Applied Physics 1

Energy — Kinetic, Potential, and Conservation of Mechanical Energy

1. Energy and Its Units

Energy is defined as the capacity or ability of a body to do work. A body is said to possess energy if it is capable of exerting a force that produces a displacement, that is, if it can perform work on another body. Energy and work are therefore closely related concepts, and both are measured in the same units.

The SI unit of energy is the joule (J), the same as the unit of work, since one joule of energy is the amount of energy required to do one joule of work. In the CGS system, the unit of energy is the erg, where 1 joule = 10^5 erg.

Other common units of energy used in specific contexts include:

- Calorie (cal) — commonly used for heat energy; 1 calorie = 4.18 joules (approximately).
- Kilowatt-hour (kWh) — commonly used for electrical energy consumption; 1 kWh = 3.6×10^6 joules.
- Electron-volt (eV) — used for energy at the atomic and subatomic scale.

Energy exists in many forms, including mechanical energy, heat energy, light energy, electrical energy, chemical energy, sound energy, and nuclear energy. In this section, the focus is mainly on mechanical energy, which includes kinetic energy and potential energy.

2. Kinetic Energy

Kinetic energy is the energy possessed by a body by virtue of its motion. Any body that is moving, regardless of the direction of its motion, possesses kinetic energy, and this energy is used up in doing work as the body is brought to rest.

The kinetic energy of a body of mass m moving with velocity v is given by the formula:

- $K.E. = \frac{1}{2} m v^2$

From this formula, it is clear that kinetic energy depends on both the mass and the square of the velocity of the body. This means that doubling the velocity of a body increases its kinetic energy four times, while doubling its mass (at constant velocity) only doubles its kinetic energy.

Examples of bodies possessing kinetic energy include a moving car, a flowing river, a spinning wheel, a flying aircraft, and a bullet fired from a gun.

3. Potential Energy

Potential energy is the energy possessed by a body by virtue of its position or configuration, rather than its motion. A body raised to a height above the ground, a compressed or stretched spring, and a stretched bow all possess potential energy, since they have the capacity to do work when allowed to return to their original position or configuration.

The most common form encountered in mechanics is gravitational potential energy, which is the energy possessed by a body due to its position above the surface of the Earth (or any reference level). For a body of mass m raised to a height h above the ground, the gravitational potential energy is given by:

- P.E. = m g h

where g is the acceleration due to gravity. This energy arises because work must be done against gravity to raise the body to that height, and this work gets stored in the body as potential energy, which can later be converted into kinetic energy if the body is allowed to fall.

Examples of bodies possessing potential energy include water stored in an elevated reservoir or dam, a stretched bowstring, a compressed spring, and a book placed on a high shelf.

4. Conservation of Mechanical Energy for a Freely Falling Body

The total mechanical energy of a body is the sum of its kinetic energy and potential energy at any instant:

- Total Mechanical Energy = K.E. + P.E.

The law of conservation of mechanical energy states that, in the absence of any dissipative (energy-losing) forces such as friction or air resistance, the total mechanical energy of a body remains constant throughout its motion. As the body moves, kinetic energy may be converted into potential energy, or potential energy into kinetic energy, but their sum remains unchanged.

This principle is best illustrated by the case of a freely falling body. Consider a body of mass m released from rest at a height h above the ground, falling freely under gravity (with air resistance neglected).

The mechanical energy of the body at three key positions during its fall is summarised below:

Position of Body (falling from height h)	Height above ground	Kinetic Energy	Potential Energy	Total Mechanical Energy
At the point of release (top)	h	0	mgh	mgh
At an intermediate point	(h − x), fallen through x	mgx	mg(h − x)	mgh
Just before hitting the ground	0	mgh	0	mgh

At the point of release, the body is momentarily at rest, so its kinetic energy is zero, while its potential energy is maximum, equal to mgh. As the body falls, it loses height and therefore loses potential energy, but gains speed and therefore gains an equal amount of kinetic energy. Just before the body strikes the ground, all of its initial potential energy has been converted into kinetic energy, so its kinetic energy becomes mgh while its potential energy becomes zero.

At every stage of the fall, the sum of kinetic energy and potential energy remains exactly equal to mgh, confirming that the total mechanical energy of a freely falling body (in the absence of air resistance) is conserved throughout its motion.

Worked Example 1:
A body of mass 2 kg is dropped from a height of 20 m above the ground. Calculate its potential energy at the point of release and its kinetic energy just before it strikes the ground. (Take $g = 10\ m/s^2$)

Solution: Potential energy at release = mgh = 2 × 10 × 20 = 400 J. Since mechanical energy is conserved and the body starts from rest, the kinetic energy just before striking the ground is equal to the initial potential energy, that is, 400 J.

Worked Example 2:
A ball of mass 0.5 kg falls freely from a height of 10 m. Find its kinetic energy and potential energy after it has fallen through a height of 4 m. (Take $g = 10\ m/s^2$)

Solution: Total mechanical energy = mgh = 0.5 × 10 × 10 = 50 J. After falling 4 m, height remaining above the ground = 10 − 4 = 6 m, so potential energy at that instant = mg(6) = 0.5 × 10 × 6 = 30 J. By conservation of mechanical energy, kinetic energy at that instant = Total energy − Potential energy = 50 − 30 = 20 J. The sum (30 J + 20 J = 50 J) correctly equals the total mechanical energy at the point of release, verifying conservation of mechanical energy.

5. Transformation of Energy (Examples)

Energy can neither be created nor destroyed; it can only be transformed from one form to another. This is known as the principle of conservation of energy, one of the most fundamental principles in the whole of physics. In practice, almost every device and natural process involves the conversion of energy from one form into another, more useful, form.

