Part – 1: Introduction, Work, Scalar Product (Dot Product) and Work Done by a Constant Force

Introduction

In our daily life, we often use the word **"work"**. For example, we say that a student is studying, a labourer is carrying bricks, or a machine is lifting a load. However, in Physics, the meaning of **work** is more specific.
A force may act on a body, but **unless the body undergoes displacement, no work is said to be done**.
Thus, in Physics, **both force and displacement are necessary for work to be done**.
This chapter introduces the concepts of **Work, Energy and Power**, which form the basis of mechanics and are widely used in engineering, medicine, sports, and everyday life.

Learning Objectives

After studying this chapter, students will be able to:

- Define work in Physics.
- Distinguish between positive, negative and zero work.
- Understand the scalar (dot) product of vectors.
- Calculate work done by a constant force.
- Solve numerical problems involving inclined planes and different force directions.
- Apply concepts to NEET and JEE-level problems.

5.1 Work

Definition

Work is said to be done when a force acting on a body produces displacement of the body in the direction of the force or in a direction having a component of the force.
Thus, two conditions are essential:

1. A force must act on the body.
2. The body must undergo displacement.

If either condition is not satisfied,

$$\boxed{W = 0}$$

Examples

Example 1: Positive Work

A person pushes a box on a smooth floor.

```
F →

BOX

Displacement →
```

The applied force and displacement are in the **same direction**.
Hence, work is **positive**.

Example 2: Zero Work
A man pushes a rigid wall.

```
F → [redacted] Wall

Displacement = 0
```

Although force is applied,
s = 0
Therefore,

$$\boxed{W = 0}$$

Example 3: Negative Work
A ball is thrown vertically upward.

```
Ball

↑ Velocity

↓

Weight (mg)
```

The displacement is upward, whereas gravity acts downward.
Hence, the work done by gravity is **negative**.

Scalar (Dot) Product of Two Vectors

Before deriving the formula for work, we must understand the **scalar (dot) product**.

Definition

The scalar product of two vectors is defined as the product of their magnitudes and the cosine of the angle between them.

If two vectors are $\vec{A}$ and $\vec{B}$ then

$$\boxed{\vec{A} \cdot \vec{B} = AB\cos\theta}$$

where,

- A = magnitude of vector $\vec{A}$
- B = magnitude of vector $\vec{B}$
- θ\ = angle between the two vectors

The result of a dot product is always a **scalar quantity**.

Properties of Dot Product

1. **Commutative Law**

$$\boxed{\vec{A}\cdot\vec{B}=\vec{B}\cdot\vec{A}}$$

2. **Distributive Law**

$$\boxed{\vec{A}\cdot(\vec{B}+\vec{C})=\vec{A}\cdot\vec{B}+\vec{A}\cdot\vec{C}}$$

3. If $\theta = 0^0$

   Then

$$\boxed{\vec{A}\cdot\vec{B}=AB}$$

(Maximum value)

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4. If $\theta = 90^0$
   Then

$$\boxed{\vec{A}\cdot\vec{B}=0}$$

(The vectors are perpendicular.)

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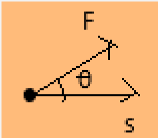
5. If $\theta = 180^0$
   Then

$$\boxed{\vec{A}\cdot\vec{B}=-AB}$$

(Minimum value)

Work Done by a Constant Force

Consider a particle displaced through a distance s under the action of a constant force F.
Let the angle between force and displacement be θ.
The component of force along the displacement is F $\cos\theta$
Hence,



$$W = (F\cos\theta)s$$

Or

$$\boxed{W = Fs\cos\theta}$$

This is the most general expression for work done by a **constant force**.

Nature of Work

(i) Positive Work

When

$$0^0 \le \theta < 90^0$$
$$\cos\theta > 0$$

Therefore,

$$W > 0$$

Examples:

- Pulling a cart

- Falling of a stone under gravity

(ii) Negative Work

When

$$90^0 < \theta \leq 180^0$$
$$\cos\theta < 0$$

Therefore,

$$W < 0$$

Examples:

- Work done by friction
- Work done by gravity on an upward-moving body

(iii) Zero Work

When

$$\theta = 90^0$$

Hence,

$$\boxed{W = 0}$$

Examples:

- Centripetal force in uniform circular motion
- A person carrying a suitcase on a horizontal road (work done by the supporting force)

SI Unit of Work

The SI unit of work is the **joule (J).**

$$\boxed{1\,J = 1\,Nm}$$

Definition:

One joule is the work done when a force of **1 N** produces a displacement of **1 m** in its own direction.

Dimensional Formula of Work

$$\boxed{[ML^2T^{-2}]}$$

Significance of the Sign of Work

- **Positive Work:** Energy is transferred to the body.
- **Negative Work:** Energy is taken away from the body.
- **Zero Work:** No energy transfer takes place due to that force.

Solved Numerical 1

A constant force of **25 N** acts on a body and produces a displacement of **4 m** in the direction of the force. Find the work done.

Solution
Given,
F=25 N, s = 4, m, θ = 0^0
Using,

$$W = Fs\cos\theta$$

Or

$$W = 25 \times 4 \times \cos 0^0 = 25 \times 4 \times 1 = 100\,J$$

Answer: $\boxed{100J}$

Solved Numerical 2

A force of **40 N** acts on a body making an angle of **60°** with the displacement of **5 m**. Find the work done.
Solution

$$W = Fs\cos\theta$$

Or

$$W = 40 \times 5 \times \cos 60^0 = 40 \times 5 \times \frac{1}{2} = 100\,J$$

Answer: $\boxed{100\,J}$

Solved Numerical 3 (NEET Level)

A force of **50 N** acts opposite to the displacement of **3 m**. Find the work done.
Solution
Here, θ =180^0
Therefore, $W = Fs\cos 180^0 = 50 \times 3 \times (-1) = -150\ J$
Answer: $\boxed{-150\,J}$

Derive the Work-Energy Theorem by Constant Force

Show that work done is equal to change in kinetic energy.

Let a particle moves in straight line by applying a constant force with uniform acceleration along the direction of displacement. The initial velocity of the particle is u and final velocity becomes v after time t. The particle covers displacement s.
Using,

$$W = Fs\cos\theta$$

Since, $\theta = 0^0$, so $\cos\theta = \cos 0^0 = 1$
Hence,

$$W = mas - -(i)$$

Since,

$$v^2 = u^2 + 2as$$

Or

$$as = \frac{v^2 - u^2}{2}$$

Substituting the value of as in equation (i), then

$$W = m\left(\frac{v^2 - u^2}{2}\right) = \frac{mv^2}{2} - \frac{mu^2}{2} = K_f - K_i = \Delta K$$

Therefore,

$$\boxed{W = K_f - K_i = \Delta K}$$

This theorem is applicable for all type of forces viz. constant force, variable force, conservative force, non-conservative , internal or external force.

Common Mistakes

- Confusing **force** with **work**.
- Using the total force instead of the component **parallel to displacement**.
- Forgetting that work is a **scalar quantity**.
- Using the wrong angle between **force** and **displacement**.
- Ignoring the sign of work (positive or negative).

