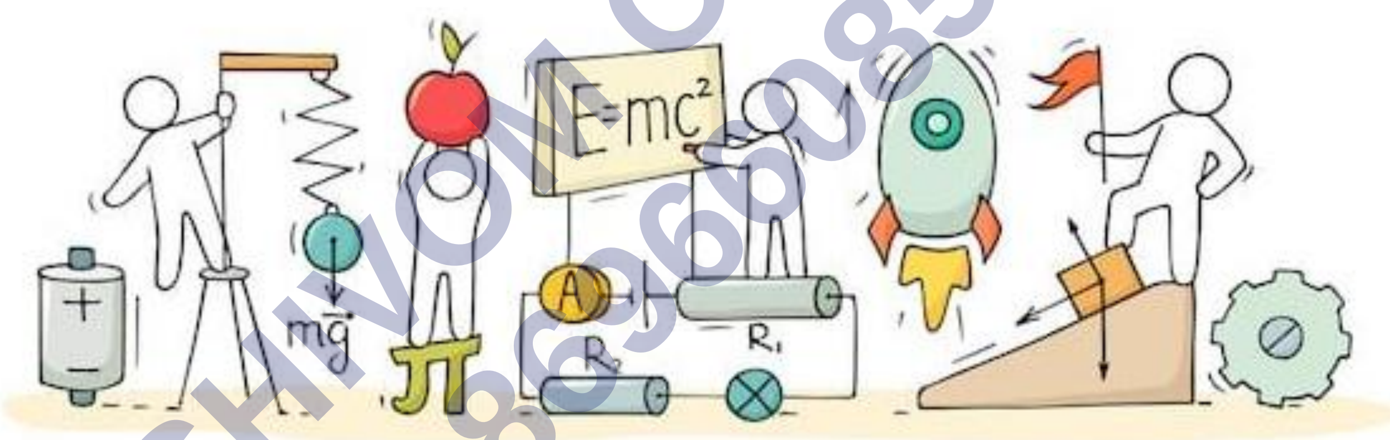
PHYSICS

Chapter 6: Work, Energy and Power



Work, Energy and Power

Introduction

Work, Energy and Power are fundamental concepts of Physics. Work is said to be done when a force (push or pull) applied to an object causes a displacement of the object. We define the capacity to do the work as energy. Power is the work done per unit of time.

We use the words work, energy and power in our day-to-day life often.

However, their meaning differ from the meaning we get from scientific definitions.

Formula of Work

The work done by a force is defined to be the product of the component of the force in the direction of the displacement and the magnitude of this displacement.

$$W = F\cos\Theta = \vec{F}\vec{d}$$

Where **W** is the work done, **F** is the force, **d** is the displacement, **θ** is the angle between force and displacement and **F cosθ** is the component of force in the direction of displacement.

We understand from the work equation that if there is no displacement, there is no work done, irrespective of how large the force is. To summarize, we can say that no work is done if:

- the displacement is zero
- the force is zero
- the force and displacement are mutually perpendicular to each other.

Unit of Work

The SI unit of work is Joule (J). For example, if a force of 5 newtons is applied to an object and moves 2 meters, the work done will be 10 newton-meter or 10 Joule. It should be noted that 1 J = 1 N · m = 1 kg · m_2/s_2.

Work done by a variable force

The variable force is more commonly encountered than the constant force.

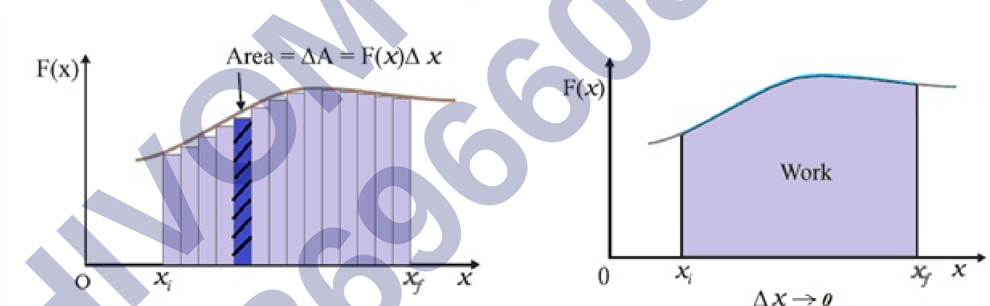
If the displacement Dx is small, we can take the force F (x) as approximately constant, and the work done is then

DW =F (x) Dx

For total work, we add all work done along small displacements.

$$W = \lim_{x \to 0} \Sigma_{x_i}^{x_f} F(x) \Delta x$$

$$W = \int_{x_i}^{x_f} F(x)\, dx$$



The Work-Energy Theorem for a Variable Force

- $\frac{dK}{dt} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right) = \frac{dK}{dt} = m\left(\frac{dv}{dt}\right)v$
- Since dv/dt is acceleration, m.a becomes force $\frac{dK}{dt} = Fv = F\,\frac{dx}{dt}$
- dK = F dx , integrating this equation we get $K_f - K_i = W$

The force you apply to pull the dumbbells is variable, not constant always

Energy

Energy is the ability to perform work. Energy can neither be created nor destroyed, and it can only be transformed from one form to another. The unit of Energy is the same as of Work, i.e. Joules. Energy is found in many things, and thus there are different types of energy.

All forms of energy are either kinetic or potential. The energy in motion is known as Kinetic Energy, whereas Potential Energy is the energy stored in an object and is measured by the amount of work done.

Types of Energy

Some other types of energy are given below:

Mechanical energy

Mechanical wave energy

Chemical energy

Electric energy

Magnetic energy

Radiant energy

Nuclear energy

Ionization energy

Elastic energy

Gravitational energy

Thermal energy

Heat Energy

Unit of Energy

The SI unit of energy is Joules (J), named in honour of James Prescott Joule.

Kinetic energy

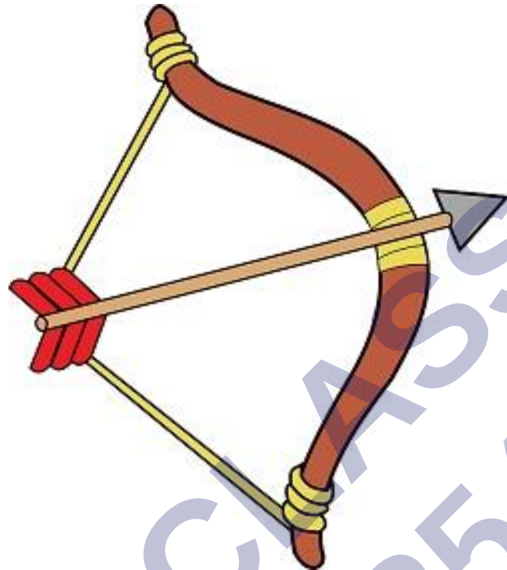
The kinetic energy of an object is a measure of the work an object can do by the virtue of its motion.

If an object of mass m has velocity v, its kinetic energy K is

Kinetic energy is a scalar quantity.

Potential energy

Potential energy is the 'stored energy' by virtue of the position or configuration of a body.



Physically, the notion of potential energy is applicable only to the class of forces where work done against the force gets 'stored up' as energy.

