

CHAPTER

5

Work, energy, power

In common usage, the word 'work' means any physical or mental exertion. But in physics, work has a distinctly different meaning. Let us consider the following situations : (1) A student holds a heavy chair at arm's length for several minutes. (2) A student carries a bucket of water along a horizontal path while walking at constant velocity. (3) A student applying force against a wall. (4) A student studying whole day to prepare for examinations. It might surprise you to know that in all the above situations, no work is done according to the definition of work in physics., even though effort is required in all cases.

5.1

The concept of work

In physics, the word 'work' has a definite and precise meaning. Work is not done on an object unless the object is moved with the action of a force. The application of a force alone does not constitute work. For example, when a student holds the chair in his hand, he exerts a force to support the chair. But, work is not done on the chair as the chair does not move.

- Two important conditions that must be satisfied for work to be done are : (i) a force should act on an object (ii) the object must be displaced. If any one of the above conditions does not exist, work is not done. This is the concept of work that we use in science.

Mathematical definition of work

A constant force is applied in the direction of the displacement of an object : Let a constant force, F acts on an object. Let the object be displaced through a distance, s in the direction of the force (see fig.1(a)). Let W be the work done. Here, we define work to be equal to **'the product of the force and displacement'**.

Work done = force $\times$ displacement

$$W = F \times s$$

A constant force is applied at a certain angle with the direction of the displacement of an object : When the force on an object and the object's displacement are in different directions, the work done on the object is given by,

$$W = F \times s \times \cos \theta$$

Where, the angle between the force and the direction of the displacement is θ (see fig.1(b)).

Here, we define work to be equal to **'the force multiplied by the displacement multiplied by the cosine of the angle between them'**.

- Work is a scalar quantity, it has only magnitude and no direction.

Unit of work : S.I. unit : Joule 1 Joule = 1 newton $\times$ metre or 1 J = 1 N m

C.G.S. unit : Erg 1 erg = 1 dyne $\times$ centimetre or 1 erg = 1 Dyne cm

$$1 \text{ Joule} = 10^7 \text{ ergs}$$

Definition of 1 joule : 1 J is the amount of work done on an object when a force of 1 N displaces it by 1 m along the line of action of the force.

Some important points related to work

- If $\theta = 0^\circ$, then $\cos 0^\circ = 1$ and $W = F \times s$.
- If $\theta = 90^\circ$, then, $W = 0$ because $\cos 90^\circ = 0$. So, no work is done on a bucket being carried by a girl walking horizontally. The upward force exerted by the girl to support the bucket is perpendicular to the displacement of the bucket, which results in no work done on the bucket.
- If $\theta = 180^\circ$, then $\cos 180^\circ = -1$ and $W = -F \times s$.

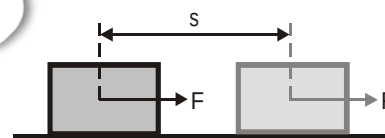


Fig.1(a) Work done by a constant force acting in the direction of displacement

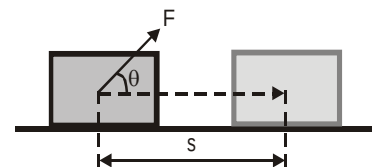


Fig.1(b) Work done by a constant force acting at an angle with the direction of displacement

Concept of negative and positive work

The work done by a force can be either positive or negative.

Whenever angle (θ) between the force and the displacement is acute, i.e., $0^\circ < \theta < 90^\circ$, the work done is positive. Also, when angle (θ) between the force and displacement is zero, i.e., force and displacement are in same direction, the work done is positive.

Whenever angle (θ) between the force and the displacement is obtuse, i.e., $90^\circ < \theta < 180^\circ$, the work done is negative. Also, when angle (θ) between the force and displacement is 180° , i.e., force and displacement are in opposite direction, the work done is negative.

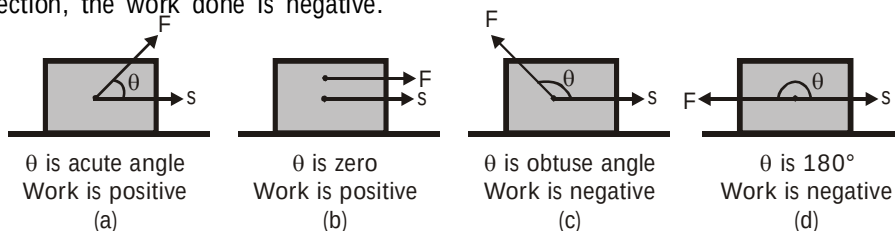


Fig.2 Concept of positive and negative work

- Area under the force (F) - displacement (s) graph gives the work done on an object or a system.
- An artificial satellite is moving around the Earth in a circular path under the influence of centripetal force provided by the gravitational force between them. Centripetal force (F) is always perpendicular to the displacement (s) of the particle moving along a circular path. That is, the angle (θ) between them is 90° .

$$\text{Work done, } W = F s \cos \theta = F s \cos 90^\circ = 0$$

Thus, work done by this centripetal force by the force is zero.

