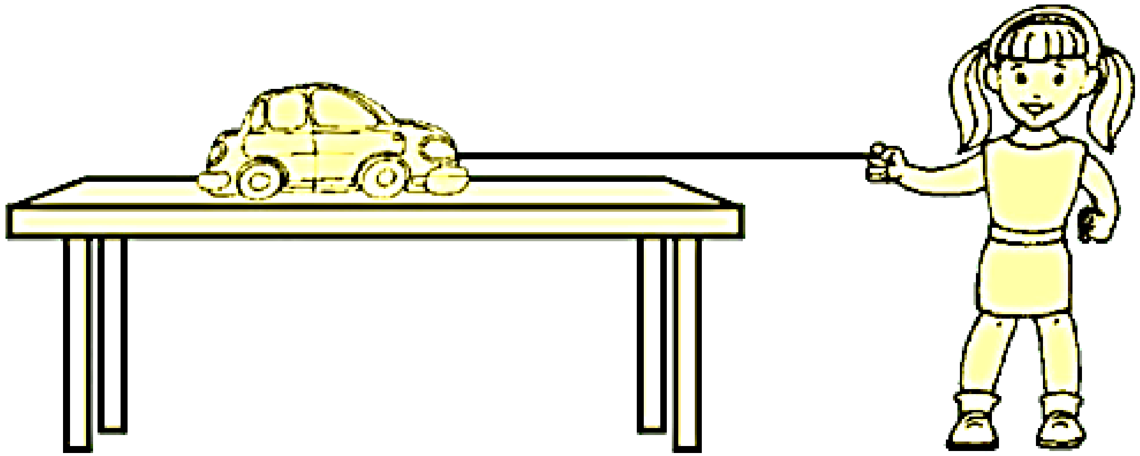
Displacement (s) = 8 m

Work done (W) = 7 N × 8 m = **56 Joules**



WORK — WORK DONE BY A CONSTANT FORCE

- When **force** and **displacement** occur in **same direction,** the **work** done is the **product of force** and **displacement,** and the work done is **positive.** E.g., a baby pulling a toy car horizontally.



- When a **retarding force** ***F*** is applied in the **opposite direction** of a moving object, the angle between the **force** and **displacement** is **180°.**
- If the object stops after a displacement *s*, the work done by the force is negative.

i.e., $W = -F \times s$ or $F \times (-s)$

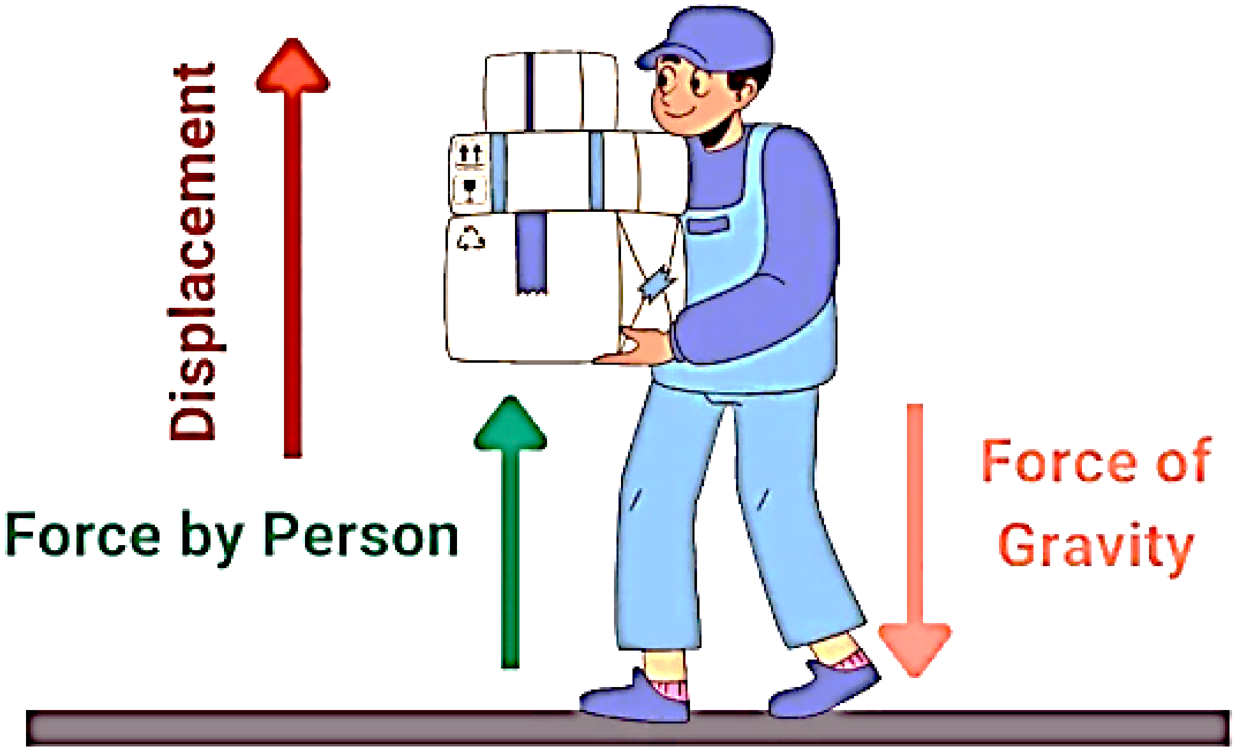
Thus, the work done by a force can be **positive** or **negative.**

WORK

WORK DONE BY A CONSTANT FORCE

Activity

- Lift an object up. The **force** exerted moves the **object upwards,** i.e., force is in the direction of displacement. **Force of gravity** acts **downward** on the object.
- The work done by the lifting force is **positive** because it is in the **direction of displacement.**
- The work done by **gravity** is **negative** because it acts **opposite to the direction of displacement.**



A person lifting objects

WORK

WORK DONE BY A CONSTANT FORCE

Example

A porter lifts a luggage of 15 kg from the ground and puts it on his head 1.5 m above the ground.

Calculate the work done by him on the luggage.

Solution

Mass of luggage, m = 15 kg

Displacement, s = 1.5 m.