Mathematically, the potential energy V(x) is defined, if the force F(x) can be written as

$$F(x) = -\frac{dV}{dx}.$$

$$\int_{x_i}^{x_f} F(x) = V_i - V_f$$

This relation is valid only for Conservative Forces

Potential energy of spring

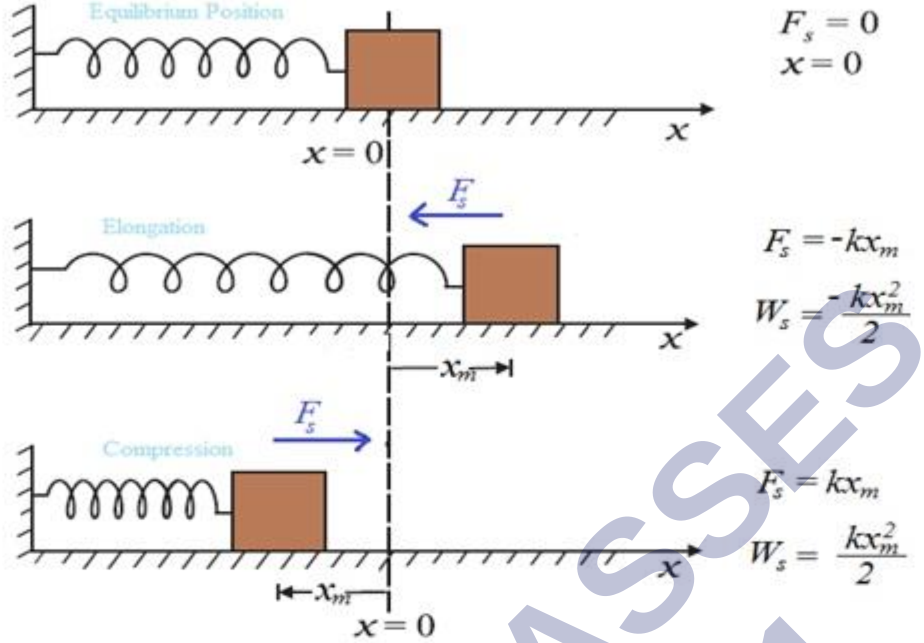
The spring force is an example of a variable force, which is conservative.

In an ideal spring, $F_s = -kx$, this force law for the spring is called Hooke's law.

The constant k is called the spring constant. Its unit is N m^{-1}.

The spring is said to be stiff if k is large and soft if k is small.

$$W_s = -\int_{x_i}^{x_f} kx\,dx$$



Spring force is position dependent as first stated by Hooke, ($F_s = -kx$)

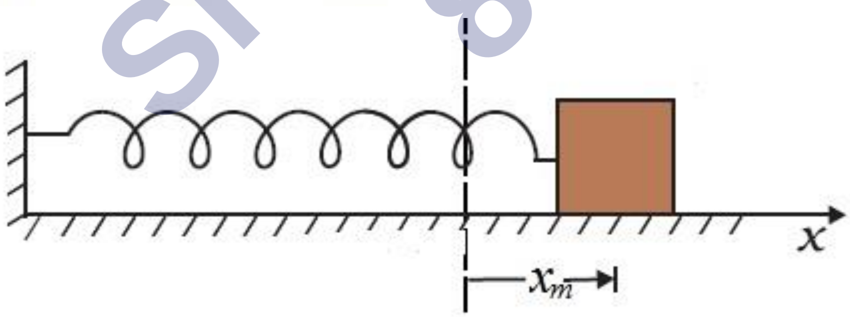
Work done by spring force only depends on the initial and final positions. Thus, the spring force is a conservative force.

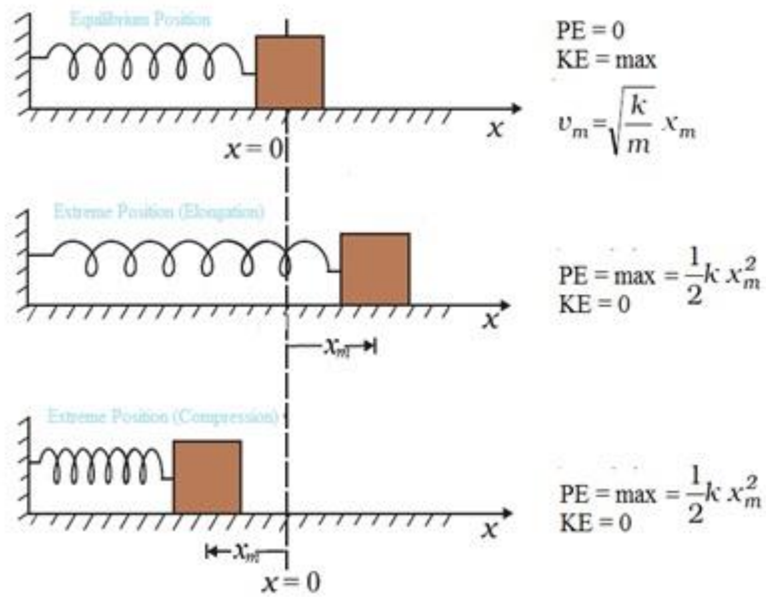
We define the potential energy V(x) of the spring to be zero when block and spring system is in the equilibrium position.

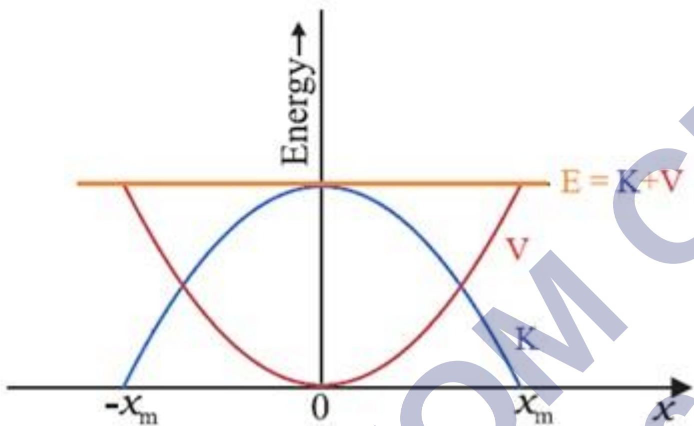
For an extension (or compression) x, $V(x) = \frac{kx^2}{2}$

If the block of mass m is extended to x_m and released from rest, then its total mechanical energy at any arbitrary point x (where x lies between $-x_m$ and $+x_m$) will be given by:

$$\frac{1}{2}kx_m^2 = \frac{1}{2}kx^2 + \frac{1}{2}mv^2$$







Various forms of energy

Heat: The work done by friction is not 'lost', but is transferred as heat energy


When you rub hands heat is produced due to friction

Chemical Energy:

Chemical energy arises from the fact that the molecules participating in the chemical reaction have different binding energies.

If the total energy of the reactants is more than the products of the reaction, heat is released and the reaction is said to be an exothermic reaction.