- Work done by the centripetal force is always zero because it is always perpendicular to the displacement. For example, if an electron moves around a nucleus in a circular path due to centripetal force provided by the electric force between them, the work done by this force is zero.

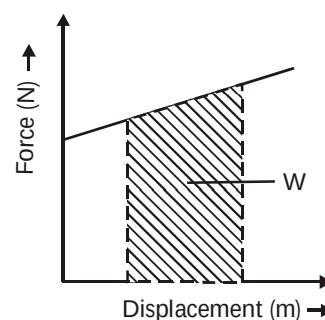


Fig.3 Area under force-displacement graph gives work done.

5.2

Work done by applied force against gravity

If an object is lifted up to a certain height (see fig.5), definitely, a work is done by the applied force. The applied force must be equal to the weight ($= mg$) of the object.

This work done is given by, $W = F \times s = mgh$

Where, m = mass of object ; g = acceleration due to gravity ; h = height.

- Whenever a person holds an object in his hands or supports an object over his head, he is always applying a force in upward direction.
 - When a person lifts a body from the ground i.e., displaces it in upward direction, the work done by him is positive (see fig.) as force and displacement are in same direction. When a person puts an object from a certain height to the ground i.e., displaces it in downward direction, the work done by him is negative (see fig.) as force and displacement are in opposite direction.
 - When a person lifts a body from the ground i.e., displaces it in upward direction, the work done by force of gravity is negative (see fig.6) as force of gravity and displacement are in opposite direction. When a person puts an object from a certain height to the ground i.e., displaces it in downward direction, the work done by the force of gravity is positive (see fig.6) as force of gravity and displacement are in same direction.

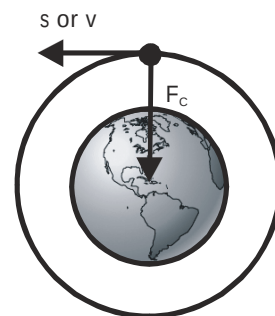


Fig.4 Work done by the centripetal force is zero

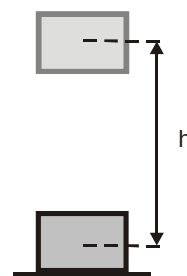


Fig.5 Work done against gravity

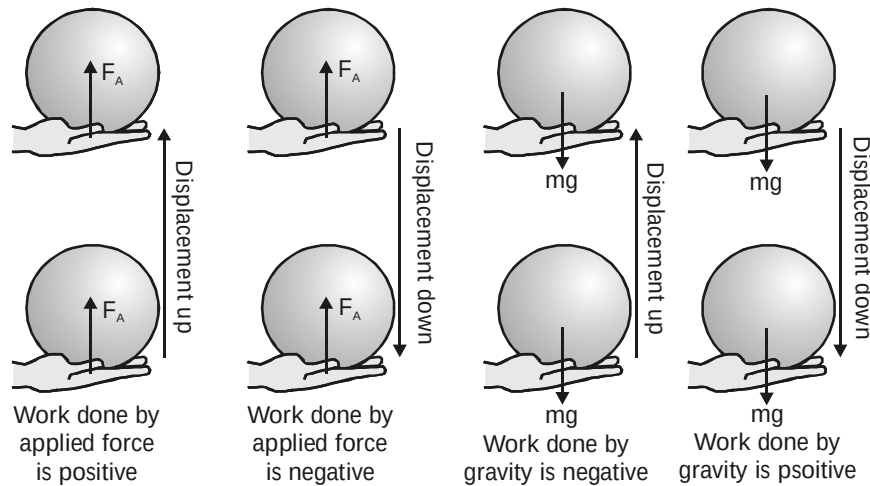


Fig.6 Work done by the applied force and gravity when an object is raised or lowered

- The work done against gravity depends on the difference in vertical heights of the initial and final positions of the object and not on the path along which the object is moved. This is because force of gravity is a conservative force. Fig.7 shows a case where a block is raised from position A to B by taking two different paths. Let the height $AB = h$. In both the situations the work done on the object is ' mgh '.