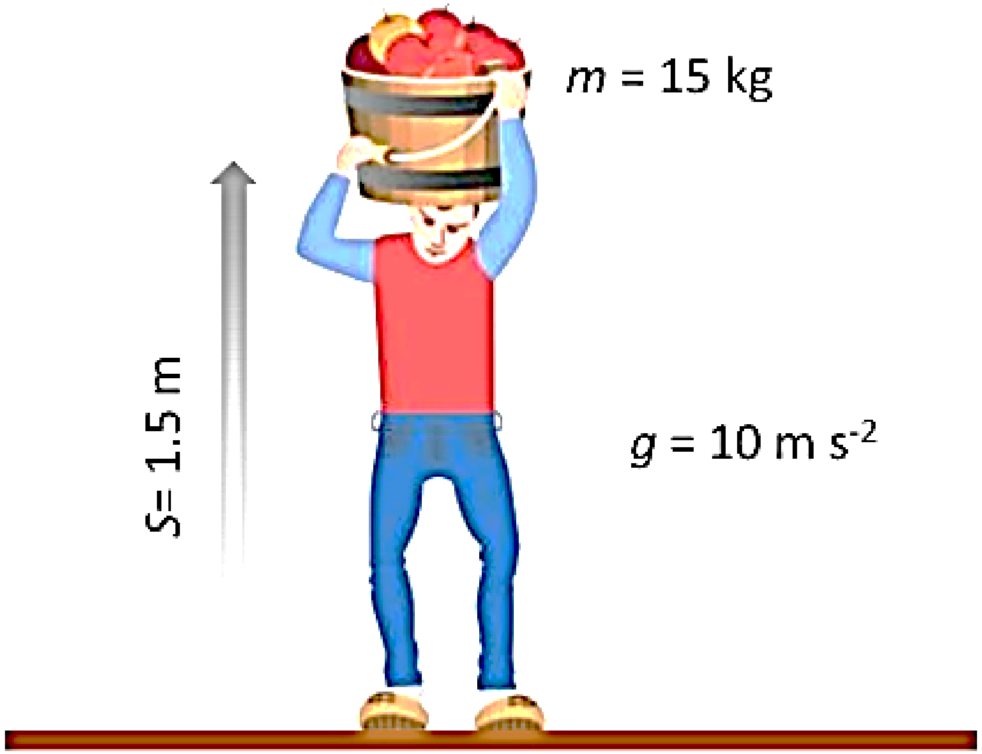
Work done, $W = F \times s$

$= mg \times s$

$= 15\ \text{kg} \times 10\ \text{m s}^{-2} \times 1.5\ \text{m}$

$= 225\ \text{kg m s}^{-2}\ \text{m}$

$= 225\ \text{N m} =$ **225 J.**



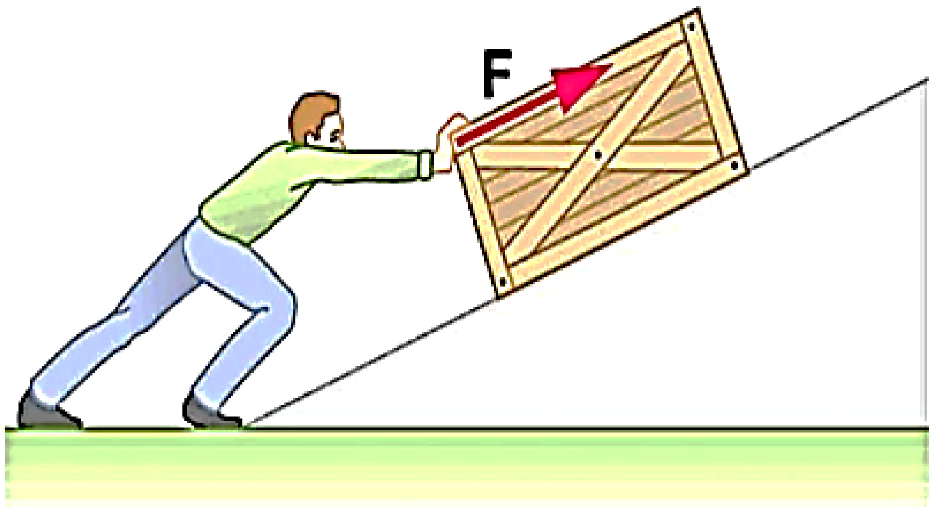
ENERGY

Objects acquire the ability of doing work through various means. E.g.,

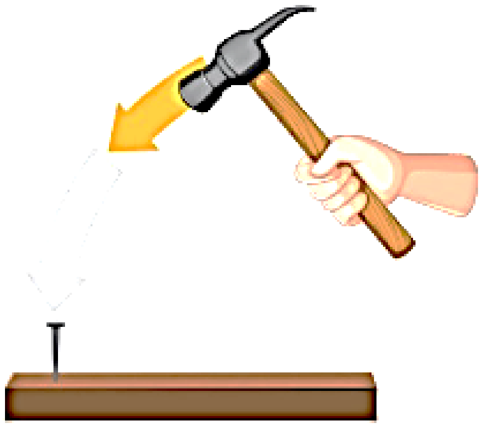
- A fast-moving cricket ball hitting a stationary wicket causes the wicket to throw away.
- An object raised to a height gains ability to do work.
- A falling hammer drives a nail into wood.
- A wound-up toy car moves when placed on the floor.
- Pressing gently an air-filled balloon changes its shape. It returns to its original shape when the force is withdrawn. If pressed hard, it explodes.

ENERGY

- The capacity of an object to do work is called **energy.**
- The object which **does the work loses energy** and the object on which the **work is done gains energy.**
- An object can exert a force on another, transferring energy to the second object. So the second object moves and does work.



- Energy is measured by its capacity to do work. So, the unit of energy is the same as that of work, i.e., **joule (J)**, named after **James Prescott Joule.**
- **1 J** is the **energy** required to do **1 joule of work.**
- **1 kilo joule (kJ) = 1000 J.**