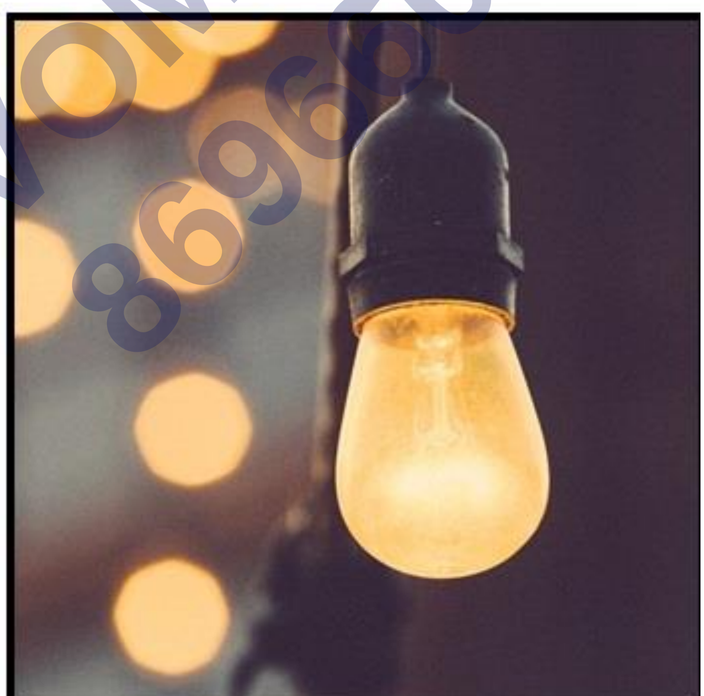
Example- When you freeze water you remove energy from water to lower its temperature and its phase is changed to ice, so it is a exothermic process

If the reverse is true, heat is absorbed, and the reaction is endothermic.

Example- While melting the ice you provide energy to the ice to increase its temperature and change its phase to water, so it is a endothermic process.

We get energy from fire because of the chemical reaction,combustion, occurs

Electrical Energy: The flow of electrical current causes bulbs to glow, fans to rotate and bells to ring. Energy is associated with an electric current.



Bulbs Light up beacuse of the electrical energy flowing

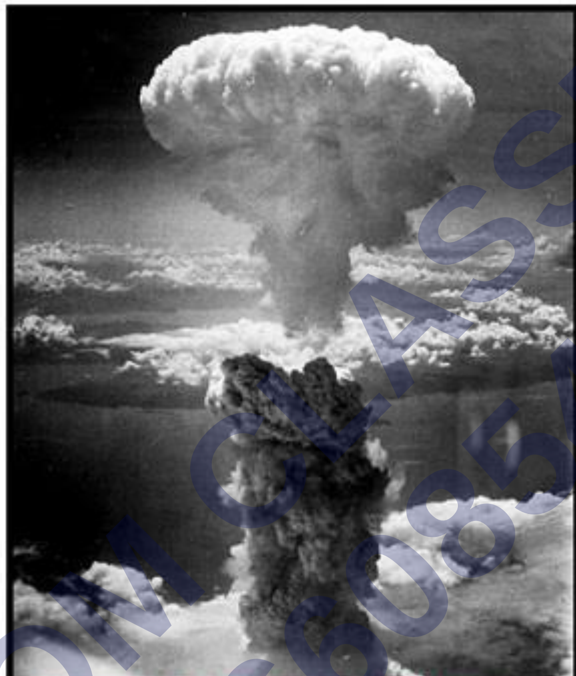
Nuclear Energy:

The energy released from the nuclear reactions, either fission or fusion, is called as nuclear energy.

Nuclear fusion and fission are manifestations of the equivalence of mass and energy.

In fusion light atom nuclei like Hydrogen fuse to form a bigger nucleus whose mass is less than the sum of the masses of the reactants.

In fission, a heavy nucleus like uranium $^{235}U_{92}$, is split by a neutron into lighter nuclei. Once again the final mass is less than the initial mass and the mass difference translates into energy.



Nuclear Bomb releases a great amount of energy

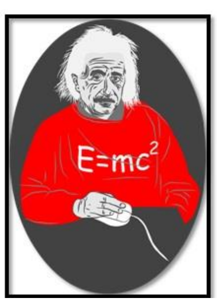
The Equivalence of Mass and Energy

Physicists believed that in every physical and chemical process, the mass of an isolated system is conserved till Albert Einstein show the relation, $E = m c^2$ where c, the speed of light in vacuum is approximately 3×10^8 m s^{-1}.

This equation showed that mass and energy are equivalent and are related by $E = m c^2$.

If there is a difference between the sum of reactants and products that difference, Dm, is called mass defect.

In case of chemical reactions the mass defect is very small and can be neglected, but in the case of nuclear reactions this becomes significant.

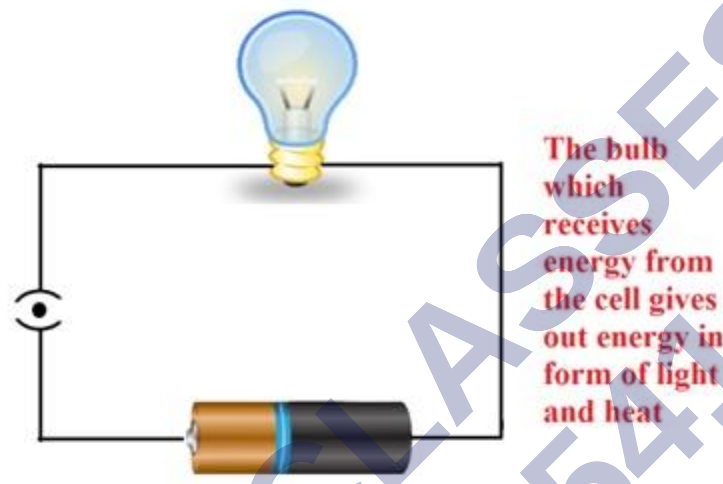


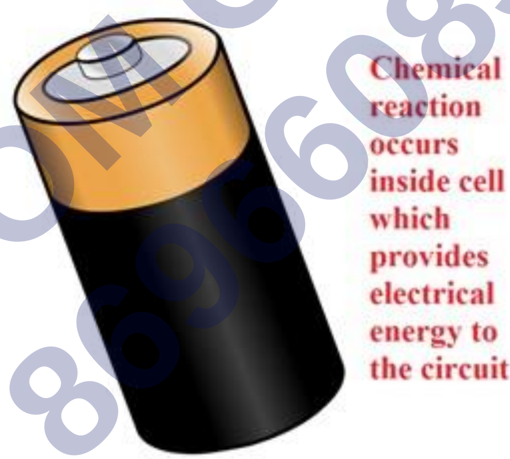
Principle of Conservation of Energy

If the forces involved are non-conservative, part of the mechanical energy may get transformed into other forms such as heat, light and sound.

However, the total energy of an isolated system does not change.

Since the universe as a whole may be viewed as an isolated system, the total energy of the universe is constant.





Collosion

A collision is an event in which two or more bodies exert forces on each other for a relatively short time.

In all collisions the total linear momentum is conserved.

The total impulse on the first object is equal and opposite to that on the second, if two bodies collide.

Elastic collision is when the initial Kinetic energy is equal to the final kinetic energy.