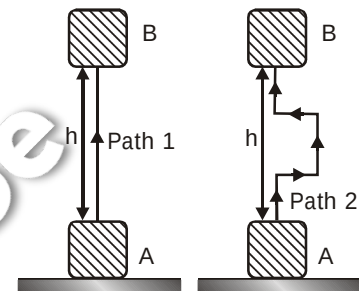


Fig.7 Work done against gravity depends only on initial position and final position

NUMERICAL CHALLENGE 5.1

- A force of 6 N is applied on an object at an angle of 60° with the horizontal. Calculate the work done in moving the object by 2 m in the horizontal direction.

Solution

Given, force, $F = 6 \text{ N}$; angle between force and displacement, $\theta = 60^\circ$; displacement, $s = 2 \text{ m}$.

We know that work done, $W = F s \cos\theta = 6 \times 2 \cos 60^\circ = 6 \times 2 \times (1/2) = 6 \text{ J}$

- A person lifts 5 kg potatoes from the ground floor to a height of 4 m to bring it to first floor. Calculate the work done.

Solution

Given, mass, $m = 5 \text{ kg}$; displacement, $h = 4 \text{ m}$; let us take, acceleration due to gravity, $g = 9.8 \text{ m/s}^2$

Since the potatoes are lifted, work is being done against gravity. Therefore, we can write,

Work done = $mgh = 49 \times 4 = 196 \text{ J}$

- A bag of grains of mass 2 kg is lifted through a height of 5 m. (a) How much work is done by the lift force ? (b) How much work is done by the force of gravity ?

Solution

Given, mass, $m = 2 \text{ kg}$; displacement, $s = h = 5 \text{ m}$

(a) Here, work done by the lift force is positive as both lift force and the displacement are in same direction (upward direction).

Thus, work done by the lift force, $W = + mgh = + 2 \times 9.8 \times 5 = 98 \text{ J}$

(b) Here, work done by the force of gravity is negative as the force of gravity acts in downward direction while the displacement is in upward direction i.e., both are in opposite directions.

Thus, work done by the force of gravity, $W = - mgh = - 2 \times 9.8 \times 5 = - 98 \text{ J}$

NUMERICAL CHALLENGE 5.2

1. Calculate the work done by applying a force of 20 N to a 0.4 kg box as it slides along a frictionless surface from rest to 10 m/s in 0.2 s.

Solution

Given, force, $F = 20 \text{ N}$; mass, $m = 0.4 \text{ kg}$; displacement, $s = ?$; initial velocity, $u = 0$;
 final velocity, $v = 10 \text{ m/s}$; time, $t = 0.2 \text{ s}$; Work done, $W = ?$

$$\text{Now, displacement, } s = \left(\frac{v+u}{2} \right) t = \left(\frac{10+0}{2} \right) \times 0.2 = 1 \text{ m}$$

$$\text{Work done, } W = F \times s = 20 \times 1 = \mathbf{20 \text{ J}}$$

2. Calculate the work done on a cyclist if a braking force of 40 N [backward] slows the cyclist from 20 m/s to 15 m/s in 2.0 s.

Solution

Given, force, $F = 40 \text{ N}$; displacement, $s = ?$; initial velocity, $u = 20 \text{ m/s}$; final velocity, $v = 15 \text{ m/s}$;
 time, $t = 2 \text{ s}$; Work done, $W = ?$

Since, the displacement and force are in opposite direction, angle between them is 180° i.e., $\theta = 180^\circ$.

$$\text{Now, displacement, } s = \left(\frac{v+u}{2} \right) t = \left(\frac{15+20}{2} \right) \times 2 = 35 \text{ m}$$

$$W = F s \cos \theta = 40 \times 35 \times \cos 180^\circ = 40 \times 35 \times (-1) = \mathbf{-1400 \text{ J}} \quad (\cos 180^\circ = -1)$$

3. Calculate the work done in graph shown in fig.8.

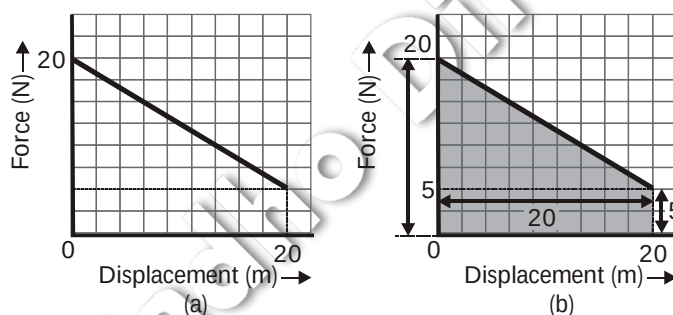


Fig.8 Numerical challenge 5.2

Solution

We know that area under the Force- displacement graph gives the total work done. Using fig.8(b), we can find the area under the given graph.