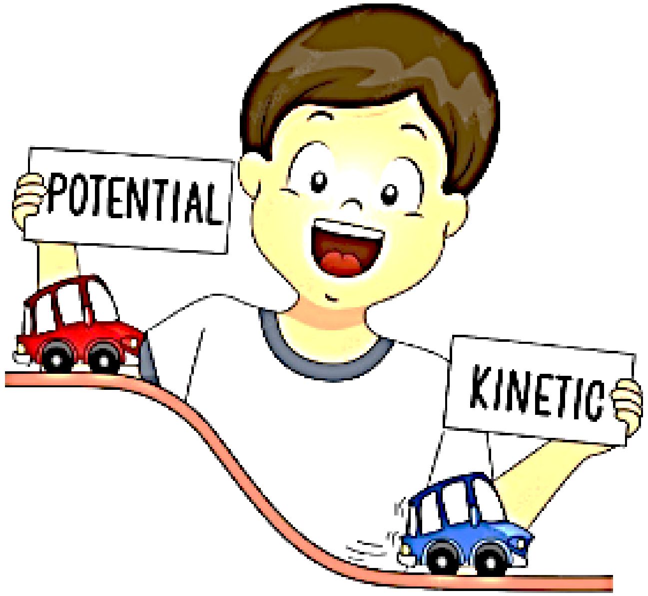


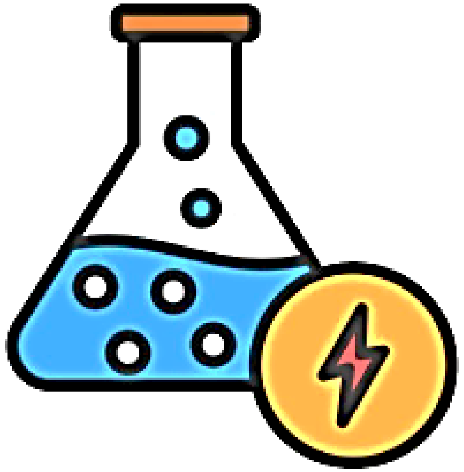

Prescott Joule

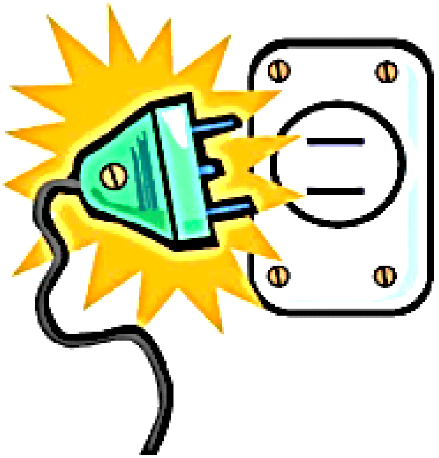
ENERGY

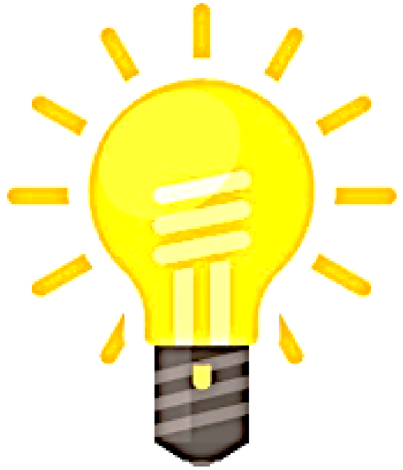
Various forms energy

- Mechanical energy (potential energy + kinetic energy)
- Heat energy
- Chemical energy
- Electrical energy
- Light energy









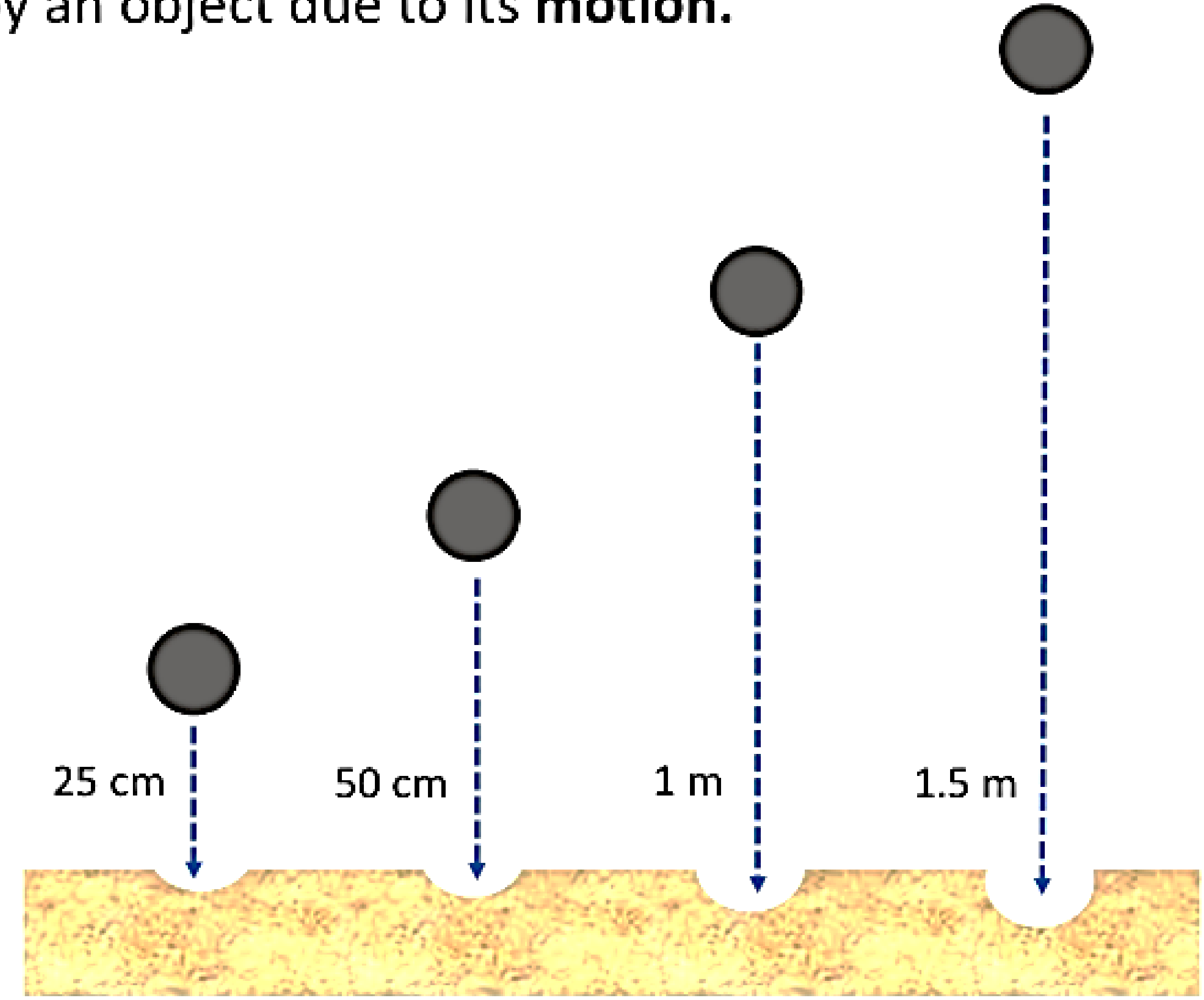
ENERGY

KINETIC ENERGY

It is the energy possessed by an object due to its **motion.**

Activity

- Drop a heavy ball on a thick bed of wet sand from heights of 25 cm, 50 cm, 1 m, and 1.5 m. It creates depressions on the sand.
- The depth of the depression increases with height, as a ball dropped from a **greater height has more kinetic energy.** It exerts a stronger force on the sand and create a deeper dent.

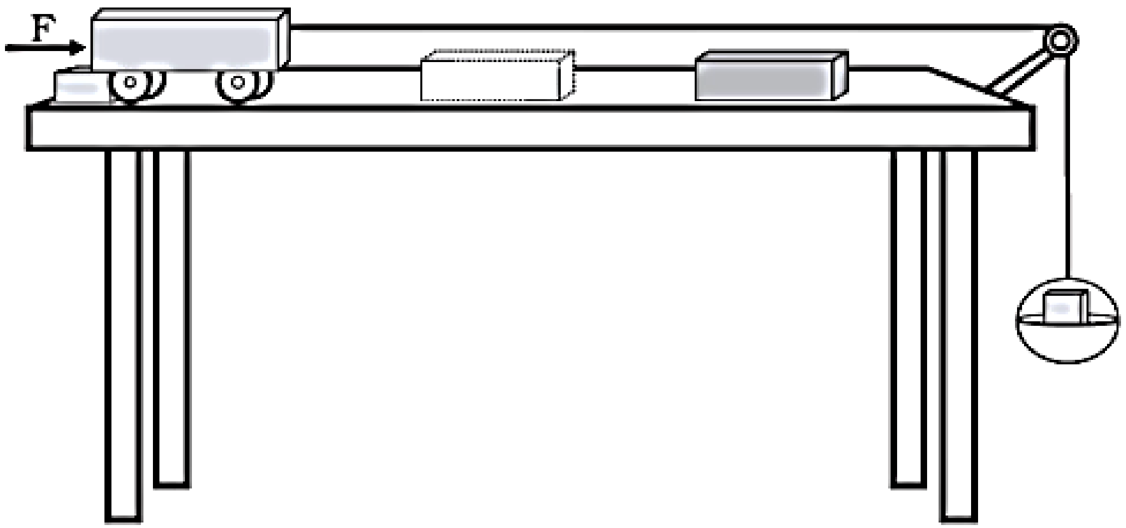


ENERGY

KINETIC ENERGY

Activity

- Set up the apparatus as shown in figure.
- Place a **wooden block** of known mass in front of the **trolley** at a fixed distance.
- Place a known mass on the pan. The **trolley moves** and **hits the block.** The block is displaced. (Fix a stop on the table so the trolley stops after hitting the block).
- The block's displacement shows that work is done on it by the trolley, as the block has gained energy.
- This energy comes from the potential energy of the mass on the pan, converted into kinetic energy of the trolley.
- Increasing the mass on the pan raises trolley's energy causing greater displacement of the block and more work done.
- The moving trolley has energy as it performs work.