Formula Summary

$$\boxed{W = \vec{F} \cdot \vec{s}}$$

$$\boxed{W = Fs\cos\theta}$$

$$\boxed{1J = 1Nm}$$

$$\boxed{[W] = [ML^2T^{-2}]}$$

$$\boxed{W = \vec{F} \cdot (\vec{r}_2 - \vec{r}_1)}$$

Chapter Summary (Part–1)

- Work is done only when a **force produces displacement**.
- The work done by a constant force is given by **W=Fs cosθ**
- The **dot product** is used to calculate work because only the component of force along the displacement contributes.
- Work may be **positive, negative, or zero**, depending on the angle between the force and the displacement.
- The SI unit of work is the **joule (J)**.

Part – 2: Work Done by a Variable Force, Force–Displacement Graph and Work Done by a Spring Force

5.2 Work Done by a Variable Force

In the previous section, we studied work done by a **constant force**.
However, in many practical situations, the force acting on a body is **not constant**. It may change with displacement, time, or position.
Examples:

- Stretching or compressing a spring
- Gravitational force between planets
- Electrostatic force between charges
- Elastic force in a rubber band

In such cases, the formula $W = Fs\ \cos\theta$ cannot be used directly because **F** is not constant.

Elementary Work

Consider a particle moving through a very small displacement **dx** under a variable force **F(x)**.

```
        F(x)

●——————————————→ x

Small displacement = dx
```

The elementary work done is

$$\boxed{dW = \vec{F} \cdot d\vec{x}}$$

If the force acts along the displacement,

$$\boxed{dW = F(x)dx}$$

Total Work Done

To obtain the total work done from position r_1 to r_2 integrate the elementary work:

$$\boxed{W = \int_{r_1}^{r_2} \vec{F} \cdot d\vec{r}}$$

This is the **general expression** for work done by a variable force.
In the case of displacement is in x −direction along the direction of force, then

$$W = \int_{x_1}^{x_2} F(x)dx$$

Special Case: Constant Force

If the force is constant, F(x) = F, then,

$$W = \int_{x_1}^{x_2} F dx = F(x_2 - x_1) = Fs$$

Hence, the familiar equation $W = Fs$ is obtained.

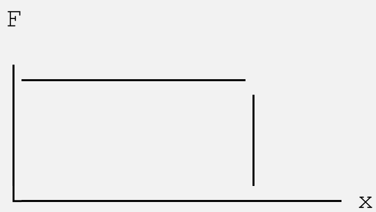
Work Done from a Force–Displacement (F–x) Graph

One of the most important applications of integration is calculating work from an **F–x graph**.

Principle

The work done by a force is equal to the area under the Force–Displacement graph.

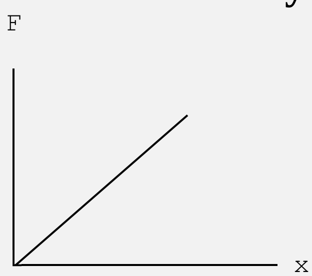
Case 1: Constant Force



Area of rectangle = $F \times x$

Therefore, $W = Fx$

Case 2: Linearly Increasing Force

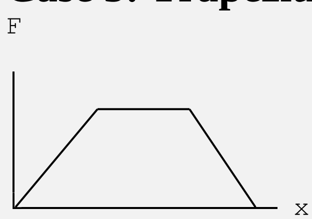


Area of triangle = $\frac{1}{2} \times base \times height$

Hence,

$$\boxed{W = \frac{1}{2} Fx}$$

Case 3: Trapezium Graph



Area of trapezium = Work done =
$\frac{1}{2}(sum\ of\ parallel\ sides) \times perpendicular\ distnace\ between\ two\ parallel\ sides$

Important Observation

- Area **above** the x-axis → Positive work
- Area **below** the x-axis → Negative work
- Total work = Algebraic sum of all areas

Work Done by a Spring Force

When a spring is stretched or compressed, it exerts a restoring force opposite to the displacement.
According to Hooke's Law,

$$F = -kx$$

where,

- k = spring constant
- x = extension or compression

The negative sign indicates that the spring force opposes the displacement.

Derivation of Work Done by a Spring

The work done by the spring while its extension changes from x_1 to x_2 is

$$W = \int_{x_1}^{x_2} F dx = \int_{x_1}^{x_2} (-kx) dx = \frac{-k}{2}({x_2}^2 - {x_1}^2)$$

Therefore,

$$\boxed{W_{spring} = -\frac{1}{2}k({x_2}^2 - {x_1}^2)}$$

Special Cases

From Natural Length to Extension x

Here,
$x_1 = 0, x_2 = x$
Hence,

$$\boxed{W_{spring} = -\frac{1}{2}kx^2}$$

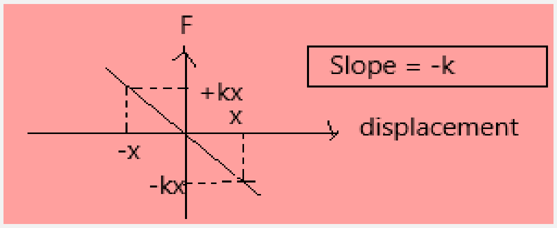
This is the work done **by the spring**.

Work Done by an External Agent

To stretch the spring slowly from 0 to x,

$$\boxed{W_{ext} = +\frac{1}{2}kx^2}$$

Graph of Spring Force



The graph is a straight line with negative slope because F = −kx

Work Done from the Spring Graph

The magnitude of work done is equal to the area under the graph.
Area of triangle

$= W = -\left(\frac{1}{2}\right) \times x \times (-kx) = \left(\frac{1}{2}\right) kx^2$

Hence,

$$\boxed{W = \frac{1}{2}kx^2}$$

This agrees with the integration result (magnitude).

Physical Meaning

- The external agent does positive work while stretching the spring.
- The spring does an equal amount of negative work.
- The energy supplied is stored in the spring as **elastic potential energy**, which we shall study in the next part.

Solved Numerical 1

A spring of spring constant 200 N m^{-1} is stretched by 10 cm. Find the work done by the external agent.

Solution

Given,

k=200 N m^{-1}, x = 10 cm = 0.10m

Using,

$$W = \frac{1}{2}kx^2$$

Putting the value, we get

$$W = \frac{1}{2} \times 200 \times (0.10)^2 = 1\,J$$

Answer: $\boxed{1J}$

Solved Numerical 2

The force acting on a particle varies uniformly from **0 N** to **40 N** over a displacement of **6 m**. Find the work done.

Solution

Area under the graph = Area of triangle

$$W = \frac{1}{2}Fx$$

Or

$$W = \frac{1}{2} \times 40 \times 6 = 120\, J$$

Answer: $\boxed{120\, J}$

Solved Numerical 3 (JEE Foundation)

A spring is compressed from **5 cm** to **15 cm**. The spring constant is **300 N m⁻¹**. Find the work done by the spring.

Solution

Given,

$x_1 = 0.05\, m$ and $x_2 = 0.15\, m$, Spring constant k = 300 N/m

Using,

$$W = -\frac{1}{2}k({x_2}^2 - {x_1}^2)$$

Putting the values, we get

$$W = -\frac{1}{2} \times 300 \times (0.0225 - 0.0025) = -\frac{1}{2} \times 300 \times 0.0200 = -3\, J$$

Answer: $\boxed{\boldsymbol{-3J}}$

Common Mistakes

- Using W = Fs for a variable force.
- Forgetting that **work is the area under the F–x graph**.
- Ignoring the negative sign in Hooke's law.
- Confusing **work done by the spring** with **work done on the spring**.
- Using centimetres instead of metres in spring problems.