Work done, $W =$ area of trapezium shown in fig.8(b)

$$= \frac{1}{2} (\text{Sum of the parallel sides}) \times (\text{distance between them}) = \frac{1}{2} (20 + 5) \times (20) = \mathbf{250 \text{ J}}$$

4. A truck pulls a 3000 kg car from rest with a horizontal force of 5000 N. The truck and car accelerate at 2.5 m/s^2 for 5.0 s to reach the speed of 45 km/h. How much work is done by the truck ?

Solution

Given, force, $F = 5000 \text{ N}$; displacement, $s = ?$; acceleration, $a = 2.5 \text{ m/s}^2$; initial velocity, $u = 0$;
 final velocity, $v = 45 \text{ km/h} = (5/18) \times 45 = 12.5 \text{ m/s}$; Work done, $W = ?$

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

$$\text{or } (12.5)^2 - (0)^2 = 2 \times 2.5 \times s$$

$$\text{or } s = \frac{12.5 \times 12.5}{2 \times 2.5} = 31.25 \text{ m}$$

$$\text{Work done, } W = F s \cos \theta = F s \cos 0^\circ = 5000 \times 31.25 = 156250 \text{ J} = \mathbf{156.25 \text{ kJ}}$$

5.3

Energy

Without light that comes to us from the Sun, life on Earth would not exist. With the light energy, plants can grow and the oceans and atmosphere can maintain temperature ranges that support life. Although energy is difficult to define comprehensively, a simple definition is that **energy is the capacity to do work**. Thus, when you think of energy, think of what work is involved.

- An object that possesses energy can exert a force on another object. When this happens, energy is transferred from first object to the second object. The second object may move as it receives energy and therefore do some work. Thus, the first object had a capacity to do work. This implies that any object that possesses energy can do work.

Unit of energy :

S.I. unit : Since, energy is the capacity to do work, its unit is same as that of work, that is, joule (J). 1 J is the energy required to do 1 joule of work. Sometimes a larger unit of energy called kilo joule (kJ) is used, 1 kJ = 1000 J.

C.G.S. unit : Erg 1 J = 10^7 ergs

Forms of energy

The world we live in provides energy in many different forms. The various forms include potential energy, kinetic energy, heat energy, chemical energy, electrical energy and light energy.

Mechanical energy

The capacity to do mechanical work is called mechanical energy. Mechanical energy can be of two types :
 (1) Kinetic energy (2) Potential energy

- The sum of the gravitational potential energy and the kinetic energy is called mechanical energy.

Kinetic energy

This is the energy a body has due to its movement. To give a body KE, work must be done on the body. The amount of work done will be equal to the increase in KE.

- Kinetic energy is the energy associated with an object in motion.
- Kinetic energy possessed by an object of mass, m and moving with a uniform velocity, v is

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

- For a given mass, kinetic energy $E_k \propto v^2$. That is, more the value of v , more will be the kinetic energy. Also, if we double the velocity, the kinetic energy becomes four times, if we triple the velocity, the kinetic energy becomes nine times, and so on.
- For a given velocity, $E_k \propto m$. That is, more the mass, more will be the kinetic energy of a body. If a car and a truck are moving with same velocity, the truck possesses more kinetic energy than that of car because the truck has more mass than that of the car.

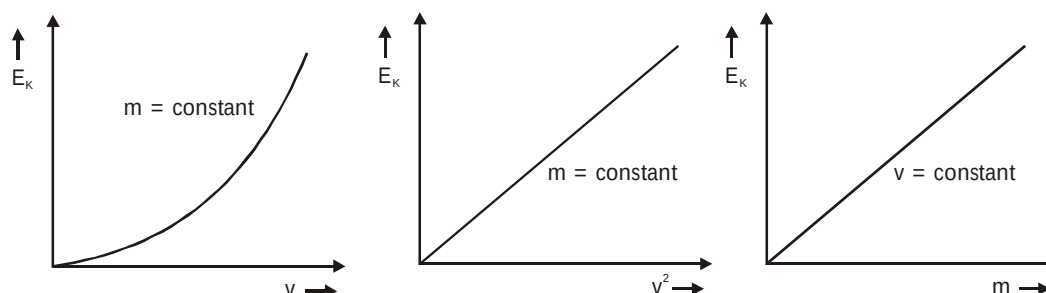


Fig.9 Graphs relating kinetic energy, velocity and mass.