ENERGY

KINETIC ENERGY

- A moving object can do work. A faster object can do more work than a slower one. E.g.,
  - ❖ A moving bullet can pierce a target.
  - ❖ Wind can turn the blades of a windmill.
- Objects in motion possess kinetic energy. E.g., A falling coconut, a speeding car, a rotating wheel, a rolling stone, a flying aircraft, flowing water, a running athlete etc.
- Kinetic energy increases with the speed.

The **kinetic energy of a moving body** is defined as the **work done to accelerate it to its current velocity.**

ENERGY

KINETIC ENERGY

The work done on the object will cause a change in its velocity. Let its velocity change from *u* to *v*.

$$v^2 - u^2 = 2a\,s$$ or $$s = \frac{v^2 - u^2}{2a}$$

$F = m\,a$

The work done, $W = F\,s$.

Then $$W = m\,a\,\frac{v^2 - u^2}{2a}$$ or $$W = \frac{1}{2}m\,(v^2 - u^2)$$

If the object is starting from its stationary position, i.e., $u = 0$, then

$$W = ½\,m\,v^2$$

The work done is equal to the change in the kinetic energy of an object. Thus, the kinetic energy (E_k) of an object with mass, *m* moving with a uniform velocity, *v* is

$$E_k = ½\,m\,v^2$$

ENERGY

KINETIC ENERGY

Example

An object of mass 15 kg is moving with a uniform velocity of 4 m s^{-1}. What is the kinetic energy possessed by the object?

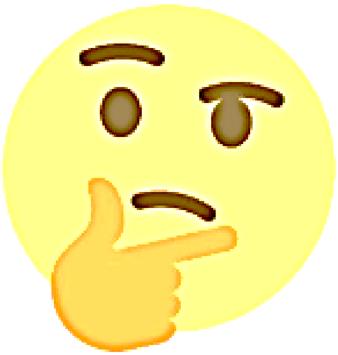
Solution

Mass, m = 15 kg

Velocity, v = 4 m s^{-1}

Kinetic energy, $E_k = \frac{1}{2}\, m\, v^2$

$\frac{1}{2} \times 15$ kg $\times$ 4 m s–1 $\times$ 4 m s^{-1} = <u>120 J.</u>



ENERGY

KINETIC ENERGY

Example

What is the work to be done to increase the velocity of a car from 30 km h^{-1} to 60 km h^{-1} if the mass of the car is 1500 kg?

Solution

Mass of the car, m =1500 kg

Initial velocity u = 30 km h^{-1} $= \dfrac{30 \times 1000 \text{ m}}{60 \times 60 \text{ s}}$ = 25/3 m s^{-1}.

The final velocity of the car, v = 60 km h^{-1} = 50/3 m s^{-1}.

∴ the initial kinetic energy of the car, $E_{ki} = \frac{1}{2} m u^2$

= ½ × 1500 kg × (25/3 m s^{-1})^2 = 156250/3 J.

The final kinetic energy of the car,

E_{kf} = ½ × 1500 kg × (50/3 m s^{-1})^2 = 625000/3 J.

The work done = Change in kinetic energy

$= E_{kf} - E_{ki}$ = **156250 J**

ENERGY

POTENTIAL ENERGY

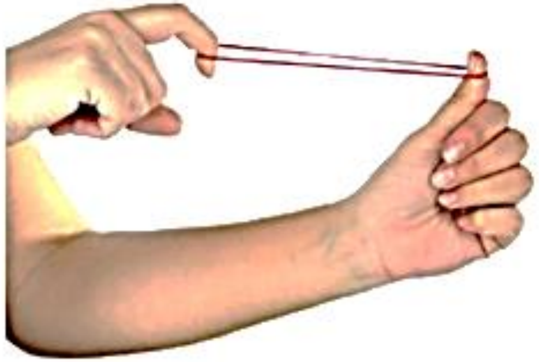
It is the **stored energy** of an object due to its **position or configuration.**

Activity 1

- When a rubber band is stretched, it acquires potential energy from the work done to pull it. When released, the stored energy is converted back into kinetic energy as the band returns to its original length.

Activity 2

- Stretch a slinky by holding one end while moving away from the other end.
- Release the slinky. It returns to its original shape.
- Energy is stored as **potential energy** when **stretched** or **compressed.**