Formula Summary

$$\boxed{dW = \vec{F} \cdot d\vec{x}}$$

$$\boxed{W = \int \vec{F} \cdot d\vec{x}}$$

$$\boxed{W = \int_{x_1}^{x_2} F(x)dx}$$

$$\boxed{F = -kx}$$

$$\boxed{W_{spring} = -\frac{1}{2}({x_2}^2 - {x_1}^2)}$$

$$\boxed{W_{ext} = \frac{1}{2}kx^2}$$

Chapter Summary (Part–2)

- For a **variable force**, work is obtained by **integration**, not by W = Fs.
- The **area under the Force–Displacement graph** gives the work done.
- A spring obeys **Hooke's law** within its elastic limit.
- The work done **by the spring** is negative during stretching, while the work done **on the spring** is positive.
- These concepts form the basis of **elastic potential energy**, which is discussed in the next part.

Part – 3: Kinetic Energy, Work–Energy Theorem and Potential Energy

5.3 Energy

Definition

Energy is the capacity of a body or system to do work.
Whenever a body performs work, it transfers energy from one form to another.
Energy can neither be created nor destroyed; it can only be transformed from one form into another.

SI Unit

The SI unit of energy is the **joule (J).**

$$\boxed{1J = 1Nm}$$

Dimensional Formula

$$\boxed{[W] = [ML^{-2}T^{-2}]}$$

Forms of Energy

Some common forms of energy are:

- Mechanical Energy
- Kinetic Energy
- Potential Energy
- Thermal Energy
- Electrical Energy
- Chemical Energy
- Nuclear Energy
- Light (Radiant) Energy

In this chapter, we shall mainly study **Mechanical Energy**.

Mechanical Energy

Mechanical energy is the sum of:

- Kinetic Energy
- Potential Energy

$$\boxed{E = K + U}$$

Where,

- K = Kinetic Energy
- U = Potential Energy

Kinetic Energy

Definition

Kinetic Energy is the energy possessed by a body due to its motion.
A body at rest has zero kinetic energy.

Derivation of Kinetic Energy

Consider a body of mass m, initially moving with velocity u.
A constant force F acts on it and changes its velocity to v after travelling a distance s.
Using Newton's Second Law,

$$F = ma$$

Work done,

$$W = Fs$$

Substituting F = ma,

$$W = mas$$

Using the third equation of motion,

$$v^2 = u^2 + 2as$$

Therefore,

$$as = \frac{v^2 - u^2}{2}$$

Substituting in the expression for work,

$$W = m\left(\frac{v^2 - u^2}{2}\right) = m\frac{v^2}{2} - m\frac{u^2}{2} = K_f - K_i$$

Or,

$$\boxed{K_f - K_i = \frac{1}{2}mv^2 - \frac{1}{2}mu^2}$$

According to the Work–Energy Principle, this work produces a change in kinetic energy.
Hence,

$$\boxed{W = \Delta K}$$

If the body starts from rest, u = 0
Therefore,

$$\boxed{K = \frac{1}{2}mv^2}$$

This is the expression for kinetic energy.

Characteristics of Kinetic Energy

- It is a scalar quantity.
- It is always positive or zero.
- It depends on both mass and velocity.
- It is directly proportional to the mass.

- It is proportional to the square of velocity.

Thus,

$$K \propto m$$

And

$$K \propto v^2$$

Work–Energy Theorem

Statement

The net work done on a body is equal to the change in its kinetic energy.

Mathematically,

$$\boxed{W_{net} = \Delta K}$$

or,

$$\boxed{W_{net} = K_f - K_i}$$

Work–Energy Theorem by Variable Force

Let a particle of mass m is moving with initial velocity u and final velocity v under the influence of variable force in the straight line and covers a displacement s.

Small work done by the body

$$dW = \vec{F} \cdot d\vec{x}$$

Or,

$$W = \int m\vec{a} \cdot d\vec{s}$$

Or

$$W = \int m\frac{d\vec{v}}{dt} \cdot d\vec{s} = \int md\vec{v} \cdot \frac{d\vec{s}}{dt} = \int m\vec{v} \cdot \, d\vec{v} = \int mv\, dv$$

Or

$$W = \int_u^v mv\, dv = \left[\frac{mv^2}{2} - \frac{mu^2}{2}\right] = K_f - K_i = \Delta K$$

Hence

$$\boxed{W = \Delta K}$$

Importance

The Work–Energy Theorem provides an alternative method to solve mechanics problems **without directly using Newton's laws**.

It is especially useful when:

- Multiple forces act simultaneously.
- Variable forces are involved.
- Motion occurs along curved paths.

Applications of Work–Energy Theorem

(i) Accelerating a Car
The engine performs positive work.
Hence, the kinetic energy of the car increases.

(ii) Applying Brakes
The frictional force performs negative work.
Hence, the kinetic energy decreases.

(iii) Falling Object
Gravity performs positive work.
The potential energy decreases, while kinetic energy increases.

Potential Energy

Definition

Potential Energy is the energy possessed by a body due to its position or configuration.
Examples:

- Water stored in a dam.
- A stretched spring.
- A lifted stone.
- A compressed spring.

Types of Potential Energy

1. Gravitational Potential Energy
2. Elastic Potential Energy

Gravitational Potential Energy

Consider a body of mass m raised through a vertical height h.
The force required to lift the body slowly is equal to its weight, F = mg
Work done, W = Fh
Substituting,

$$W = mgh$$

This work is stored as gravitational potential energy.
Hence,

$$\boxed{U = mgh}$$

Important Notes

- Valid near the Earth's surface where g is approximately constant.
- Depends on the chosen reference level.
- The **change** in potential energy is physically meaningful.

Elastic Potential Energy

When a spring is stretched or compressed, the work done by an external agent is stored as elastic potential energy.
From Part–2,

$$W = \frac{1}{2}kx^2$$

Therefore,

$$\boxed{U = \frac{1}{2}kx^2}$$

Where,
- k = spring constant
- x = extension or compression

Comparison: Kinetic vs Potential Energy

Kinetic Energy	Potential Energy
Due to motion	Due to position or configuration
Depends on velocity	Depends on position
$K = \frac{1}{2}mv^2$	$U = mgh, U = \frac{1}{2}kx^2$
Zero when body is at rest	Can exist even when body is at rest

Solved Numerical 1

A body of mass **4 kg** moves with a speed of **6 m s⁻¹**. Calculate its kinetic energy.
Solution

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

Putting values, m = 4 kg, v = 6 m/s, we get

$$K = \frac{1}{2} \times 4 \times 36 = 72\,J$$

Answer

$\boxed{72\,J}$

Solved Numerical 2

A **3 kg** body is lifted vertically through **8 m**. Take g = 9.8 m/ s^2. Find the increase in gravitational potential energy.
Solution

$$U = mgh = 3 \times 9.8 \times 8 = 235.2\,J$$

Answer

$\boxed{235.2\,J}$

Solved Numerical 3 (NEET/JEE Level)

A spring of spring constant **400 N m⁻¹** is compressed by **5 cm**. Find the elastic potential energy stored.