- **Relationship between momentum and kinetic energy**

Momentum, $p = mv$ ----- (1)

Kinetic energy, $E_k = \frac{1}{2}mv^2 = \frac{1}{2}mv^2 \times \frac{m}{m} = \frac{1}{2} \frac{(mv)^2}{m}$ ----- (2)

From (1) & (2), we get, $E_k = \frac{p^2}{2m}$ Also, $p = \sqrt{2mE_k}$

For a given momentum, kinetic energy is inversely proportional to mass ($E_k \propto 1/m$). This means smaller the mass, more will be the kinetic energy and vice-versa. For a given kinetic energy, momentum is directly proportional to the square root of mass ($p \propto \sqrt{m}$). This means heavier body will have more momentum and vice-versa. For a given mass, momentum is directly proportional to the square root of kinetic energy ($p \propto \sqrt{E_k}$). This means more the kinetic energy, more will be the momentum and vice-versa. (see fig. 10)

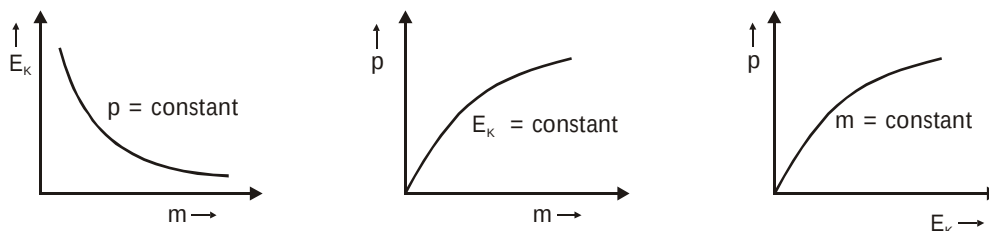


Fig.10 Graphs related to momentum, kinetic energy and mass.

Potential energy

The energy possessed by an object due to its position or configuration is called 'potential energy'.

- Potential energy is associated with an object that has the potential to move because of its position or configuration.

Gravitational potential energy

The energy associated with an object due to the object's position relative to a gravitational source is called gravitational potential energy.

- Gravitational potential energy is energy due to an object's position in a gravitational field. Imagine an egg falling off a table. As it falls, it gains kinetic energy. But, where does the egg's kinetic energy come from? It comes from the gravitational potential energy that is associated with the egg's initial position on the table relative to the floor.

We know that, the work done on the object against gravity is $W = mgh$. This work done is the energy gained by the object. This is the potential energy (E_p) of the object. That is,

$$E_p = W = mgh$$

The above formula actually represents, change in potential energy $\Delta PE = (U_f - U_i)$. Assuming initial potential energy (U_i) as zero and final potential energy (U_f) = E_p , we get, $E_p = mgh$.

- If in a problem, several masses are involved at different vertical positions, then you can assume the potential energy of the mass at the lowest position as zero and you find the potential energies of other masses with respect to the mass at lowest position.

Elastic potential energy

Suppose a spring is placed on a tabletop and it is fixed at one end.

Now, push a block on the spring, compressing the spring, and then release the block. The block slides across the tabletop. The kinetic energy of the block came from the stored energy in the compressed spring (see fig.11). This potential energy is called **elastic potential energy**.

Elastic potential energy is stored in any compressed or stretched object, such as a spring or the stretched strings of a tennis racket or guitar.

The length of a spring when no external forces are acting on it is called the **relaxed length** of the spring. When an external force compresses or stretches the spring, elastic potential energy is stored in the spring. The amount of energy depends on the distance the spring is compressed or stretched from its relaxed length.

The elastic potential energy stored in a spring is given by,

$$E_p = \frac{1}{2} Kx^2$$

Where, K = spring constant or force constant and x = distance compressed or stretched from the relaxed position of a spring.

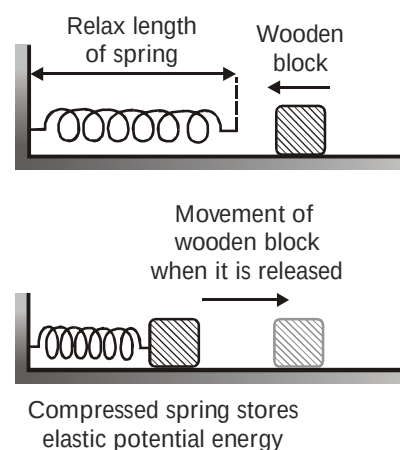


Fig.11 Elastic potential energy of a spring

Some important points relate to work and energy

(1) Net work done on a particle or a system of particles is given by,

$$W_{\text{net}} = W_c + W_{\text{nc}} + W_{\text{ext}}$$

Where, W_c = work done by conservative forces ; W_{nc} = work done by the non conservative forces ;

W_{ext} = work done by external or applied forces.

- Work done by conservative forces like elastic forces, gravitational forces is given by,

$$W_{\text{nc}} = - \text{change in potential energy} = - \Delta PE = - (U_f - U_i) = U_i - U_f$$

Where, U_f = final potential energy ; U_i = initial potential energy

- Work done by non conservative forces like frictional forces, air resistance, etc. is always negative as they are always opposite to displacement.