ENERGY

POTENTIAL ENERGY

Activity 3

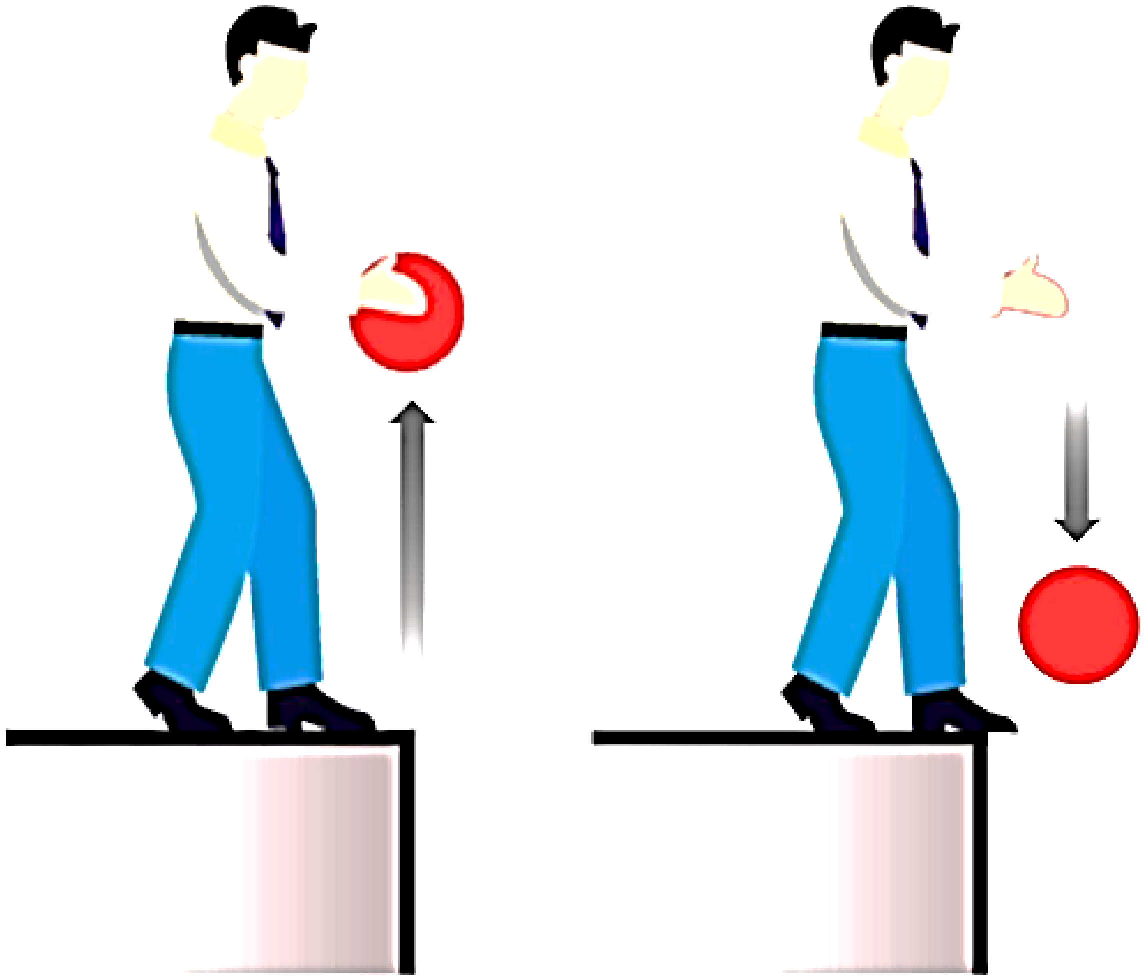
- Place a **wound-up toy car** on the ground. It moves.
- It acquires energy from the **potential energy** stored in the **wound-up spring.**
- The energy acquired depend on the number of windings. **More windings** store **more potential energy.**
- It can be tested by winding the car different numbers of times and measuring the distance it travels each time.

ENERGY

POTENTIAL ENERGY

Activity 4

- Lift an object to a **certain height.** It can now do work.
- It begins to fall when released. This implies that it has acquired some energy.
- If raised to a **greater height** it can do **more work** and hence possesses **more energy.** This energy is acquired from the work done against gravity during lifting.



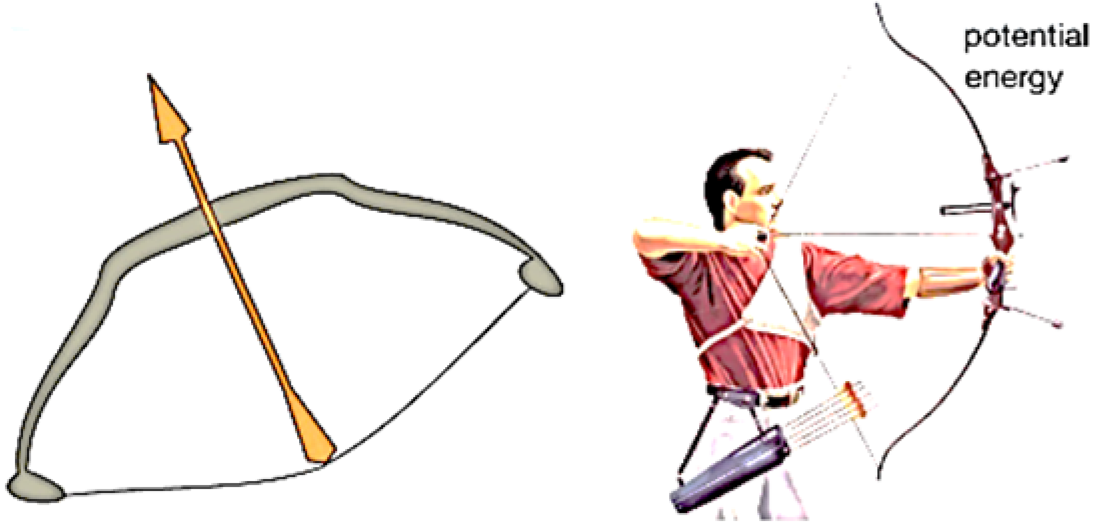
ENERGY

POTENTIAL ENERGY

- Energy transferred to an object is stored as potential energy if not used to change its velocity.
- When a person stretches a rubber band, his energy is transferred to it, which becomes its potential energy.
- Winding a toy car's key involves work, storing energy in the spring as potential energy.

Activity

- ❖ Make a bamboo bow, place a light stick arrow on it, stretch the string, and release the arrow.
- ❖ The arrow flies off as the shape of the bow changes. The potential energy stored in the bow due to the change of shape is used as kinetic energy to throw off the arrow.



An arrow and the stretched string on the bow

ENERGY — POTENTIAL ENERGY OF AN OBJECT AT A HEIGHT

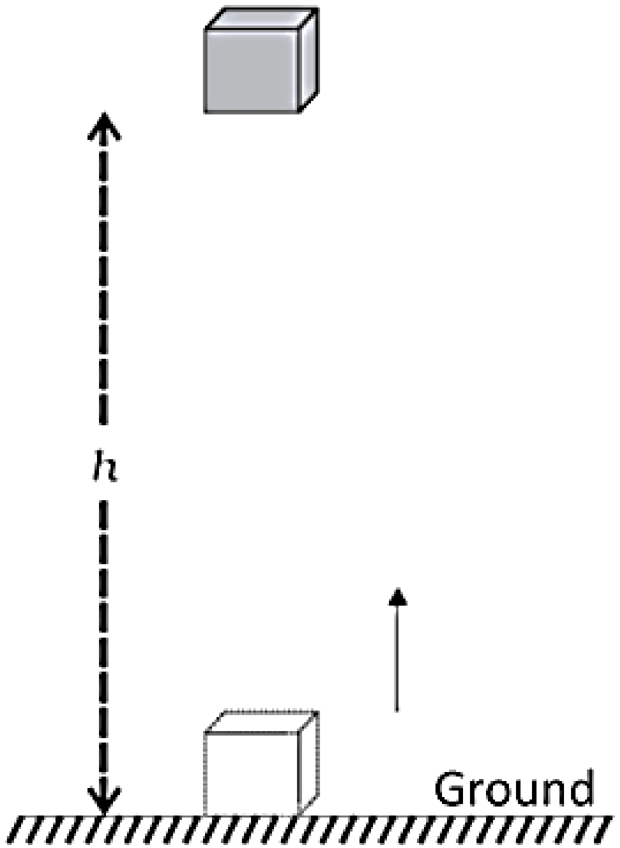
- When an object is raised, work is done against gravity. So, its **gravitational potential energy** increases. It is ***the work done to raise an object from the ground to a point against gravity.***
- Consider an object of mass, m is raised through a height, h from the ground.
- The minimum force required to raise the object is equal to object's weight, mg and the work done on the object against gravity is W.