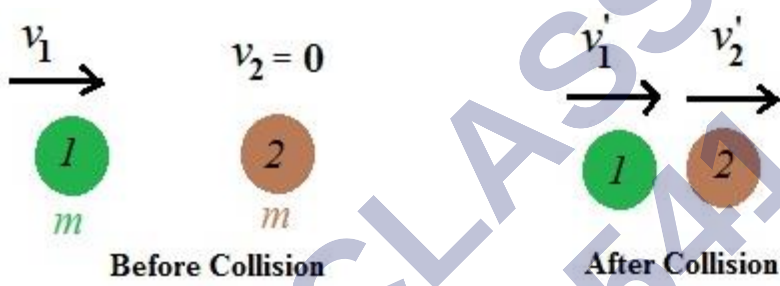
Inelastic collision is when some of the kinetic energy is lost after collision.

Completely inelastic collision is when the bodies after collision move together.

Collision in 1-D

If the initial velocities and final velocities of both the bodies are along the same straight line, then it is called a one-dimensional collision, or head-on collision.

Elastic collision:



(A ball of mass m1 with initial velocity v_1 strikes a ball of mass m_2 initially at rest and after collision ball 1 moves with velocity v'_1 and ball 2 moves with velocity v'_2, in the same direction)

Momentum conservation: $m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$

KE conservation: $m_1 v_1^2 + m_2 v_2^2 = m_1 v'^2_1 + m_2 v'^2_2$

Where m_1, m_2 are the masses of the two blocks

v_1 is initial velocity of block 1, v_2=0 here

v'_1 is final velocity of block 1

After solving these two equations we get,

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} v_1$$

$$v_2' = \frac{2\, m_1}{m_1 + m_2} v_1$$

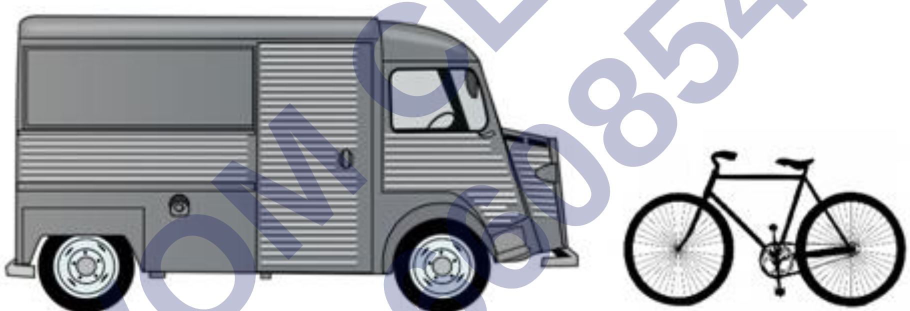
Special cases in elastic collision:

Case 1 – If the two masses are equal m_1=m_2, then, v_1' = 0 & v_2' = v_1

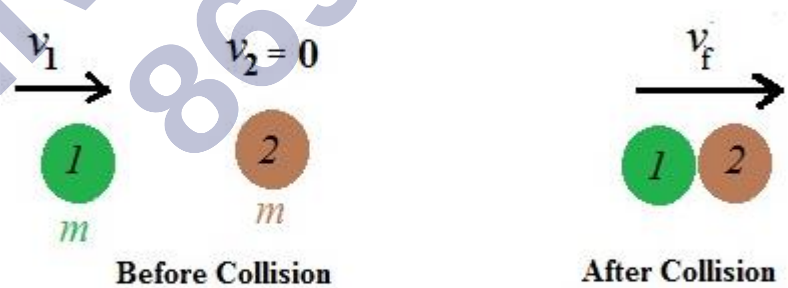
The first mass comes to rest and pushes off the second mass with its initial speed on collision.

Case 2 – If $m_2 >> m_1$ then, $v_1' » -v_1$ & $v_2' » 0$

The heavier mass is undisturbed while the lighter mass reverses its ve



Completely inelastic collision



(A ball of mass m_1 with initial velocity v_1 strikes a ball of mass m_2 initially at rest and the two ball stick to each other after collision, in the same direction)

Momentum conservation: $m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$

$$v_f = \frac{m_1}{m_1 + m_2} v_1$$

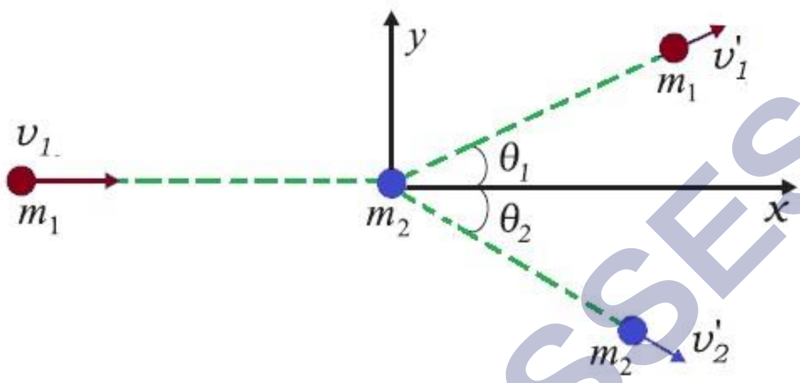
KE conservation: $m_1 v_1^2 + m_2 v_2^2 = (m_1 + m_2) v_f^2$

Where m_1, m_2 are the masses of the two blocks

v_1 is initial velocity of block 1, $v_2 = 0$ here

v_f is final velocity of the two block moving together

Collosions in 2-D



(A ball of mass m_1 with initial velocity v_1 strikes a ball of mass m_2 initially at rest after collision, ball 1 moves with velocity v'1 and ball 2 moves with velocity v'2 with directions as shown in figure)

- Momentum conservation :

  x-axis : $m_1 v_1 = m_1 v_1' cos\theta_1 + m_2 v_2' cos\theta_2$

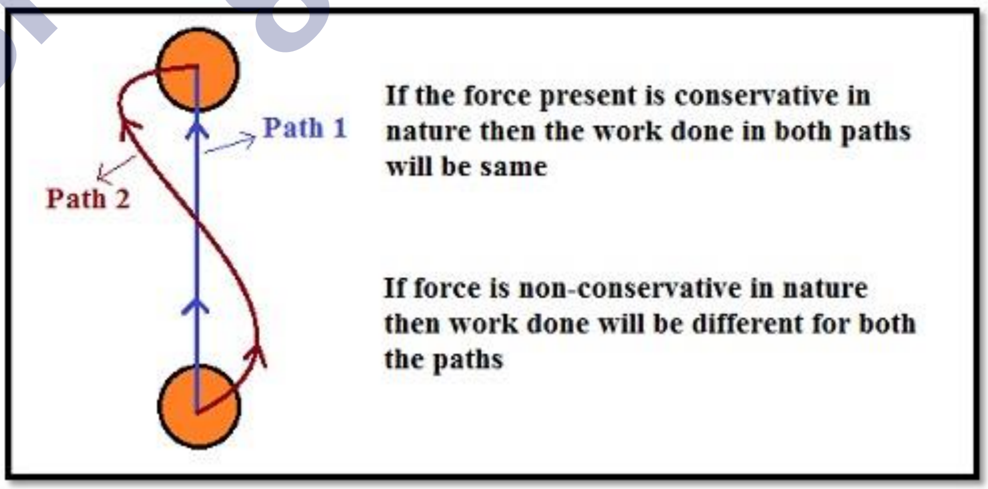
  y-axis : $0 = m_1 v_1' \, sin\theta_1 - m_2 v_2' \, sin\theta_2$

- If collision is elastic , Kinetic Energy conservation :

  $\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 \, v_2'^2$

With the above equations we have to solve the problem

Conservative & Non-Conservative Forces



Conservative forces are those for which work done depends only on initial and final points.