(2) Net work done by all the forces i.e., the work done by the unbalanced force is always equal to change in kinetic energy.

$$W_{\text{net}} = \Delta KE = K_f - K_i \quad \text{or} \quad \boxed{W_{\text{net}} = \frac{1}{2}mv^2 - \frac{1}{2}mu^2} \quad \text{This is called work-energy theorem.}$$

$$\text{or } W_c + W_{\text{nc}} + W_{\text{ext}} = K_f - K_i$$

(3) **Work done by the spring** : Since elastic forces are conservative forces, the work done by the spring is given by,

$$W = - \Delta PE = - (U_f - U_i) = U_i - U_f \quad \text{or} \quad \boxed{W = \frac{1}{2}Kx_i^2 - \frac{1}{2}Kx_f^2}$$

(4) If non conservative forces are absent, $W_{\text{nc}} = 0$. Then,

$$W_c + W_{\text{ext}} = K_f - K_i \quad \text{or} \quad U_i - U_f + W_{\text{ext}} = K_f - K_i$$

$$\text{or } W_{\text{ext}} = (K_f + U_f) - (K_i + U_i) = E_f - E_i$$

Where, E_f = final mechanical energy ; E_i = initial mechanical energy

(5) If non conservative forces are absent, $W_{\text{nc}} = 0$ and if no external forces are acting, $W_{\text{ext}} = 0$. Then,

$$W_c = K_f - K_i$$

$$\text{or } U_i - U_f = K_f - K_i$$

$$\text{or } U_f + K_f = U_i + K_i \quad \text{or} \quad E_f = E_i$$

Where, E_f = final mechanical energy ; E_i = initial mechanical energy

Thus, in the absence of conservative forces and external forces, total mechanical energy remains conserved or constant.

(6) If a body is lifted with certain acceleration to reach height h , then work done by the external force is given by,

$$W_c + W_{\text{nc}} + W_{\text{ext}} = K_f - K_i$$

$$\text{or } W_c + (0) + W_{\text{ext}} = K_f - K_i \quad [W_{\text{nc}} = 0]$$

$$\text{or } (U_i - U_f) + W_{\text{ext}} = K_f - K_i$$

$$\text{or } (0 - U_f) + W_{\text{ext}} = K_f - K_i \quad [\text{Assuming, } U_i = 0]$$

$$\text{or } W_{\text{ext}} = K_f - K_i + U_f \quad \text{or} \quad \boxed{W_{\text{ext}} = \left(\frac{1}{2}mv^2 - \frac{1}{2}mu^2 \right) + mgh}$$

NUMERICAL CHALLENGE 5.3

1. A 1400 kg car accelerates from 36 km/h to 54 km/h.
 (a) How much work is done on the car ?
 (b) If the car then brakes to a stop, how much work is done on it ?

Solution

- (a) Given, mass of car, $m = 1400$ kg ; initial velocity, $u = 36$ km/h $= 36 \times (5/18) = 10$ m/s ;
 final velocity, $v = 54$ km/h $= 54 \times (5/18) = 15$ m/s

According to work-energy theorem, work done, $W = \text{Change in kinetic energy}$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times 1400 \times [(15)^2 - (10)^2] = \frac{1}{2} \times 1400 \times [225 - 100]$$

$$\text{or } W = \frac{1}{2} \times 1400 \times 125 = 87500 \text{ J} = 8.75 \times 10^4 \text{ J}$$

- (b) If the car is then stopped, then its final velocity becomes zero.

Now, initial velocity, $u = 54$ km/h $= 15$ m/s ; final velocity, $v = 0$

$$\text{Work done, } W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times 1400 \times [(0)^2 - (15)^2] = \frac{1}{2} \times 1400 \times [0 - 225]$$

$$\text{or } W = \frac{1}{2} \times 1400 \times [-225] = -157500 \text{ J} = -1.575 \times 10^5 \text{ J}$$

2. A mass of 2 kg is attached to a light spring of force constant $K = 100$ N/m. Calculate the work done by an external force in stretching the spring by 10 cm from its unstretched position.