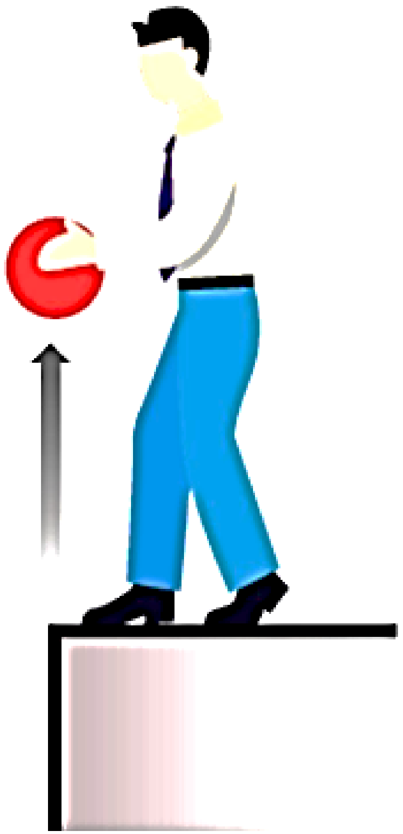
  i.e., work done, W = force × displacement = $mg \times h$

  $$\boxed{W = mgh}$$

- This equals potential energy (E_p) gained by the object.

  $$\boxed{Ep = mgh}$$





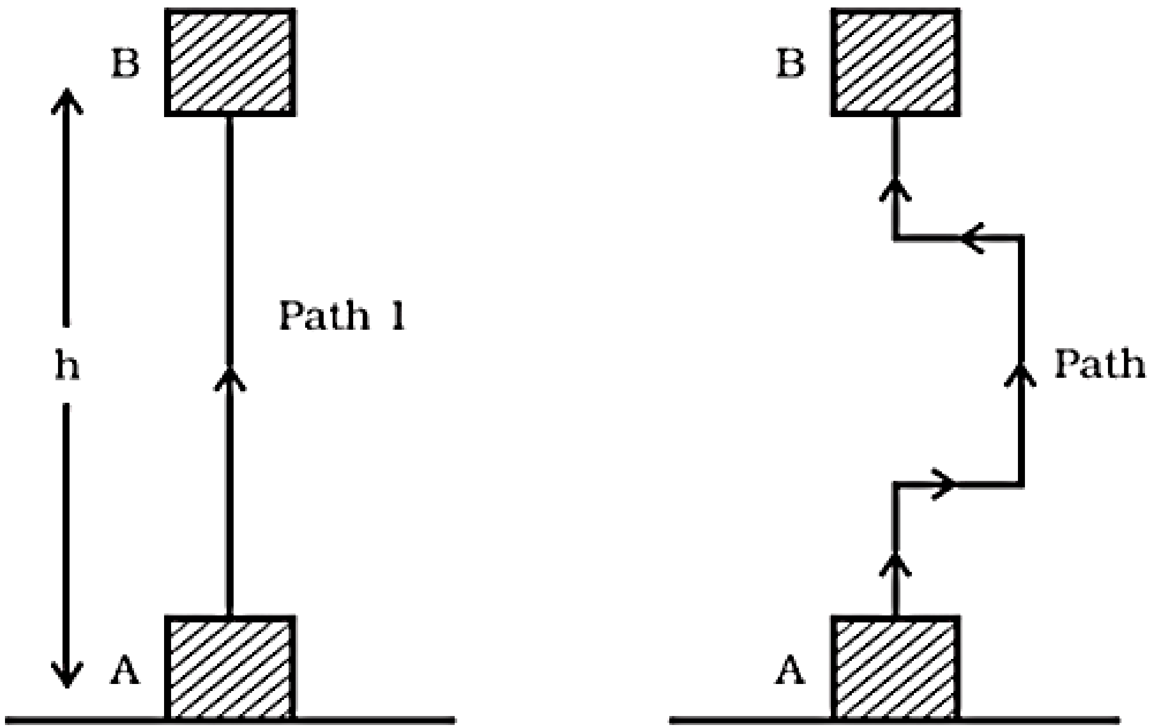
ENERGY

POTENTIAL ENERGY OF AN OBJECT AT A HEIGHT

Potential energy of an object at a height varies depending on the chosen reference point (ground level or zero level). The same object can have different potential energy values based on the level used for measurement.

- The work done by gravity depends on the difference in **vertical heights** between the **initial** and **final positions** of the object, **not the path taken.**
- Consider a block is raised from position A to B via two different paths.

  In both cases, **height AB = *h*,** and the **work done is *mgh*.**



ENERGY — POTENTIAL ENERGY OF AN OBJECT AT A HEIGHT

Example

Find the energy possessed by an object of mass 10 kg when it is at a height of 6 m above the ground. Acceleration due to gravity, $g = 9.8\ \text{m s}^{-2}$.

Solution

Mass of the object, $m = 10$ kg

Displacement (height), $h = 6$ m

$g = 9.8\ \text{m s}^{-2}$.

Potential energy = mgh

$= 10\ \text{kg} \times 9.8\ \text{m s}^{-2} \times 6\ \text{m} \quad = \underline{\underline{588\ \text{J}}}$

Example

An object of mass 12 kg is at a certain height above the ground. If the potential energy of the object is 480 J, find the height at which the object is with respect to the ground. Given, $g = 10\ \text{m s}^{-2}$.

Solution

Mass of the object, $m = 12$ kg

Potential energy, $E_p = 480$ J.

$E_p = mgh \qquad 480\ \text{J} = 12\ \text{kg} \times 10\ \text{m s}^{-2} \times h$

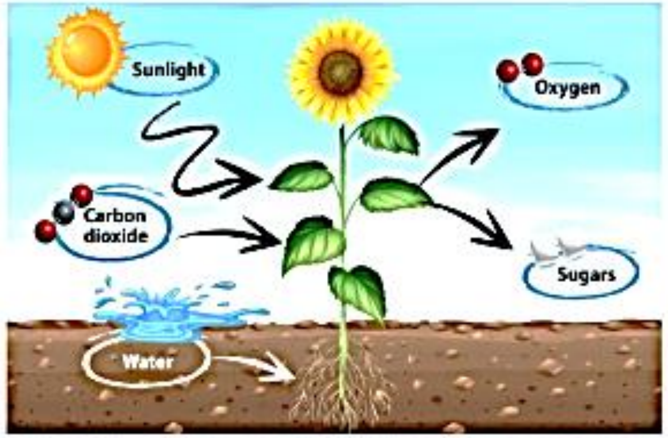
Height, $h = \dfrac{480\ \text{J}}{120\ \text{kg ms}^{-2}} = \underline{\underline{4\ \text{m}}}$

ENERGY ARE VARIOUS ENERGY FORMS INTERCONVERTIBLE?

Energy can be converted from one form to another.

Examples from Nature

- **Green Plants:** During **photosynthesis, solar energy** is converted into **chemical energy.**
- **Air Movement: Solar energy** heats the Earth's surface, causing **wind,** converting **solar energy** into **kinetic energy.**
- **Fuels: Coal** & **petroleum** store **chemical energy** formed from ancient organic matter over time.
- **Water Cycle: Solar energy** drives **evaporation, condensation** and **precipitation.**



ENERGY — ARE VARIOUS ENERGY FORMS INTERCONVERTIBLE?