Solution

Given,

k=400 N m^{-1}, x = 5 cm = 0.05 m

Using,

$$U = \frac{1}{2}kx^2$$

Or,

$$U = \frac{1}{2} \times 400 \times 0.0025 = 0.5\, J$$

Answer

$\boxed{0.5\, J}$

Concept Box (NEET/JEE)

Important Observation

If the velocity of a body is doubled,

$$K' = \frac{1}{2}m(2v)^2 = \frac{1}{2}mv^2 \times 4$$

Hence,

If velocity doubles, kinetic energy becomes four times.

Similarly,

- Velocity becomes **3 times** → Kinetic Energy becomes **9 times**.
- Velocity becomes **half** → Kinetic Energy becomes **one-fourth**.

This is a very common **NEET and JEE** concept.

Common Mistakes

- Confusing **work** with **energy**.
- Using mgh for large heights where g is not constant.
- Forgetting that kinetic energy depends on the **square of velocity**.
- Ignoring the initial kinetic energy while applying the Work–Energy Theorem.

Formula Summary

$$\boxed{K = \frac{1}{2}mv^2}$$

$$\boxed{W_{net} = \Delta K}$$

$$\boxed{U = mgh}$$

$$\boxed{U = \frac{1}{2}kx^2}$$

$$\boxed{E = K + U}$$

Chapter Summary (Part–3)

- **Energy** is the capacity to do work.
- **Kinetic Energy** arises due to motion and is given by $K = (1/2)mv^2$.
- The **Work–Energy Theorem** states that the net work done equals the change in kinetic energy.
- **Gravitational Potential Energy** near the Earth's surface is U = mgh
- **Elastic Potential Energy** stored in a spring is U=12kx2U=\frac12kx^2U=21kx2.
- Mechanical Energy is the sum of kinetic and potential energies.

Part – 4: Conservative and Non-Conservative Forces, Conservation of Mechanical Energy and Power

5.4 Conservative Force

Definition

A **conservative force** is a force for which the work done in moving a body between two points is **independent of the path followed** and depends only on the initial and final positions.
Mathematically,

$$\boxed{W_{A\to B} = Constant}$$

for all possible paths between points **A** and **B**.

Characteristics of Conservative Forces

- Work done depends only on the initial and final positions.
- Work done over a **closed path** is zero.

$$\boxed{\oint \vec{F}\cdot d\vec{r} = 0}$$

- A potential energy function can be defined.
- Mechanical energy remains conserved if only conservative forces act.

Examples

- Gravitational force
- Spring (elastic) force
- Electrostatic force

Non-Conservative Force

Definition

A **non-conservative force** is a force whose work done depends on the **path followed** between two points.

Characteristics

- Work done depends upon the path.
- Work done over a closed path is **not zero**.
- Mechanical energy is not conserved when only non-conservative forces act.
- Energy is converted into heat, sound, etc.

Examples

- Friction
- Air resistance (drag)

- Viscous force

Comparison Between Conservative and Non-Conservative Forces

Conservative Force	Non-Conservative Force
Path independent	Path dependent
Closed path work = 0	Closed path work ≠ 0
Potential energy can be defined	No unique potential energy
Mechanical energy is conserved	Mechanical energy is not conserved

Mechanical Energy

The total mechanical energy of a body is the sum of its kinetic energy and potential energy.

$$\boxed{E = K + U}$$

where

- $K = (1/2)mv^2$
- U = mgh (near Earth's surface)

Law of Conservation of Mechanical Energy

Statement

When only conservative forces act on a body, its total mechanical energy remains constant.

Mathematically,

$$\boxed{K_i + U_i = K_f + U_f}$$

Or

$$\boxed{K + U = Constant}$$

Proof Using a Freely Falling Body

Consider a body of mass **m** released from a height **h**.

Position A (Top)

Height = h, Velocity = 0, Potential Energy, $U_A = mgh$, Kinetic Energy, $K_A = 0$
KA=0K_A=0KA=0
Total Energy, $E_A = mgh$

Position B (Intermediate)

Height = y, Velocity = v, Potential Energy, $U_B = mgy$, Kinetic Energy, $K_B = \frac{1}{2}mv^2$
Total Energy, $E_B = mgy + \frac{1}{2}mv^2$
Using

$$v^2 = 2g(h - y) = 2gh - 2gy$$

Substituting,

$$E_B = mgy + \frac{1}{2}m(2gh - 2gy) = mgh$$

Therefore,

$$E_B = mgh$$

Position C (Ground)
Height = 0, Potential Energy, $U_C = 0$, Velocity $v = \sqrt{2gh}$
Kinetic Energy,

$$K_C = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\sqrt{2gh}\right)^2 = mgh$$

Hence,

$$E_C = mgh$$

Conclusion
At every point,

$$\boxed{E_A = E_B = E_C = mgh}$$

Thus,
Mechanical energy remains constant.

Energy Conversion During Free Fall

```
Top

PE = Maximum
KE = Zero

↓

Middle

PE ↓
KE ↑

↓

Ground

PE = Zero
KE = Maximum
```

Important Note

Mechanical energy remains conserved **only if friction and air resistance are neglected**.
If non-conservative forces act,

$$\boxed{W_{nc} = \Delta(K + U)}$$

where Wnc is the work done by non-conservative forces.

Power

Definition

Power is the rate at which work is done or energy is transferred.
Mathematically,

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

Where

- P = Power
- W = Work done
- t= Time taken

SI Unit

The SI unit of power is the **watt (W).**

$$\boxed{1W = 1J/s}$$

Larger Units

1 kW=1000 W
1 MW=10^6 W

Horsepower

A commonly used unit for engines is **horsepower (hp).**

$$\boxed{1\ hp = 746\ W}$$

Instantaneous Power

From

$$P = \frac{dW}{dt}$$

And

$$dW = \vec{F} \cdot d\vec{r}$$

we obtain

$$\boxed{P = \vec{F} \cdot \vec{v}}$$

Or

$$\boxed{P = Fv\ cos\theta}$$

Special Cases:

- If force and velocity are in the same direction,
$$P = Fv$$
- If they are perpendicular,
$$P = 0$$

Average Power

It is defined as the ratio of total work done and the total time taken.

$$\boxed{P_{av} = \frac{\Delta W}{\Delta t}}$$

- If power is a function of time then average power can be calculated in the time interval from t_1 to t_2 as

$$\boxed{P_{av} = \frac{\int_{t_1}^{t_2} p(t)dt}{\int_{t_1}^{t_2} dt}}$$

Important Points Regarding the graph between Power and Time; Work and time and Force and Displacement

- Area under the graph between power and time represents work done
- Slope of the graph between work and time represents Power
- Area under the graph between force and displacement represents work done

---

Efficiency
Definition

Efficiency is the ratio of useful output work (or power) to the input work (or power).

$$\boxed{\eta = \frac{Output\ Power}{Input\ Power}}$$

In percentage,

$$\boxed{\%\eta = \frac{Output}{Input} \times 100}$$

Solved Numerical 1

A body of mass **5 kg** falls freely from a height of **20 m**. Calculate its velocity just before reaching the ground. Take g = 9.8 m s^{-2}

Solution

Using conservation of mechanical energy,

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

Or

$$v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 20} = 19.8\ m/s$$

Answer

$\boxed{19.8\ m/s}$

Solved Numerical 2

A machine performs **9000 J** of work in **30 s**. Find its power.