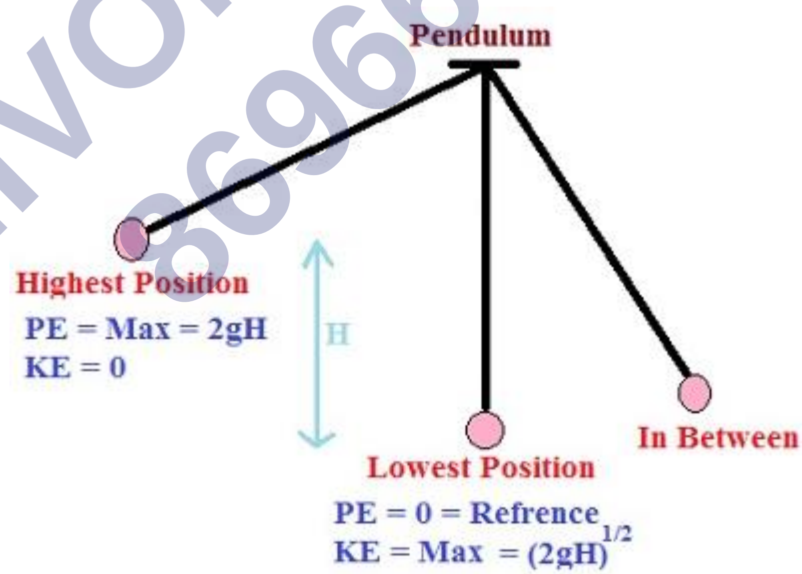
Example- Gravitational force, Electrostatic force.

Non-Conservative forces are those where the work done or the kinetic energy did depend on other factors such as the velocity or the particular path taken by the object.

Example- Frictional force.

The Conservation of Mechanical Energy

- Mechanical Energy is the energy associated with the motion and position of an object.
- The quantity K +V(x), is called the total mechanical energy of the system.
- For a conservative force, $\Delta K = \Delta W = F(x)\ \Delta x$
- Also, $-\ V(x) = F(x)\ \Delta x$
- This employs $\Delta(K+V) = 0$ for a conservative force.
- Individually the kinetic energy K and the potential energy V(x) may vary from point to point, but the sum is a constant.
- Conservative Force:
- A force F(x) is conservative if it can be derived from a scalar quantity V(x) by the relation: $F(x) = -\frac{dv}{dx}$
- The work done by the conservative force depends only on the end points.
- A third definition states that the work done by this force in a closed path is zero.
- The total mechanical energy of a system is conserved if the forces, doing work on it, are conservative.



Power

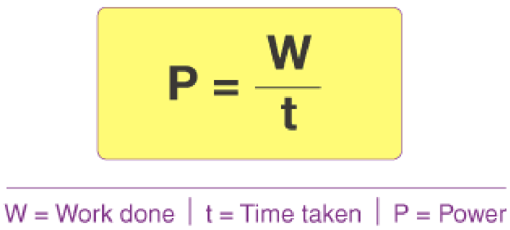
Power is a physical concept with several different meanings, depending on the context and the available information. We can define power as the rate of doing work, and it is the amount of energy consumed per unit of time.

Formula of Power

As discussed, power is the rate of doing work. Therefore, it can be calculated by dividing work done by time.

$$P = \frac{W}{t}$$

Where, P is the power, W is the work done and t is the time taken.



Unit of Power

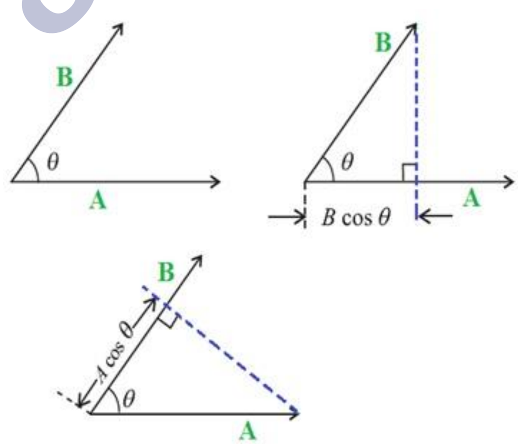
As power doesn't have any direction, it is a scalar quantity. The SI unit of power is Joules per Second (J/s), which is termed as Watt. Watt can be defined as the power needed to do one joule of work in one second. The unit Watt is dedicated in honour of Sir James Watt, the developer of the steam engine.

Scalar product

The scalar product or dot product of any two vectors A and B, denoted as A.B (Read A dot B) is defined as, where q is the angle between the two vectors.

A, B and cos θ are scalars, the dot product of A and B is a scalar quantity. Both vectors, A and B, have a direction but their scalar product does not have a direction.

B is the product of the magnitude of A and the component of B along A. Alternatively, it is the product of the magnitude of B and the component of A along B.



- B = B.A , i.e. Scalar product is commutative.
- (B + C) = A.B + A.C , i.e. Scalar product is distributive.

- Further, λ A. (λ B) = λ (A.B) where λ is a real number.

$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{z}$ & $\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{z}$ then the scalar product

$\vec{A}.\vec{B} = A_xB_x + A_yB_y + A_zB_z$

Top Formulae

The Scalar Product	**A.B** = AB cos θ
The scalar product follows the commutative law	**A.B = B.A**
The scalar product follows the distributive law	**A. (B + C) = A.B + A.C** λ **A. (**λ **B) =** λ **(A.B)** Where λ is a real number
Work	W = (F cos θ) d = **f·d**
Kinetic energy	$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
The equivalence of mass and energy	$E = m c^2$
Average power	$P_{av} = \frac{W}{t}$
Instantaneous power	$P = \frac{dW}{dt}$ P = **F·v**
Unit of power	horsepower (hp) 1 hp = 746 W 1 kWhr = 1000 (watt) × 1 (hour) = 1000 watt hour = 1 kilowatt hour (kWh) = 10^3 (W) × 3600 (s) = 3.6×10^6 J
Collisions in one dimension	$v_{1f} = \frac{(m_1 - m_2)}{m_1 + m_2} V_{1i}$ $v_{2f} = \frac{2m_1 v_{1i}}{m_1 +}$ If the two masses are equal, $v_{1f} = 0$ $v_{2f} = v_{1f}$

	If one mass dominates, e.g. $m_2 >> m_1$ $v_{1f} : -v_{1f}$ $v_{2f} : 0$
Work done by a variable force	W = $\int_{r_1}^{r_2} \vec{F}.d\vec{r}$ = Area under the F – r curve and position axis $W = \int_{x_1}^{x_2} F_x\,dx + \int_{y_1}^{y_2} F_y\,dy + \int_{z_1}^{z_2} F_z\,dz$
Work done by a spring force	$W = \frac{1}{2}kx_2^2 = \frac{1}{2}kx_1^2$ if $x_1 = 0$ and $x_2 = x$. Then $W = \frac{1}{2}kx^2$
For conservative force	$W_{AB.\,1} = W_{AB.\,2}$
For non-conservative force	$W_{AB.\,1} \neq W_{AB.\,2}$
Potential energy	(i) Of a system is always defined corresponding to a conservative internal force. (ii) Change in PE = Work done by the internal conservative force on the system $\Delta U = U_f - U_i = -W_c = -\int \vec{F}_c.d\vec{r}$
Gravitational potential energy	PE near the Earth's surface with respect to the ground = mgh
Spring potential energy	$= \frac{1}{2}kx^2$

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Work, Energy, and Power

Collision

An instance of one moving body striking against another

Types

Perfectly Elastic Collision
- Total mechanical/kinetic energy is conserved.
- Momentum is conserved.