Solution

Given, $K = 100$ N/m ; $x_i = 0$; $x_f = 10$ cm $= 0.10$ m

$$\text{Work done by the external force} = - \text{work done by the spring} = - \left(\frac{1}{2}Kx_i^2 - \frac{1}{2}Kx_f^2 \right) = \left(\frac{1}{2}Kx_f^2 - \frac{1}{2}Kx_i^2 \right)$$

$$\text{or } W_{\text{ext}} = \frac{1}{2}K(x_f^2 - x_i^2) = \frac{1}{2}K(x_f^2 - 0) = \frac{1}{2} \times 100 \times [(0.1)^2 - (0)^2] = \frac{1}{2} \times 100 \times 0.01 = 0.5 \text{ J}$$

5.4

Conservation of energy

Energy appears in many forms, such as heat, motion, height, pressure, electricity, and chemical bonds between atoms.

Energy transformations

Energy can be converted from one form to another form in different systems, machines or devices. Systems change as energy flows from one part of the system to another. Parts of the system may speed up, slow down, get warmer or colder, etc. Each change transfers energy or transforms energy from one form to another. For example, friction transforms energy of motion to energy of heat. A bow and arrow transform potential energy in a stretched bow into energy of motion (i.e., kinetic energy) of an arrow.

Law of conservation of energy

Energy can never be created or destroyed, just converted from one form into another. This is called **the law of conservation of energy**.

- The law of conservation of energy is one of the most important laws in physics. It applies to all forms of energy.

Energy has to come from somewhere : The law of conservation of energy tells us energy cannot be created from nothing. If energy increases somewhere, it must decrease somewhere else. The key to understanding how systems change is to trace the flow of energy. Once we know how energy flows and transforms, we have a good understanding of how a system works. For example, when we use energy to drive a car, that energy comes from chemical energy stored in petrol. As we use the energy, the amount left in the form of petrol decreases.

- When a body is dropped from a certain height under gravity then, in the absence of any non conservative forces like air resistance, the total mechanical energy of the body remains constant.
- When a spring fixed at one end and attached with other end is stretched or compressed on a frictionless surface and then allowed to release, it oscillates about its equilibrium position. But its total mechanical energy remains constant.

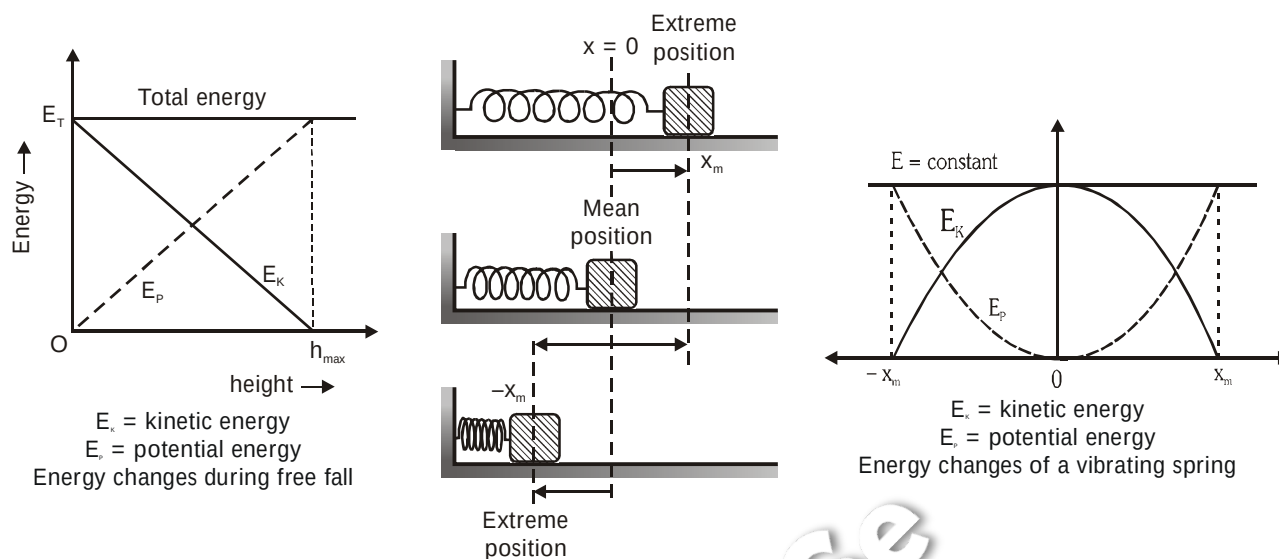


Fig.12 Conservation of energy during free fall and in a spring-mass system

NUMERICAL CHALLENGE 5.4

In fig.13, a frictionless metal block of mass 5.0 kg slides at a speed of 6.0 m/s into a fixed spring bumper with a spring constant of 720 N/m. What is the maximum compression of the block?