Energy can be converted from one form to another.

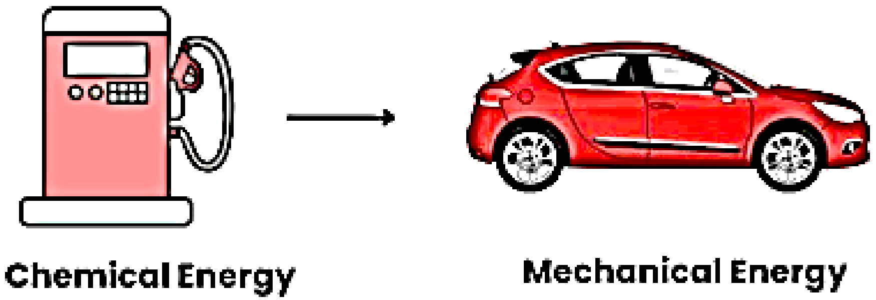
Human Activities & Gadgets

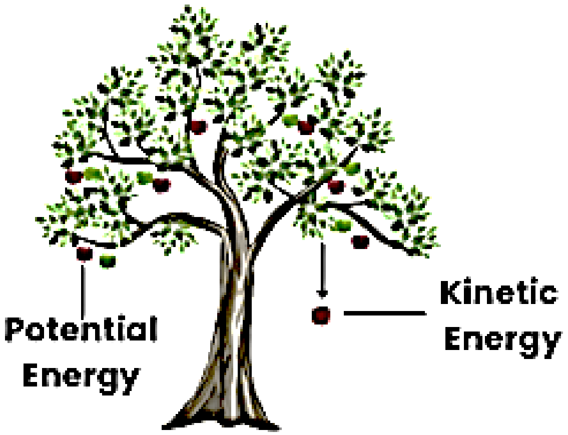
- **Electric Bulb:** Converts **electrical energy** to **light** & **heat.**
- **Car Engine:** Converts **chemical energy** (fuel) to **mechanical energy.**
- **Wind Turbine:** Converts **kinetic energy** (wind) to **electrical energy.**

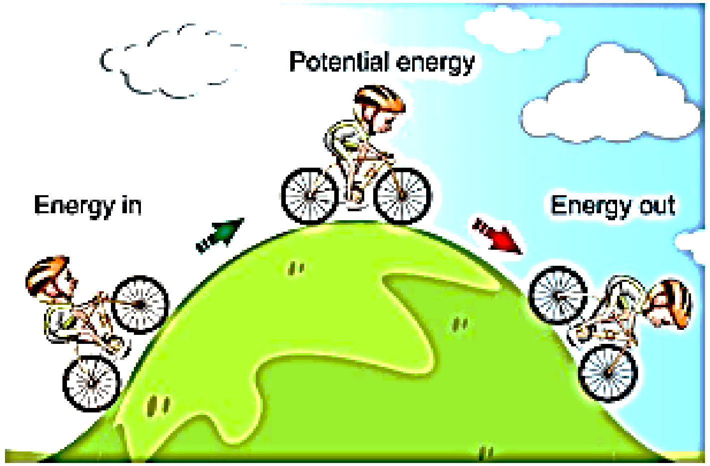
ENERGY

LAW OF CONSERVATION OF ENERGY

- It states that ***energy can only be converted from one form to another; it can neither be created or destroyed.***
- The total energy before and after the transformation remains the same.
- This law is valid in all situations and for all kinds of transformations.
- E.g., Let an object of mass, m is falling freely from a height, h. At the start, **potential energy** is ***mgh*** and **kinetic energy** is **zero** because its velocity is zero. Thus, total energy of the object is mgh.





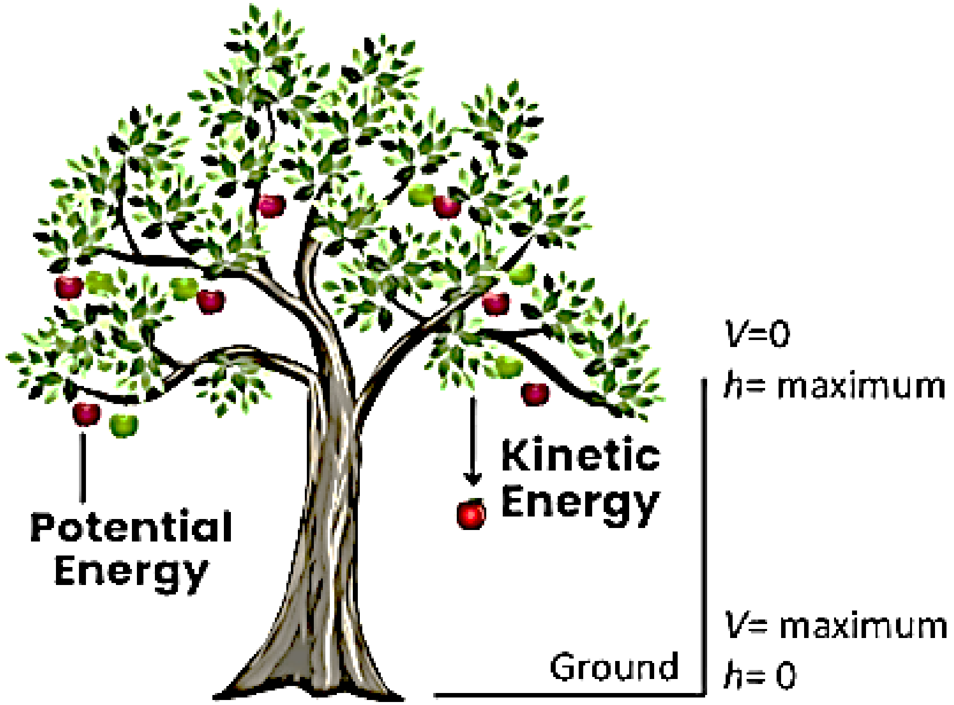


ENERGY — LAW OF CONSERVATION OF ENERGY

- As the object **falls, potential energy decreases** while **kinetic energy increases.** When it approaches the ground, height, h=0 and velocity, v will be the highest. Therefore, kinetic energy is greatest and potential energy is least. However, the total energy remains constant throughout the fall.

  i.e., **potential energy + kinetic energy = constant**

  or $mgh + \frac{1}{2} mv^2$ **= constant.**



- Sum of **kinetic energy** and **potential energy** of an object is its total **mechanical energy.**
- During free fall, the **decrease in potential energy at any point equals the increase in kinetic energy** (effect of air resistance is ignored). Thus, there is a **continual transformation of gravitational potential energy into kinetic energy.**

ENERGY

LAW OF CONSERVATION OF ENERGY

Activity

An object of mass 20 kg is dropped from a height of 4 m. Fill in the blanks in the table by computing the potential energy and kinetic energy. $g = 10\ m\ s^{-2}$.