Solution

$$P = \frac{W}{t} = \frac{9000}{30} = 300\,W$$

Answer

$\boxed{300\,W}$

Solved Numerical 3 (NEET/JEE)

A force of **40 N** acts on a body moving with a constant velocity of **5 m s^{-1}** in the direction of the force. Find the instantaneous power.

Solution

$$p = Fv = 40 \times 5 = 200\,W$$

Answer

$\boxed{200\,W}$

Concept Box (NEET/JEE)

Can Mechanical Energy Increase?

Yes, **if an external agent performs positive work** on the system.

Example:

- A person lifting a suitcase.
- An engine accelerating a vehicle.

Thus, conservation of mechanical energy applies only to an **isolated system with only conservative forces**.

Common Mistakes

- Assuming mechanical energy is always conserved, even when friction is present.
- Confusing **power** with **energy**.
- Forgetting that **power is the rate of doing work**, not the amount of work.
- Using P = Fv when force and velocity are **not parallel**. In general, use $P = Fv\cos\theta$.

Chapter Summary (Part–4)

- **Conservative forces** are path independent and allow a potential energy function to be defined.
- **Non-conservative forces** (such as friction) are path dependent and convert mechanical energy into other forms.
- In the absence of non-conservative forces, **mechanical energy remains constant**.
- **Power** is the rate of doing work and is measured in watts.
- **Efficiency** compares useful output with the total input and is usually expressed as a percentage.

Part – 5: Advanced Applications of Work–Energy Theorem, Mechanical Energy and Collision

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5.5 Applications of the Work–Energy Theorem

The **Work–Energy Theorem** provides a direct relationship between the **net work done** on a body and the **change in its kinetic energy**.

$$\boxed{W_{net} = \Delta K}$$

It is often easier to solve problems using energy methods than by applying Newton's laws, especially when the acceleration is variable.

Application 1: Motion on a Smooth Inclined Plane

Consider a block of mass m sliding down a smooth incline of height h.

Figure

```
          □
         /|
        / |
       /θ |
______/___|
```

Since the surface is smooth,

- Friction = 0
- Mechanical energy remains conserved.

At the top,

$K_i = 0, U_i = mgh$

At the bottom,

$K_f = \frac{1}{2}mv^2 \text{ and } U_f = 0$

Hence,

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

Therefore,

$$\boxed{v = \sqrt{2gh}}$$

Important Result: The final speed depends only on the vertical height, not on the angle of inclination.

Application 2: Motion on a Rough Inclined Plane

If the coefficient of kinetic friction is μ_k, the frictional force is

$$f_k = \mu_k N = \mu_k mg \cos\theta$$

Hence,

$$f_k = \mu_k mg \cos\theta$$

Work done by friction f_k

$$W_f = f_k s$$

Applying the Work–Energy Theorem,

$$W_g + W_f = \Delta K$$

or,

$$mgh - \mu_k mg\cos\theta = \frac{1}{2}mv^2$$

This equation is widely used in **NEET** and **JEE Main**.

Application 3: Vertical Motion

A body is projected vertically upward with speed u. At the highest point, v = 0

Applying conservation of mechanical energy,

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

Therefore,

$$\boxed{h = \frac{u^2}{2g}}$$

Application 4: Spring–Block System

A block compresses a spring by a distance x. At maximum compression,

- Velocity = 0
- Kinetic energy = 0
- Entire kinetic energy converts into elastic potential energy.

Thus,

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

Hence,

$$\boxed{x = v\sqrt{\frac{m}{k}}}$$

Work Done by Gravity

Gravity is a conservative force.

Therefore,

- Work done depends only on the initial and final positions.
- It is independent of the path followed.

For a body moving vertically through a height h,

$$\boxed{W_g = mgh}$$

if the body moves downward.

If the body moves upward,

$$\boxed{W_g = -mgh}$$

Work Done by Friction

Friction always opposes the motion.
Hence,

$$\boxed{W_f = -fs}$$

Where

- f = frictional force
- s = displacement

The negative sign indicates that friction reduces the mechanical energy of the system.

Solved Numerical 1

A body of mass **2 kg** slides from rest down a smooth incline of height **5 m**.
Take g=9.8 m s^{-2}.
Find its speed at the bottom.

Solution

Using conservation of mechanical energy,

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

Or

$$2 \times 9.8 \times 5 = \frac{1}{2} \times 2 \times v^2$$

Or

$$v = 7\sqrt{2} = 9.9\ m/s$$

Answer

$\boxed{9.9\ m/s}$

Solved Numerical 2

A spring of spring constant **500 N m^{-1}** is compressed by **8 cm**. Calculate the energy stored.

Solution

Given,
x = 0.08m
Using,

$$U = \frac{1}{2}kx^2 = \frac{1}{2} \times 500 \times 64 \times 10^{-4} = 1.6\ J$$

Answer

$\boxed{1.6\ J}$

Solved Numerical 3 (NEET Level)

A **10 kg** body is pulled horizontally through **12 m** by a force of **50 N**. The frictional force is **20 N**. Find the net work done.

Solution
Net force,
$$F_{net} = 50 - 20 = 30\ N$$
Therefore,
$$W = Fs = 30 \times 12 = 360\ J$$
Answer
$\boxed{360\ J}$

Collision
Definition
A **collision** is an event in which two or more bodies interact with each other for a very short time by exerting large forces.

Types of Collision
(A) Elastic Collision
Characteristics
- Total momentum is conserved.
- Total kinetic energy is conserved.
- No permanent deformation occurs.

Examples:
- Collision between steel balls (approximately)
- Molecular collisions in gases (ideal approximation)

(B) Inelastic Collision
Characteristics
- Momentum is conserved.
- Kinetic energy is **not** conserved.
- Some kinetic energy is converted into heat, sound or deformation.

Examples:
- Clay striking a wall
- Car accidents

(C) Perfectly Inelastic Collision
Bodies stick together after collision and move with a common velocity.
This is the maximum possible loss of kinetic energy while still conserving momentum.

One-Dimensional Collision
Consider two bodies:
- Masses: m_1, m_2
- Initial velocities: u_1

- Final velocities: v_2

Conservation of Momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

This equation is valid for **all collisions** (if external forces are negligible).

Coefficient of Restitution (e)

Definition

The coefficient of restitution is the ratio of the **relative speed of separation** to the **relative speed of approach**.

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

(assuming motion along the same straight line and $u_1 > u_2$)

Limits of e

Perfectly Elastic Collision

$$e = 1$$

Perfectly Inelastic Collision

$$e = 0$$

Partially Inelastic Collision

$$0 < e < 1$$

Important Relations

For an elastic collision, Momentum conserved and Kinetic Energy conserved

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For an inelastic collision, Momentum conserved but Kinetic Energy decreases

---

Show that e = 1 for perfectly elastic collision in one dimension

Also find the final velocities expressions:

Let two bodies A and B of masses m_1 and m_2 are moving with initial velocities u_1 and u_2 ($u_1 > u_2$) in one dimension, collide and after collision, their final velocities become v_1 and v_2 respectively in the same direction.