Perfectly Inelastic Collision
- Total energy and linear momentum conserved.
- Kinetic energy not conserved.

power (P)

Rate of doing work

$$P = \frac{\text{Work}(w)}{\text{Time}(t)}$$

$$P_{inst.} = \vec{F}\cdot\frac{\vec{ds}}{dt} = \vec{F}\cdot\vec{v}$$

1hp=746watt
1kWH=3.6×10^6J

Work (w)

Work is said to be done when force produces displacement.

Work done by constant force

$$W = Fs\cos\theta = \vec{F}\cdot\vec{s}$$

Work done by a variable force

$$W = \int_{s_1}^{s_2} Fds\cos\theta = \int_{s_1}^{s_2}\vec{F}\cdot\vec{ds}$$

Types

Positive Work
When force (F) and displacement (S) are in same direction.
W will be +ve when $0<\theta<\frac{\pi}{2}$

Negative Work
When force (F) and displacement (S) are in opposite direction.
W will be (-ve) when $\frac{\pi}{2}<\theta<\pi$

Zero work
When force and displacement are perpendicular to each other. W = zero when $\theta = \frac{\pi}{2}$

Energy

Capacity of doing work

Various forms
Heat Energy
Chemical Energy
Electrical Energy
Nuclear Energy

Formula
Equivalence of mass and Energy
$E=\Delta mc^2$

law of conservation of Energy
Energy can neither be created nor destroyed; it can only be transformed from one form to another.

Work Energy theorem
Change in Kinetic Energy = Work done by net force on the body i.e;
$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = W$$

Types of mechanical energy

Potential Energy
By virtue of position
$E_p = mgh$

Kinetic Energy
By virtue of velocity
$$E_K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

Potential Energy of Spring
$$U = \frac{1}{2}kx^2$$
k= spring constant

Important Questions

Multiple Choice questions-

1. When a force of 50 N acts on a body, the body is displaced through a distance of 3 m in a direction normal to the direction of the force. The work done by the force

(a) 150 J

(b) 1470 J

(c) Zero

(d) -150 J

2. A body of mass 20 kg is initially at a height of 3 m above the ground. It is lifted to a height of 2 m from that position. Its increase in potential energy is

(a) 100 J

(b) 392 J

(c) 60 J

(d) -100 J

3. A wooden cube having mass 10 kg is dropped from the top of a building. After 1 s, a bullet of mass 20 g fired at it from the ground hits the block with a velocity of 1000 m/s at an angle of 30° to the horizontal moving upwards and gets imbedded in the block. The velocity of the block/bullet system immediately after the collision is

(a) 17 m/s

(b) 27 m/s

(c) 52 m/s

(d) 10 m/s

4. A body of mass 10 kg is moved parallel to the ground, through a distance of 2 m. The work done against gravitational force is

(a) 196 J

(b) -196 J

(c) 20 J

(d) zero

5. A quantity of work of 1000 J is done in 2 seconds. The power utilized is

(a) 998 W

(b) 1002 W

(c) 2000 W

(d) 500 W

6. A body of mass 1 kg travels with a velocity of 10 m/s, this a wall and rebounds. If 50% of its initial energy is wasted as heat, its kinetic energy at the instant of rebounding is

(a) 20 J

(b) 60 J

(c) 50 J

(d) 25 J

7. A marble moving with some velocity collides perfectly elastically head-on with another marble at rest having mass 1.5 times the mass of the colliding marble. The percentage of kinetic energy by the colliding marble after the collision is

(a) 4

(b) 25

(c) 44

(d) 67

8. A particle of mass m is moving in a horizontal circle of radius r under a centripetal force given by ($-kr^2$) where k is a constant , then

(a) the total energy of the particle is ($- k/2r$)

(b) the kinetic energy of the particle is (k/r)

(c) the potential energy of the particle is ($k/2r$)

(d) the kinetic energy of the particle is ($- k/r$)

9. A sphere of mass m moving with a constant velocity u hits another stationary sphere of the same mass. If e is the coefficient of restitution, then the ratio of velocity of the two spheres after the collision will be

(a) $1 – e / 1 + e$

(b) $1 + e / 1 – e$

(c) $e + 1 / e – 1$

(d) $e – 1 / e + 1$

10. Two masses 1 g and 4 g are moving with equal kinetic energies.s The ratio of the magnitudes of their linear momenta is

(a) 4 : 1

(b) 0 : 1

(c) 1 : 2

(d) 1 : 6

Very Short:

1. What is the source of the kinetic energy of the falling raindrops?
2. A spring is stretched. Is the work done by the stretching force positive or negative?
3. What is the type of collision when?

   (a) Does a negatively charged body collide with a positively charged body?

   (b) Do macroscopic bodies collide?

   (c) Do two quartz balls collide?
4. (a) Give two examples of potential energy other than gravitational potential energy.

   (b) Give an example of a device that converts chemical energy into electrical energy.

   (c) Heat energy is converted into which type of energy in a steam engine?

   (d) Where is the speed of the swinging pendulum maximum?

   (e) A heavy stone is lowered to the ground. Is the work done by the applied force positive or negative?
5. What is the work done by the centripetal force? Why?
6. (a) What is the work done by the tension in the string of simple pendulum?

   (b) What is the work done by a porter against the force of gravity when he is carrying a load on his hand and walking on a horizontal platform?

   (c) Name the force against which the porter in part (A) is doing some work.
7. When an arrow is shot, wherefrom the arrow will acquire its K.E.?
8. When is the exchange of energy maximum during an elastic collision?
9. Does the work done in raising a load onto a platform depend upon how fast it is raised?
10. Name the parameter which is a measure of the degree of elasticity of a body.

Short Questions:

1. An airplane's velocity is doubled,

   (a) What happens to its momentum? Is the law of conservation of momentum obeyed?

(b) What happens to its kinetic energy? Is the law of conservation of energy obeyed?

2. In a thermal station, coal is used for the generation of electricity. Mention how energy changes from one form to the other. before it is transformed into electrical energy?
3. Chemical, gravitational and nuclear energies are nothing but potential energies for different types of forces in nature. Explain this statement clearly with examples.
4. What went wrong at the Soviet atomic power station at Chernobyl?
5. A man can jump higher on the moon than on Earth. With the same effort can a runner improve his timing for a 100 m race on the moon as compared to that on Earth?
6. How many MeV are there in a 1-watt hour?
7. What is Newton's experimental law of impact?
8. Two masses one n times as heavy as the other have the same K.E. What is the ratio of their momenta?