Answer

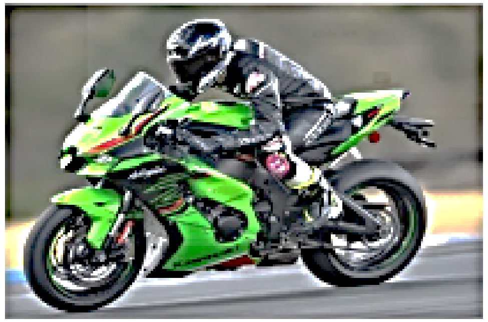
Height at which object is located m	Potential energy ($E_p = mgh$) J	Kinetic energy ($E_k = mv^2/2$) J	$E_p + E_k$ J
4	800	0	800
3	600	200	800
2	400	400	800
1	200	600	800
Just above ground	0	800	800

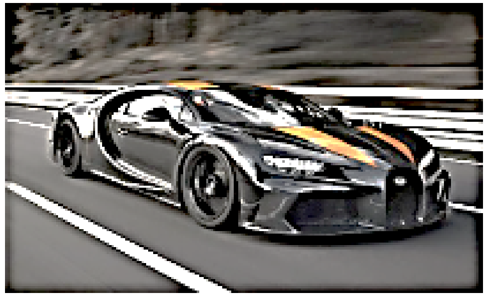
If nature had no transformation of energy, life would not exist, as all organisms depend on energy conversions to sustain biological processes. E.g., plants convert solar energy into chemical energy through photosynthesis.

RATE OF DOING WORK

Activity

Two children, A & B, of equal weight climb an 8-meter rope. A takes 15 seconds, while B takes 20 seconds to finish the task. Though both do the same work by reaching the same height, A finishes faster. It indicates A has a higher rate of work or power.





- A stronger person does work faster. A more powerful vehicle completes a journey in a shorter time.
- Machines like motorbikes and cars are classified based on how quickly they change energy or do work.
- **Power** measures the speed of work done. It is defined as ***the rate of doing work*** or ***the rate of transfer of energy.***
- If an agent does a work W in time t, then **Power = work/time** or $P = W/t$

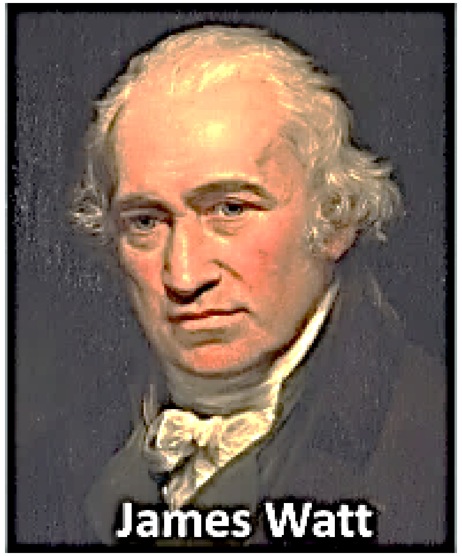
RATE OF DOING WORK

- Unit of power is **watt (W)** [in honour of **James Watt**].
- **1 watt** is the power of an agent working at the rate of 1 joule per second.
- Power is 1 W when the rate of consumption of energy is 1 J s^{-1}.

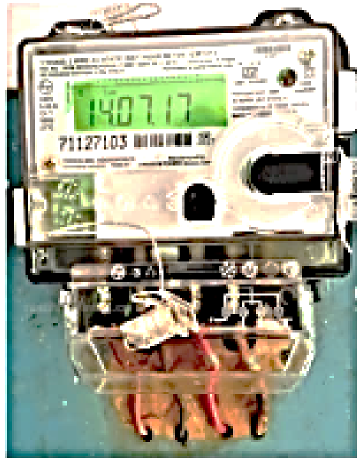
i.e., **1 watt (W) = 1 joule/second (1 J s^{-1})**

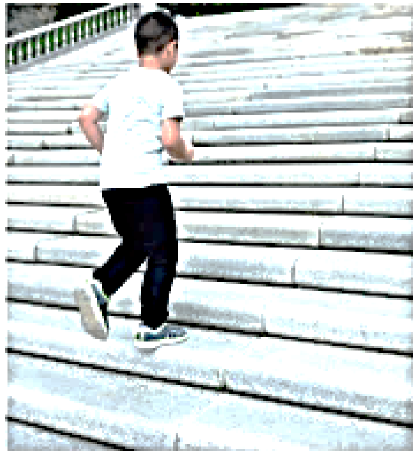
- Larger energy transfer rate is measured in **kilowatts (kW).**

1 kilowatt (kW)= 1000 watts (W) or 1000 J s^{-1}



Power of an agent may vary with time. i.e., work may be done at different rates at different intervals of time. So, **Average power** is calculated by dividing total energy consumed by the total time taken.





RATE OF DOING WORK

Example

Two girls A and B, each of weight 400 N climb up a rope through a height of 8 m. A takes 20 s while B takes 50 s to accomplish this task. What is the power expended by each girl?

Solution

(i) Power expended by girl A

Weight of the girl, mg = 400 N

Displacement (height), h = 8 m

Time taken, t = 20 s

Power, P = Work done/time taken

$$P = \frac{mgh}{t} = \frac{400\text{ N} \times 8\text{ m}}{20\text{ s}}$$

$= \underline{\underline{160\text{ W}}}$

(ii) Power expended by girl B

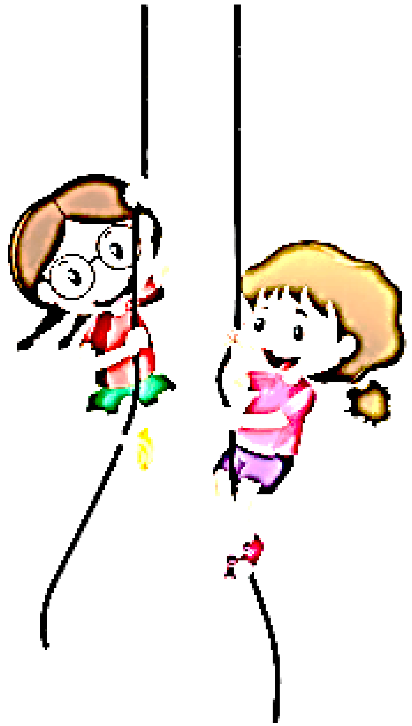
Weight of the girl, mg = 400 N

Displacement (height), h = 8 m

Time taken, t = 50 s

$$P = \frac{mgh}{t} = \frac{400\text{ N} \times 8\text{ m}}{50\text{ s}}$$

$= \underline{\underline{64\text{ W}}}$



RATE OF DOING WORK

Example

A boy of mass 50 kg runs up a staircase of 45 steps in 9 s. If the height of each step is 15 cm, find his power. Take $g = 10\ \mathrm{m\ s^{-2}}$.

Solution

Weight of the boy, $mg = 50\ \mathrm{kg} \times 10\ \mathrm{m\ s^{-2}} = 500\ \mathrm{N}$

Height of the staircase, $h = 45 \times 15/100\ \mathrm{m} = 6.75\ \mathrm{m}$

Time taken to climb, $t = 9\ \mathrm{s}$

$$\text{Power, } P = \frac{mgh}{t} = \frac{500\ \mathrm{N} \times 6.75\ \mathrm{m}}{9\ \mathrm{s}}$$

$$= \underline{375\ \mathrm{W}}$$


thank
you