Since, in perfectly elastic collision, linear momentum and kinetic energy are conserved, therefore,

For Linear Momentum conserved,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 - - - -(1)$$

For Kinetic Energy conserved,

$$\frac{1}{2}m_1{u_1}^2+\frac{1}{1}m_2{u_2}^2=\frac{1}{2}m_1{v_1}^2+\frac{1}{2}m_2{v_2}^2 ----(2)$$

(i) Coefficient of Restitution

Rewriting equation (1) and (2) as

$$m_1u_1-m_1v_1=m_2v_2-m_2u_2$$

Or

$$m_1(u_1-v_1)=m_2(v_2-u_2) ----- (3)$$

Also,

$$\frac{1}{2}m_1{u_1}^2-\frac{1}{1}m_1{v_1}^2=\frac{1}{2}m_2{v_2}^2-\frac{1}{2}m_2{u_2}^2$$

Or

$$m_1({u_1}^2-{v_1}^2)=m_2({v_2}^2-{u_2}^2)$$

Or

$$m_1[(u_1+v_1)(u_1-v_1)]=m_2[(v_2+u_2)(v_2-u_2)] ----(4)$$

Dividing equation (4) by (3), we get

$$u_1+v_1=v_2+u_2 ----(5)$$

Since, coefficient of restitution is the ratio of relative velocity of separation to the relative velocity of approach.

Therefore, from equation (5), we get

$$u_1-u_2=v_2-v_1 ----- (6)$$

Or

$$\frac{v_2-v_1}{u_1-u_2}=1 ----(7)$$

Equation (7) is the coefficient of restitution.

$$\boxed{e=1=\frac{v_2-v_1}{u_1-u_2}}$$

Derived

(ii) To find their final velocities after collision

From equation (5),

$$v_2=u_1+v_1-u_2 ----- (8)$$

Substituting the value of v_2 in equation (1), we get

$$m_1u_1+m_2u_2=m_1v_1+m_2(u_1+v_1-u_2)$$

Or

$$v_1=\frac{2m_2u_2+(m_1-m_2)u_1}{m_1+m_2} ----(9)$$

We can also get the expression of v_2 by putting its value in equation (1), and also by replacing 1 by 2 as

$$v_2=\frac{2m_1u_1+(m_2-m_1)u_2}{m_1+m_2} ----(10)$$

These equations (9) and (10) are the expressions of final velocities.

Hence, final velocities of each body after perfectly head on elastic collision in one dimension is

$$\boxed{v_1 = \frac{2m_2u_2 + (m_1 - m_2)u_1}{m_1 + m_2}}$$

And

$$\boxed{v_2 = \frac{2m_1u_1 + (m_2 - m_1)u_2}{m_1 + m_2}}$$

Solved Example 1

A force of **100 N** acts on a body for **0.20 s**. Find the impulse.

Solution

J = FΔt =100×0.20 =20 N s

Answer

20 N s

Solved Example 2

A **2 kg** body moving with **8 m s⁻¹** comes to rest. Find the impulse.

Solution

Initial momentum =2×8 =16

Final momentum = 0

Impulse J = $\Delta p = p_f - p_i$ 0−16 =−16 N s

Negative sign indicates that the impulse acts opposite to the initial motion.

Solved Example 3

A **2 kg** body moving at **6 m s⁻¹** collides head-on with a **4 kg** body at rest. After collision, the first body moves with **2 m s⁻¹**. Find the velocity of the second body.

Solution

Using conservation of momentum,

$$m_1u_1 + m\ \ u_2 = m_1v_1 + m_2v_2$$

Hence,

2(6)+4(0) = 2(2)+4v

Or

12=4+4v

Or

v = 2 m s^{-2}

Answer

2 m s^{-1}

Solved Example 4

Two bodies approach each other with speeds **8 m s⁻¹** and **2 m s⁻¹**. After collision, they separate with speeds **4 m s⁻¹** and **1 m s⁻¹**, respectively. Find the coefficient of restitution.

Solution
Relative speed of approach
= 8−2 = 6
Relative speed of separation
= 4−1 = 3
Hence,
e=6/3=2:1
Answer
e= 0.5

Solved Example 5

Two bodies A and B with masses each m and velocities 2 u and u are moving in one dimension in the same direction, collide head on elastically. Find their final velocities.

Solution:
Given,
Body A
$m_1 = m, u_1 = 2u$
Body B
$m_2 = m, u_2 = u$
There is perfectly head-on collision, therefore,
Final velocity of body A is

$$v_1 = \frac{2m_2u_2 + (m_1 - m_2)u_1}{m_1 + m_2}$$

Substituting their values, we obtain

$$v_1 = \frac{2m \times u + (0)(2u)}{m + m} = u$$

And, final velocity of body B is

$$v_2 = \frac{2m_1u_1 + (m_2 - m_1)u_2}{m_1 + m_2}$$

Substituting their values, we obtain

$$v_2 = \frac{2m \times 2u + (0)u}{m + m} = 2u$$

Answer
$\boxed{v_1 = u}$
$\boxed{v_2 = 2u}$

NEET/JEE Concept Box

Is Momentum Conserved in Every Collision?
Yes, provided the net external force during the collision is negligible.
However,
Kinetic Energy is conserved only in elastic collisions.

Comparison Table

Property	Elastic	Inelastic	Perfectly Inelastic
Momentum	Conserved	Conserved	Conserved
Kinetic Energy	Conserved	Not conserved	Maximum loss
Bodies Stick Together	No	Not necessarily	Yes
e	1	Between 0 and 1	0

Common Mistakes

- Assuming kinetic energy is conserved in every collision.
- Ignoring the direction (sign) of velocities.
- Using the wrong expression for the coefficient of restitution.
- Forgetting that impulse is a **vector quantity**.
- Confusing the **F–t graph** with the **F–x graph**.

Formula Sheet

Impulse

$$J = F\Delta t$$

Variable Force

$$J = \int F\,dt$$

Impulse–Momentum Theorem

$$J = \Delta p$$

Momentum Conservation

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Coefficient of Restitution

$$e = \frac{relative\ speed\ of\ separation}{relative\ speed\ of\ approach}$$

Practice Questions

Level–1

1. Define impulse.
2. State the Impulse–Momentum Theorem.
3. Define the coefficient of restitution.

Level–2 (NEET)

4. Explain why airbags reduce injuries during accidents.
5. Differentiate between elastic and inelastic collisions.
6. Why is momentum conserved in collisions even though kinetic energy may not be conserved?

Level–3 (JEE)

7. Derive the Impulse–Momentum Theorem.
8. Obtain the relation for the coefficient of restitution for a one-dimensional collision.
9. Two particles collide head-on. Given their masses and initial velocities, determine their final velocities for an elastic collision.