Long Questions:

1. (a) State work-energy theorem or principle.

   (b) State and prove the law of conservation of energy.

Assertion Reason Questions:

1. ***Directions:*** Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

   (a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.
   (b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion
   (c) Assertion is correct, reason is incorrect
   (d) Assertion is incorrect, reason is correct.

Assertion: A work done by friction is always negative.
Reason: If frictional force acts on a body its K.E. may decrease.

2. ***Directions:*** Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

(a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.
(b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion
(c) Assertion is correct, reason is incorrect
(d) Assertion is incorrect, reason is correct.

Assertion: The work done in moving a body over a closed loop is zero for every force in nature.
Reason: Work done depends on nature of force.

Case Study Questions:

1. The scalar product or dot product of any two vectors A and B, denoted as A.B (read A dot B) is defined as

   A.B = A B cos θ

   Where q is the angle between the two vectors. Since A, B and cos θ are scalars, the dot product of A and B is a scalar quantity. Each vector, A and B, has a direction but their scalar product does not have a direction. Following are properties of dot product

   - the scalar product follows the commutative law: A.B = B.A
   - Scalar product obeys the distributive law: (B + C) = A.B + A.C Further, A. (λ B) = λ (A.B) where λ is a real number.
   - For unit vectors i, j, k we have

   i × i = j × j = k × k = 1 and i × j = j × k = k × i = 0

   - A x A = |A | |A| cos 0 = A^2.
   - B = 0, if A and B are perpendicular.

The work done by the force is defined to be the product of component of the force in the direction of the displacement and the magnitude of this displacement. Thus

W = (F cos θ) d = F.d (We see that if there is no displacement, there is no work done even if the force is large. Work has only magnitude and no direction. Its SI unit is (N m) or joule (J). Thus, when you push hard against a rigid brick wall, the force you exert on the wall does not work.

No work is done if:

- The displacement is zero.
- The force is zero. A block moving on a smooth horizontal table is not acted upon by Horizontal force (since there is no friction) but may undergo a large displacement.
- The force and displacement are mutually perpendicular. This is so since, for θ = π/2 rad

- Cos (π/2) = 0. For the block moving on a smooth horizontal table, the gravitational force mg does no work since it acts at right angles to the displacement. If we assume that the moon's orbits around the earth are perfectly circular, then the earth's gravitational force does not work. The moon's instantaneous displacement is tangential while the earth's force is radially inwards and θ = π/2.

   i. Scalar product A.B = B.A is
      a. Commutative law
      b. Distributive law
      c. Both a and b
      d. None of these
   ii. When force acts in the direction of displacement then work done will be
      a. Positive
      b. Negative
      c. Both a and b can possible
      d. None of these
   iii. Define scalar product. give its properties
   iv. Define work done. Give its SI unit
   v. Write down the conditions for which work done is zero

2. The kinetic energy possessed by an object of mass, m and moving with a uniform velocity, v is

$$K = \frac{1}{2} * mv^2 = \frac{1}{2} v.v$$

Kinetic energy is a scalar quantity. The kinetic energy of an object is a measure of the work and the energy possessed by an object is thus measured in terms of its capacity of doing work. The unit of energy is, therefore, the same as that of work, that is, joule (J).

Work energy theorem: The change in kinetic energy of a particle is equal to the work done on it by the net force. Mathematically

$$K_f - K_i = W$$

Where K_i and K_f are respectively the initial and final kinetic energies of the object. Work refers to the force and the displacement over which it acts. Work is done by a force on the body over a certain displacement.

   i. Kinetic energy is

a. Scalar quantity
b. Vector quantity
c. None of these

ii. Which of the following has same unit?
a. Potential energy and work
b. Kinetic energy and work
c. Force and weight
d. All of the above

iii. What is work energy theorem?

iv. Kinetic energy is scalar quantity. Justify the statement.

v. Give formula for kinetic energy of body.

✓ Answer Key:

Multiple Choice Answers-

1. Answer: (c) Zero
2. Answer: (b) 392 J
3. Answer: (a) 17 m/s
4. Answer: (d) zero
5. Answer: (d) 500 W
6. Answer: (d) 25 J
7. Answer: (a) 4
8. Answer: (a) the total energy of the particle is (- k/2r)
9. Answer: (a) 1 – e / 1 + e
10. Answer: (c) 1 : 2

Very Short Answers:

1. Answer: It is the gravitational potential energy that is converted into kinetic energy.
2. Answer: Positive because the force and the displacement are in the same direction.
3. Answer:

(a) Perfectlyjnelastic collision.

(b) Inelastic collision.

(c) Perfectly elastic collision.

4. Answer:

(a) Electrostatic P.E. and elastic P.E.

(b) Daniell cell.

(c) Mechanical energy.

(d) At the bottom of the swing.

(e) Negative work.

5. Answer: Zero. This is because the centripetal is always perpendicular to the displacement.

6. Answer:

(a) zero

(b) zero

(c) Frictional force.

7. Answer: It is the potential energy of the bent bow which is converted into K.E.

8. Answer: When two colliding bodies are of the same mass, there will be a maximum exchange of energy.

9. Answer: The work done is independent of time.

10. Answer: Coefficient of restitution.

Short Questions Answers:

1. Answer:

(a) The momentum of the airplane will be doubled. Yes, the law of conservation of momentum will also be obeyed

because the increase in momentum of the airplane is simultaneously accompanied by an increase in momentum of exhaust gases.

(b) K.E. becomes four times. Yes, the law of conservation of energy is obeyed with the increase in K.E. coming from the chemical energy of fuel i. e. from the burning of its fuel.

2. Answer: When coal is burnt, heat energy is produced which converts water into steam. This steam rotates the turbine and thus heat energy is converted into mechanical energy of rotation. The generator converts this mechanical energy into electrical energy.

3. Answer: A system of particles has potential energy when these particles are held a certain distance apart against some force. For example, chemical energy

is due to the chemical bonding between the atoms. Gravitational energy arises when the objects are held at some distance against the gravitational attraction.

Nuclear energy arises due to the nuclear force acting between the nuclear particles.

4. Answer: In this reactor, graphite was used as a moderator. The fuel elements were cooled by water and steam was produced from within the reactor. Both water and the steam came in contact with hot graphite. Due to this hydrogen and carbon-monoxide (CO) were released. When they came in contact with air, there was a big explosion.

5. Answer: Man can jump higher on the moon because the acceleration due to gravity on the moon is less than that on the Earth. But acceleration due to gravity does not affect the horizontal motion. Hence the runner can't improve his timing on the moon for the 100 m race.