Solution

Given, mass, $m = 5 \text{ kg}$; speed, $v = 6 \text{ m/s}$,
spring constant, $K = 720 \text{ N/m}$

At maximum compression, the total kinetic energy will be converted to potential energy, i.e., $E_K = E_P$

$$\text{or } \frac{1}{2}mv^2 = \frac{1}{2}Kx^2 \quad \text{or } mv^2 = Kx^2 \quad \text{or } x = v\sqrt{\frac{m}{K}} = 6 \times \sqrt{\frac{5}{720}} = 6 \times \sqrt{\frac{1}{144}} = \frac{6}{12} = 0.5 \text{ m}$$

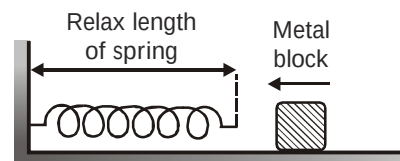


Fig.13 Numerical challenge 6.5

5.5

Power

The engine in an old school bus could, over a long period of time, do as much work as jet engines do when a jet takes off. However, the school bus engine could not begin to do work fast enough to make a jet lift off. In this and many other applications, the rate at which work is done is more critical than the amount of work done.

Power is the rate at which work is done. Power can also be defined as the rate at which energy is transferred.

$$P = \frac{\text{Work done}}{\text{time taken}} = \frac{W}{t}$$

SI unit of power : Watt (W)

1 Watt = 1 joule/second

or $1 \text{ W} = 1 \text{ J s}^{-1}$

Definition of 1 watt : If 1 joule work is done per second by a device or a machine then the power of that device or machine is 1 watt.

$$\bullet \text{ We know that, } P = \frac{\text{Work done}}{\text{time taken}} = \frac{W}{t} = \frac{F \times s}{t} = F \times \left(\frac{s}{t}\right) = F \times v$$

NUMERICAL CHALLENGE 5.5

1. A car with a mass of 1.50×10^3 kg starts from rest and accelerates to a speed of 18.0 m/s in 12.0 s. Assume that the force of resistance remains constant at 400.0 N during this time. What is the power developed by the car's engine ?

Solution

Given, mass, $m = 1.50 \times 10^3$ kg ; initial velocity, $u = 0$; final velocity, $v = 18$ m/s ; time, $t = 12$ s ;

force of resistance, $F_r = 400$ N

Now, from first equation of motion,

$$v = u + at \quad \text{or} \quad 18 = 0 + a(12) \quad \text{or} \quad a = (18/12) = 1.5 \text{ m/s}^2$$

$$\text{Net force, } F_n = ma = 1.50 \times 10^3 \times 1.5 = 2250 \text{ N}$$

Also, net force, $F_n = \text{Force developed by car's engine} - \text{Force of resistance}$

$$\text{or } F_n = F_c - F_r \quad \text{or} \quad F_c = F_n + F_r = 2250 \text{ N} + 400 \text{ N} = 2650 \text{ N}$$

$$\text{Displacement, } s = \left(\frac{v+u}{2} \right) t = \left(\frac{18+0}{2} \right) \times 12 = 108 \text{ m}$$

$$\text{Work done by car's engine, } W = F \times s = 2650 \times 108 \text{ J}$$

$$\text{Power developed by car's engine, } P = \frac{W}{t} = \frac{2650 \times 108}{12} = 23850 \text{ W} = 2.385 \times 10^4 \text{ W}$$

2. A man exerts a force of 200 N in pulling a cart at a constant speed of 16 m/s. Calculate the power spent by man.

Solution

Given, force, $F = 200$ N ; speed, $v = 16$ m/s

$$\text{Power, } P = F \times v = 200 \times 16 = 3200 \text{ Watt}$$

3. Calculate the power of an engine required to lift 10^5 kg of coal per hour from a mine 360 m deep. ($g = 10 \text{ m/s}^2$).

Solution

Given, mass, $m = 10^5$ kg ; $t = 1 \text{ hr} = 3600$ s ; $h = 360$ m ; $g = 10 \text{ m/s}^2$

Since, work is done against gravity, thus, work done, $W = mgh$

$$\text{Power of the engine, } P = \frac{W}{t} = \frac{mgh}{t} = \frac{10^5 \times 10 \times 360}{3600} = 10^5 \text{ W}$$

Commercial unit of energy

The unit joule is an extremely small unit, it is inconvenient to express large quantities of energy in terms of joule. We use a bigger unit of energy called kilowatt hour (kWh). It is called commercial unit of energy.

Definition of 1 kWh : If a machine or a device of power 1 kW or 1000 W is used continuously for one hour, it will consume 1 kW h of energy. Thus, 1 kWh is the energy used in one hour at the rate of 1000 W (or 1 kW).

$$1 \text{ kW h} = 1 \text{ kW} \times 1 \text{ h} = 1000 \text{ W} \times 3600 \text{ s} = 3600000 \text{ J} \quad \text{or} \quad 1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$