Chapter Summary

- **Work** is done only when a force causes displacement.
- **Energy** is the capacity to do work.
- The **Work–Energy Theorem** relates net work to the change in kinetic energy.
- **Mechanical energy** is conserved in systems where only conservative forces act.
- **Power** measures how quickly work is done, while **efficiency** measures how effectively input energy is converted into useful output.
- **Impulse** is the product of force and time and equals the **change in momentum**.
- The area under the **Force–Time graph** represents the impulse.
- In every isolated collision, **linear momentum is conserved**.
- **Elastic collisions** conserve both momentum and kinetic energy.
- **Inelastic collisions** conserve momentum but not kinetic energy.
- The **coefficient of restitution** measures the elasticity of a collision and lies between **0 and 1** for ordinary collisions.

Quick Revision Points

- Work is a **scalar quantity**.
- Energy is the **capacity to do work**.
- Kinetic energy depends on the **square of velocity**.
- Potential energy depends on the **reference level**.
- Mechanical energy is conserved only when **non-conservative forces are absent**.
- Friction always reduces mechanical energy.
- Power is the **rate of doing work**.

Common Examination Mistakes

- Using $W = Fs$ for a variable force.
- Forgetting the angle in $W = Fs\cos\theta$.
- Ignoring the sign of work done by gravity or friction.
- Applying conservation of mechanical energy when friction is present.
- Mixing up power and energy.

Frequently Confused Concepts

Incorrect Idea	Correct Concept
Larger force always means larger work	Work also depends on displacement and angle
Friction always does negative work	Static friction can do positive work in some situations
Mechanical energy is always conserved	Only when non-conservative forces are absent
Power and energy are the same	Power is the rate of doing work
Potential energy cannot be negative	It depends on the reference level

Concept Booster (NEET | JEE Main | JEE Advanced)

Concept–1

Is work a Scalar or a Vector?

 Work is a Scalar Quantity.

Although force and displacement are vectors, their **dot product** is a scalar.

Concept–2

Can work be negative?

Yes.

Whenever force acts opposite to displacement,

$W < 0$

Examples:

- Friction
- Gravity on an upward-moving body

Concept–3

Can work be zero even if force is acting?

Yes.

If

- displacement is zero, or
- force is perpendicular to displacement,

then $W = 0$

Example:

A satellite moving in a circular orbit

Concept–4

Why does centripetal force do zero work?

Because centripetal force is always directed towards the centre, while the instantaneous displacement is tangential to the path.

Thus, $\theta = 90^0$ and $W = Fs\cos 90^0 = 0$

Concept–5

Can friction do positive work?

Yes.

Although friction usually opposes relative motion, it can do **positive work** in certain situations.

Example:

A block placed on a moving conveyor belt is accelerated by **static friction**. Here, static friction acts in the direction of the block's displacement, so it does **positive work** on the block.

JEE Insight: Friction does **not always** do negative work. Its sign depends on the displacement of the body under consideration.

Concept–6

Can kinetic energy be negative?

No.

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

Since

- m > 0
- $v^2 \geq 0$

Therefore, $K \geq 0$

Concept–7

Can potential energy be negative?

Yes.

Potential energy depends upon the chosen reference level.

For example, in gravitational problems,

$U = -GMm/r$

is negative when the reference is taken at infinity.

NCERT Note: Near the Earth's surface, we usually use U = mgh, where the zero level is chosen conveniently.

Concept–8

Is work path dependent?

It depends upon the force.

- **Conservative Force** → Path independent
- **Non-conservative Force** → Path dependent

Concept–9

Why is gravity called a conservative force?

Because the work done by gravity depends only upon the initial and final positions.

For any closed path, $\oint F \cdot dr = 0$

Concept–10

Why is friction called a non-conservative force?

Because the work done by friction depends upon the path length.
Longer path → More energy lost.

Concept–11

Is mechanical energy always conserved?

No.
It is conserved **only when conservative forces alone act**. If friction or air resistance acts, mechanical Energy decreases.

Concept–12

Does total energy decrease because of friction?

No.
Only **mechanical energy** decreases.
The "lost" mechanical energy is converted into:

- Heat
- Sound
- Internal energy

The **total energy of the system** remains conserved.

Concept–13

Which quantity is always conserved?

Total Energy is always conserved in an isolated system.
Mechanical energy is conserved only under special conditions.

Concept–14

Why is kinetic energy proportional to the square of velocity?

Because $(1/2)mv^2$
Hence,

- Double the speed → Four times the kinetic energy.
- Triple the speed → Nine times the kinetic energy.

Concept–15

Which changes more rapidly: Momentum or Kinetic Energy?

If velocity doubles: Momentum, p = mv, becomes **2 times**.
Kinetic Energy, $K = (1/2)mv^2$, becomes **4 times**.
Hence, kinetic energy changes more rapidly with speed.

Concept–16

Can power be negative?

Yes.
If force acts opposite to the velocity, $P = F \cdot v < 0$

Example:
Braking a moving vehicle.

Concept–17

Is power a vector?

No.
Power is a **scalar quantity**.

Concept–18

Is zero power possible?

Yes.
If

- no work is done, or
- force is perpendicular to velocity,

then P=0

Concept–19

Does a body at rest always have zero energy?

No.
A body at rest has:

- Zero kinetic energy
- But it may possess **potential energy**.

Example:
A stone kept on a rooftop.

Concept–20

Which force changes only the direction of velocity?

Centripetal Force
It changes the direction of velocity but not its magnitude in **uniform circular motion**.
Hence, it does no work.

Concept–21

Does a larger force always do more work?

No.
Work depends on $W = Fs\cos\theta$
If displacement is zero or perpendicular, the work may still be zero.

Concept–22

Can a body possess energy without motion?

Yes.
Examples:

- A stretched spring

- Water stored in a dam
- A compressed spring

Concept–23

Why is the spring force negative in Hooke's law?

$F = -kx$

The negative sign indicates that the spring force is always directed opposite to the displacement from the equilibrium position.

Concept–24

Why is area under the F–x graph equal to work?

Because $dW = Fdx$

Adding the work done over many small displacements gives the integral, $W = \int F dx$ which is geometrically equal to the area under the graph.

Concept–25

Can work done by gravity be positive, negative, or zero?

Yes.

- Downward motion → Positive
- Upward motion → Negative
- Horizontal displacement → Zero (near the Earth's surface, where gravity is vertical)

Concept–26

Why is lifting a body slowly often assumed in derivations?

When the body is lifted slowly, Acceleration ≈ 0.
Hence,
Applied force = Weight = mg.
This simplifies the derivation of gravitational potential energy.

Concept–27

Can two bodies have the same kinetic energy but different momenta?

Yes.
Since $K = (1/2)mv^2$, different combinations of mass and velocity can give the same kinetic energy but different momentum.

Concept–28

Why do airbags reduce injuries?

Airbags increase the **time** over which the passenger comes to rest.
For the same change in momentum, the average force decreases.
Note: This idea will be derived mathematically in the chapter on **Impulse and Momentum**.

Concept–29

Why are heavy trucks harder to stop than motorcycles?

Because a heavier vehicle generally has greater **momentum** and often greater **kinetic energy**, requiring more work by the brakes to bring it to rest.

Concept–30

Golden Rule for Solving Problems

Before solving any numerical, ask:

- Is the force **constant** or **variable**?
- Can I use the **Work–Energy Theorem**?
- Is **Mechanical Energy Conservation** applicable?
- Is friction present?
- Should I resolve the force into components?
- Are all quantities in **SI units**?