6. Answer:

We know that 1 watt hour = 1 JS^{-1} × 3600 s = 3600 J

Also we know that $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

or $1 \text{ J} = \dfrac{1}{1.6\times10^{-19}} \text{ eV}$

$\therefore$ $1 \text{ watt hour} = 3600 \times \dfrac{1}{1.6\times10^{-19}} \text{ eV}$

$= 2.25 \times 10^{22} \text{ eV}$

Now $1 \text{ MeV} = 10^{6} \text{ eV}$

or $1 \text{ eV} = 10^{-6} \text{ MeV}$

$1 \text{ watt hour} = 2.25 \times 10^{22} \times 10^{-6} \text{ MeV}$

$= 2.25 \times 10^{16} \text{ MeV}.$

7. Answer: The ratio of the relative speed of separation after a collision to the relative speed of approach before the collision is always constant. This constant is known as the coefficient of restitution. It is denoted by e.

$\therefore e = \dfrac{v_{2f} - v_{1f}}{u_{1i} - u_{2i}}$

where u_{1i} and u_{2i}, are the velocities of the bodies before collision and v_{2f}, v_{1f} are the velocities of the bodies after the collision.

8. Answer:

We know that $p = \sqrt{2mE_k}$ or $E_k = \frac{p^2}{2m}$

Since E_k is constant

$\therefore \quad p \propto \sqrt{m}$

$\therefore \quad p_1 \propto \sqrt{nm}$ and $p_2 \propto \sqrt{m}$

$\therefore \quad \frac{p_1}{p_2} = \frac{\sqrt{nm}}{\sqrt{m}} = \frac{\sqrt{n}}{1}.$

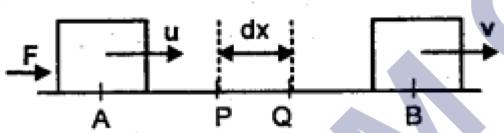
Long Questions Answers:

1. Answer:

(a) It states that the work done on a body is equal to the change in its kinetic energy.

i.e., W = change in kinetic energy

Proof: Let m = mass of a body moving in a straight line with a constant initial velocity u.



Let F = force applied on it at point A to B so that its velocity is V at B.

If dx = small displacement from P to Q

and a = acceleration produced in the body, then

F = ma

If dw be the work done from P to Q, then

$$dw = F.dx = F\,dx\cos 0$$

$$= ma\,dx = m\frac{dv}{dt}dx$$

$$= mdv.\left(\frac{dx}{dt}\right) = mv.dv$$

If W = total work done from A to B, then

$$W = \int_u^v dW = m\int_u^v u\,dv$$

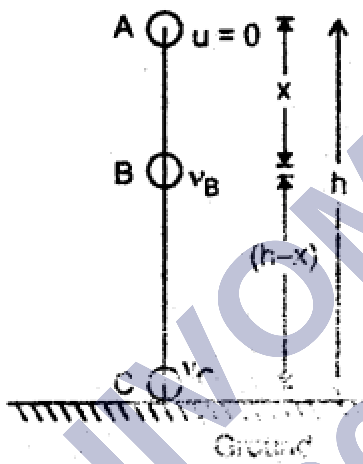
$$m\left[\frac{v^2}{2}\right]_u^v = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

= change in K.E. of body.

(b) It states that energy can neither be created nor can be destroyed but it can be changed from one form of energy into another i.e. total energy = constant.

Proof: Let a body of mass m be lying at rest at point A at a height h above the ground. Let it be allowed to fall freely and reaches a point B after falling through a distance x and it finally hits the ground at point C. Let v and V be its velocities at points B and C respectively.

∴ AB = x and BC = h – x



At point A: u = 0

∴ K.E. = 0

P.E. = mgh

If E be the total energy of the body, then

E = K.E. + P.E. = 0 + mgh

or

E = mgh …. (i)

At point B: using the relation,

$$v^2 - u^2 = 2as, \text{ we get}$$

$$v_B^2 - 0 = 2gx$$

$$(\because \text{ here } v = v_B, u = 0, a = g, s = x)$$

or $$v_B^2 = 2gx$$

$\therefore$ $$K.E. = \frac{1}{2}mv_B^2 = \frac{1}{2} m \times (2gx) = mgx$$

and $$P.E. = mg(h - x)$$

$\therefore$ $$E = K.E. + P.E. = mgx + mgh - mgx$$

or $$E = mgh \quad \text{.... }(ii)$$

At point C: Here, $v = v_C$, $a = g$, $s = h$

$\therefore$ $$v_C^2 - 0^2 = 2gh$$

$$v_C^2 = 2gh$$

Thus $$K.E. = \frac{1}{2}mv_C^2 = \frac{1}{2} m \times 2gh = mgh$$

and $$P.E. = mg(0)$$

$$(\because \text{ height from ground at point } C = 0)$$

$$= 0$$

$\therefore$ $$E = K.E. + P.E. = mgh + 0 = mgh$$

or $$E = mgh \quad \text{.... }(iii)$$

Thus, from (i), (ii), and (iii), it is clear that total energy at points A, B, and C is the same. It is purely P.E. at A and purely K.E. at point C.

Assertion Reason Answer:

1. (d) Assertion is incorrect, reason is correct.

Explanation

When frictional force is opposite to velocity, kinetic energy will decrease.

2. (b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion

Explanation:

In close loop, s = 0, and so W = Fs = 0.

Case Study Answer:

1. **i.** (a) commutative law

ii. (a) positive

iii. the scalar product or dot product of any two vectors A and B, denoted as A.B (read

A dot B) is defined as

A.B = A B cos q. where q is the angle between the two vectors. Since A, B and cos θ are scalars, the dot product of A and B is a scalar quantity. Each vector, A and B, has a direction but their scalar product does not have a direction. Following are properties of dot product

- the scalar product follows the commutative law:

  A.B = B.A

- Scalar product obeys the distributive law:

  (B + C) = A.B + A.C

  Further, A. (λ B) = λ (A.B) where λ is a real number.

- For unit vectors i, j, k we have

  i × i = j × j = k × k = 1 and i × j = j × k = k × i = 0

- A×A = |A ||A| cos 0 = A^2.

- B = 0, if A and B are perpendicular.

Iv. The work done by the force is defined to be the product of component of the force in the direction of the displacement and the magnitude of this displacement. Thus

W = (F cos θ) d = F.d

Work has only magnitude and no direction. Its SI unit is (N m) or joule (J).

v. No work is done if:

- The displacement is zero.
- The force is zero. A block moving on a smooth horizontal table is not acted upon by a Horizontal force (since there is no friction) but may undergo a large displacement.
- The force and displacement are mutually perpendicular. This is so since, for θ = π/2 rad Cos (π/2) = 0

2. **i.** (a) Scalar quantity

ii. (c)All of the above

iii. **Work energy theorem:** The change in kinetic energy of a particle is equal to the work

done on it by the net force. Mathematically

$K_f – K_i = W$

Where K_i and K_f are respectively the initial and final kinetic energies of the object. Work refers to the force and the displacement over which it acts. Work is done by a force on the body over a certain displacement. Energy possessed by object due to its motion is called as kinetic energy. Its SI unit is N-m or Joule (J).

iv. Kinetic energy is scalar quantity as it is a work done and work done is scalar quantity

hence kinetic energy is also scalar quantity and doesn't have any direction.

v. the kinetic energy possessed by an object of mass, m and moving with a uniform velocity,

v is

$$K = \frac{1}{2}*mv^2 = \frac{1}{2}\text{ v.v}$$

Kinetic energy is a scalar quantity. Having unit, the same as that of work, that is, joule (J).