Chapter 4 – Work, Energy and Power

🔋 1. Introduction

Every movement in nature involves energy.
When you push a door, climb stairs, or heat water — you're doing **work**, transferring **energy**, and using **power**.

This chapter connects forces to energy — turning Newton's laws into a language of efficiency and conservation.

⚙️ 2. Work Done by a Force

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

- Positive if force and displacement same direction.
- Zero if perpendicular (e.g., car turning a curve).
- Negative if opposite (e.g., friction).

Unit: Joule (J).
1 J = 1 N·m = kg m^2/s^2.

Example: Force 10 N moves object 3 m → W = 30 J.

🔄 3. Work by Variable Force

When force changes with position:

$$W = \int F(x)\,dx$$

Graphically, **area under F–x graph** = work done.

🧠 4. Work by Gravity and Spring

- **Gravity:** W = mgh (if height changes h).
- **Spring force (Hooke's law):** F = −kx
  → Work = ½ kx^2.

Stretching a spring stores potential energy.

⚡ 5. Energy and Its Forms

Energy is the capacity to do work.

Form	Example
Mechanical (Kinetic + Potential)	Moving car, raised stone
Heat	Stove, engine
Electrical	Battery, generator
Chemical	Food, fuel
Nuclear	Atomic reactions
Sound/Light	Vibrations, laser

🏃 6. Kinetic Energy (KE)

Energy due to motion:

KE=12mv2KE = \frac{1}{2}mv^{2}KE=21mv2

Derived from work done to accelerate a body:

W=Fs=mas=mv2/2W = F s = ma s = m v^{2}/2W=Fs=mas=mv2/2

Double speed → quadruple energy.

🧱 7. Potential Energy (PE)

Energy stored by virtue of position or configuration.

- **Gravitational:** $U = mgh$.
- **Elastic (spring):** $U = ½ kx^2$.

When a body falls, PE → KE converts smoothly; total remains constant.

🧮 8. Work–Energy Theorem

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

Wnet=ΔKE=½m(v2−u2)W_{net} = ΔKE = ½ m(v^{2}-u^{2})Wnet=ΔKE=½m(v2−u2)

If positive work → speed increases; negative → slows down.

This beautiful equation turns force problems into energy ones — a common NEET shortcut.

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9. Conservation of Mechanical Energy

In absence of non-conservative forces (like friction):

KE+PE=constantKE + PE = \text{constant}KE+PE=constant

Example: Falling body — PE decreases, KE increases, sum same.

Energy can change form but total never changes — this is the most powerful law in physics.

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10. Power

Power = rate of doing work:

P=Wt=Fvcos θP = \frac{W}{t} = Fv\cosθP=tW=Fvcosθ

Unit: Watt (W) = J/s.
1 horsepower = 746 W.

More power → same work in less time.

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11. Conservative and Non-Conservative Forces

Type	Work Depends on	Example	Energy Conversion
Conservative	initial & final position only	Gravity, spring	Total ME constant
Non-conservative	path	Friction, air drag	ME → heat

Work done by conservative force = −ΔPE.

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12. Collisions

A collision is interaction for short time between two bodies exchanging energy & momentum.

Elastic Collision

- KE and momentum conserved.
- Example: billiard balls.

Inelastic Collision

- Momentum conserved, KE not.
- Example: clay balls stick together.

Coefficient of restitution:

e=relative velocity afterrelative velocity beforee = \frac{\text{relative velocity after}}{\text{relative velocity before}}e=relative velocity beforerelative velocity after

For elastic → 1, perfectly inelastic → 0.

🌍 13. Center of Mass and Work–Energy Link

Even complex systems behave as if their whole mass were concentrated at their center of mass.
Work–energy theorem applies to the whole system if external forces act on the center of mass.

🔋 14. Power and Efficiency in Machines

Efficiency η = (output power/input power) × 100%.
A car engine converting 25% fuel energy to motion → η = 25%.

Improving efficiency = reducing losses (friction, heat).

💡 15. Important Graphs

- **F–x graph:** Area = work.
- **P–t graph:** Area = energy.
- **U–x graph:** Slope = force ($F = -dU/dx$).

🧠 16. Everyday Examples

- Falling ball → PE → KE.
- Pendulum → continuous exchange.
- Bow and arrow → elastic energy → motion.
- Regenerative brakes → convert KE back to electricity.

📘 17. Summary

1. Work = $F s \cos\theta$.
2. Power = $W/t = Fv$.
3. KE = $\frac{1}{2} mv^2$, PE = mgh or $\frac{1}{2} kx^2$.

4. Work–Energy Theorem → $W = \Delta KE$.
5. Conservation of Mechanical Energy → $KE + PE = \text{constant}$.
6. Elastic collision → momentum and energy conserved.
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