Top 10 NEET/JEE Takeaways

1. Work is a **scalar** quantity.
2. Only the component of force **parallel to displacement** does work.
3. Area under the **F–x graph** gives work done.
4. Kinetic energy can never be negative.
5. Potential energy depends on the reference level.
6. Gravity and spring forces are conservative.
7. Friction is non-conservative.
8. Mechanical energy is conserved only in the absence of non-conservative forces.
9. Centripetal force does **zero work** in uniform circular motion.
10. In many mechanics problems, the **Work–Energy Theorem** provides the shortest solution.

Basic Numerical

Q1.

A force of **25 N** acts on a body through a displacement of **8 m** in the same direction. Calculate the work done.

Q2.

A **5 kg** block moves with a speed of **4 m s^{-1}**. Find its kinetic energy.

Q3.

A **3 kg** body is lifted vertically through **12 m**. Calculate the increase in gravitational potential energy.

Q4.

A machine performs **6000 J** of work in **20 s**. Find its average power.

Q5.
A spring of spring constant **250 N m⁻¹** is compressed by **0.10 m**. Calculate the elastic potential energy stored.

Q6.
A **4 kg** body falls freely from a height of **20 m**. Find its speed just before reaching the ground.

Q7.
A force of **80 N** acts at an angle of **60°** to the displacement of **5 m**. Calculate the work done.

Q8.
A machine has an input power of **1200 W** and delivers an output power of **900 W**. Find its efficiency.

Q9.
A body initially at rest gains **450 J** of kinetic energy. Find the work done on it.

Q10.
A **6 kg** block slides down a smooth incline of height **5 m**. Find its velocity at the bottom.

Intermediate Numerical

Q11.
A force varies according to $F = 4x + 2$, where F is in newton and x is in metres.
Calculate the work done in moving the body from $x = 0$ to $x = 3$m.

Q12.
A **2 kg** body is projected vertically upward with a speed of **20 m s⁻¹**. Determine the maximum height reached.

Q13.
A spring is stretched by **15 cm**. If the spring constant is **300 N m⁻¹**, calculate the work done in stretching it.

Q14.
A **10 kg** block is pulled on a rough horizontal surface by a horizontal force of **60 N**. The frictional force is **20 N**. Find the net work done after moving **10 m**.

Q15.
A body moves along a straight line under a variable force represented by a triangular **F–x graph** with base **6 m** and height **40 N**. Calculate the work done.

Q16.
A **5 kg** body falls from a height of **45 m**. Determine its kinetic energy when it has fallen **20 m**.

Q17.
A lift raises a **500 kg** load through **15 m** in **25 s**. Calculate the power developed.

Q18.
A **4 kg** block compresses a spring of spring constant **800 N m^{-1}** by **0.20 m**. Find the elastic potential energy stored.

Q19.
A force of **100 N** acts at **120°** to the displacement of **3 m**. Calculate the work done.

Q20.
A body of mass **8 kg** moves with a speed of **12 m s^{-1}**. Calculate its kinetic energy and momentum.

NEET Level Numerical

Q21.
A **2 kg** block slides down a rough inclined plane of height **5 m**. The work done against friction is **12 J**. Find the speed of the block at the bottom.

Q22.
A spring gun fires a **0.20 kg** ball. The spring constant is **500 N m^{-1}** and the compression is **0.15 m**. Calculate the speed of the ball, assuming no energy loss.

Q23.
A particle is acted upon by a force $F = 5x^2$. Calculate the work done in moving it from $x = 1$m to $x = 3$m.

Q24.
A **6 kg** block slides on a rough horizontal surface. The coefficient of kinetic friction is **0.25**. Find the work done by friction over a distance of **12 m**.

Q25.
A **3 kg** block is released from rest at the top of a smooth hemisphere of radius **5 m**. Find its speed at the lowest point.

Q26.
A **1500 kg** car accelerates from **10 m s^{-1}** to **25 m s^{-1}**. Calculate the increase in kinetic energy.

Q27.
A motor of efficiency **80%** delivers an output power of **4 kW**. Find the input power.

Q28.
A force F = 10 + 4x acts on a particle. Find the work done in moving it from x = 2m to x = 6m.

Q29.
A body of mass **2 kg** moves in a vertical circle of radius **2 m**. Determine the change in gravitational potential energy between the lowest and highest points.

Q30.
A **10 kg** crate is pulled **15 m** by a force of **80 N** inclined at **37°** to the horizontal. The frictional force is **20 N**. Find the net work done.

JEE Main Level Numerical

Q31.
A particle moves under the force $F = 6x - x^2$. Find the work done from x = 0 to x = 4m.

Q32.
A **5 kg** block moving at **8 m s⁻¹** compresses a spring by **0.40 m** before coming to rest. Find the spring constant.

Q33.
A **2 kg** block slides down a rough incline making **30°** with the horizontal. The coefficient of friction is **0.2**. Calculate its speed after moving **5 m**.

Q34.
A body is projected upward with **30 m s⁻¹**. Determine its kinetic and potential energies after rising **20 m**.

Q35.
A **4 kg** block is pulled by a variable force represented by a trapezium on the **F–x graph**. Calculate the work done using the graph.

Q36.
A **1000 kg** car climbs a hill of height **80 m** with a constant speed. Calculate the minimum work done against gravity.

Q37.
A **2 kg** particle experiences a force $F = 12 - 2x$. Find the work done from x = 0 to x = 5m.

Q38.
A spring of spring constant **600 N m⁻¹** is compressed by **0.25 m**. Calculate the energy stored and the maximum speed of a **1.5 kg** block released from it.

Q39.
A body moving on a rough horizontal surface loses **40%** of its initial mechanical energy due to friction. Explain the energy transformation and calculate the remaining mechanical energy if initially it was **500 J**.

Q40.
Using the Work–Energy Theorem, derive an expression for the stopping distance of a vehicle moving with initial speed u under a constant braking force F.

JEE Advanced Foundation

Q41.
A particle moves under a force $F = ax^2 + bx$. Derive a general expression for the work done in moving from x_1 to x_2.

Q42.
A block slides down a rough incline and then compresses a spring at the bottom. Determine the maximum compression in terms of m, g, h, k, and the work done against friction.

Q43.
A body is projected vertically upward. Taking air resistance into account as a constant retarding force, derive the maximum height reached.

Q44.
A particle moves in a potential field where $U(x) = 3x^2 - 4x$. Find the corresponding force as a function of x.

Q45.
A spring–mass system is compressed and released on a rough horizontal surface. Determine the total distance travelled before coming to rest.

Q46.
A block slides down a smooth hemisphere and leaves the surface. Using energy conservation, determine its speed at the point of separation.

Q47.
A force varies with displacement as shown in a piecewise linear **F–x graph**. Determine the total work done by calculating the areas under different sections of the graph.

Q48.
A body is subjected to two perpendicular forces simultaneously. Using the work–energy theorem, determine the change in kinetic energy after a given displacement.

Q49.
A block attached to a spring oscillates on a frictionless surface. Show that the total mechanical energy remains constant throughout the motion.

Q50.
A roller coaster starts from rest at height H and moves along a frictionless track containing hills and loops. Determine the minimum height required to complete a vertical loop of radius R.