Some common examples of energy transformation are given below:

Device / Phenomenon	**Energy Transformation**
Electric bulb	Electrical energy → Light energy + Heat energy
Electric motor	Electrical energy → Mechanical (kinetic) energy
Electric generator / Dynamo	Mechanical energy → Electrical energy
Solar cell / Solar panel	Light (solar) energy → Electrical energy
Battery (during discharge)	Chemical energy → Electrical energy
Photosynthesis in plants	Light energy → Chemical energy
Burning of fuel (combustion)	Chemical energy → Heat energy + Light energy
Loudspeaker	Electrical energy → Sound energy
Microphone	Sound energy → Electrical energy
A swinging pendulum	Kinetic energy ⇄ Potential energy (continuous interconversion)
Hydroelectric power plant	Potential energy of water → Kinetic energy → Electrical energy

These examples show that energy transformation is central to the functioning of nearly all natural processes and modern technology, from the simplest household appliances to large-scale power generation systems, and understanding these transformations is fundamental to the study and application of physics in engineering.

6. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. Energy is defined as the capacity of a body to:

A) Remain at rest
B) Do work

C) Change its mass

D) Change its shape only

2. The SI unit of energy is:

A) Newton

B) Watt

C) Joule

D) Pascal

3. The formula for kinetic energy of a body of mass m moving with velocity v is:

A) mv

B) ½ mv

C) ½ mv^2

D) mv^2

4. The formula for gravitational potential energy of a body of mass m at height h is:

A) mgh

B) ½ mgh

C) mg/h

D) mgh^2

5. Kinetic energy of a body depends on:

A) Only its mass

B) Only its velocity

C) Both its mass and velocity

D) Neither mass nor velocity

6. The law of conservation of mechanical energy applies when:

A) Friction acts on the body

B) Only conservative forces (such as gravity) act on the body

C) Air resistance is present

D) The body loses energy to heat

7. For a freely falling body released from rest at height h, the total mechanical energy at any point during the fall is:

A) Always increasing

B) Always decreasing

C) Constant and equal to mgh

D) Zero throughout the fall

8. Just before a freely falling body (released from height h) hits the ground, its kinetic energy is:

A) Zero

B) mgh

C) ½ mgh

D) 2mgh

9. At the highest point of release, a freely falling body has:

A) Maximum kinetic energy and zero potential energy
B) Zero kinetic energy and maximum potential energy
C) Equal kinetic and potential energy
D) Zero total mechanical energy

10. The energy transformation in an electric generator is:

A) Electrical energy to mechanical energy
B) Mechanical energy to electrical energy
C) Chemical energy to electrical energy
D) Light energy to electrical energy

11. The energy transformation in a solar cell is:

A) Electrical energy to light energy
B) Chemical energy to light energy
C) Light (solar) energy to electrical energy
D) Heat energy to electrical energy

12. Which of the following is an example of continuous interconversion between kinetic and potential energy?

A) An electric bulb glowing
B) A swinging pendulum
C) A burning candle
D) A charging battery

13. The energy possessed by a body due to its motion is called:

A) Potential energy
B) Kinetic energy
C) Chemical energy
D) Thermal energy

14. The energy possessed by a body due to its position or configuration is called:

A) Kinetic energy
B) Potential energy
C) Sound energy
D) Electrical energy

15. In a hydroelectric power plant, the energy transformation sequence is:

A) Electrical → Potential → Kinetic
B) Kinetic → Chemical → Electrical
C) Potential energy of water → Kinetic energy → Electrical energy
D) Chemical → Kinetic → Potential

Answer Key

1. B) Do work | 2. C) Joule | 3. C) ½ mv^2 | 4. A) mgh | 5. C) Both its mass and velocity | 6. B) Only conservative forces (such as gravity) act on the body | 7. C) Constant and equal to mgh | 8. B) mgh | 9. B) Zero kinetic energy and maximum potential energy | 10. B) Mechanical energy to electrical energy | 11. C) Light (solar) energy to electrical energy | 12. B) A swinging pendulum | 13. B) Kinetic energy | 14. B) Potential energy | 15. C) Potential energy of water → Kinetic energy → Electrical energy

7. Broad / Long Answer and Numerical Questions

1. Define energy. State its SI unit and explain the relationship between work and energy.

2. Define kinetic energy. Derive its formula for a body of mass m moving with velocity v, starting from the work-energy relation.

3. Define potential energy. Derive an expression for the gravitational potential energy of a body of mass m raised to a height h above the ground.

4. State the law of conservation of mechanical energy. Explain the conditions under which this law holds true.

5. Show that the total mechanical energy of a freely falling body remains constant throughout its fall, by considering its energy at the point of release, at an intermediate point, and just before it strikes the ground.

6. What is meant by transformation of energy? Explain with any four examples from daily life and technology.

7. Explain the energy transformations that take place in a hydroelectric power plant, from the water stored in a dam to the electricity delivered to homes.

8. Explain, with an example, how energy continuously changes form between kinetic and potential energy in the motion of a simple pendulum.

9. A body of mass 2 kg is dropped from a height of 20 m above the ground. Calculate its potential energy at the point of release, and its kinetic energy just before it strikes the ground. (Take $g = 10\ m/s^2$)

10. A ball of mass 0.5 kg falling freely from a height of 10 m has fallen through 4 m at a certain instant. Calculate its kinetic energy and potential energy at that instant, and verify that their sum equals the total mechanical energy at the point of release. (Take $g = 10\ m/s^2$)