Unit 4

Force, Work, Energy and Power

Introduction: In Unit 3, we explored kinematics, which is concerned with describing the motion of objects. Now, in this unit, we will delve into dynamics, which examines the forces responsible for causing this motion. Forces are fundamental to understanding how objects move or change their state of motion. This unit covers the different types of forces, Newton's laws of motion, and the concepts of work, energy, and power.

1. The Concept of Force

A force is a push or pull that changes an object's state of motion. For example, when you push a cart, you exert a force that causes the cart to move. Forces can:

- **Change the motion** of a stationary object.
- **Accelerate** a moving object.
- **Deform** an object (like stretching a spring).

Types of Forces:

- **Contact Forces:** These require physical contact between objects (e.g., friction, normal force, applied force).
- **Non-Contact Forces:** These act without physical contact (e.g., gravitational force, magnetic force).

Measuring Force: The SI unit for force is the Newton (N). A common way to measure force is by using a spring scale, where the force causes the spring to stretch, and the measurement is read from a scale.

2. Newton's Laws of Motion

Newton's First Law (Law of Inertia): An object will remain at rest or continue to move in a straight line at constant speed unless acted upon by an unbalanced force. This means that an object's motion does not change unless a force is applied.

Newton's Second Law: This law states that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. It is expressed mathematically as: $F=ma$ where F is the force, m is the mass, and a is the acceleration. For example, if you push a block with a force of 10 N and it has a mass of 2 kg, its acceleration will be 5 m/s^2.

Newton's Third Law: For every action, there is an equal and opposite reaction. This means that if you push a wall, the wall pushes back with an equal force in the opposite direction.

Forces of Friction

When an object moves across a surface, it encounters a resistance called friction. This force, denoted by f, opposes the motion of the object. Friction is crucial in our daily lives, helping us walk, run, and allowing vehicles to move. For example, vehicles may get stuck in mud due to the high friction that resists their motion.

Types of Friction:

1. **Static Friction:** This is the friction that prevents an object from starting to move. It acts when the object is stationary.
2. **Kinetic Friction:** This is the friction that acts when an object is already in motion.

The magnitude of the frictional force depends on two factors:

- **Normal Force:** The force exerted by a surface perpendicular to the object.
- **Nature of the Surfaces:** Rough surfaces create more friction compared to smooth surfaces.

In general, friction increases with the roughness of the surfaces and is directly proportional to the normal force. The greater the normal force, the greater the frictional force.

The Concept of Work

In everyday language, "work" means effort or activity. However, in physics, "work" has a specific meaning. Work is done when a force causes an object to move in the direction of the force.

Scientific Definition:

- Work is done when a force (F) moves an object through a displacement (S) in the direction of the force.
- Mathematically, $W=F_{\parallel}\times S$, where $F_{\parallel}$ is the force in the direction of the displacement.

Examples:

1. **No Work Done:** Holding a chair or carrying a bucket horizontally does not involve work in physics because there is no displacement in the direction of the force applied (upward).
2. **Work Done:** Lifting a box from the ground involves work because the force applied (upward) causes a displacement (upward).

Formulas:

- $W=F_{\parallel}\times S$
    - Where W is work, $F_{\parallel}$ is the component of the force in the direction of displacement, and S is the displacement.

Example Calculation:

- If a boy applies a force of 60 N to push a box 12 meters, the work done is:
    - $W=60\text{ N}\times 12\text{ m}=720\text{ J}$ (Joules).

Kinetic and Potential Energies

Kinetic Energy:

- This is the energy of an object due to its motion.
- Formula: $E_k=\frac{1}{2}mv^2$
    - Where m is the mass and v is the speed of the object.
- **Example:** A 200 g ball moving at 20 m/s has a kinetic energy of 40 J.

Gravitational Potential Energy:

- This is the energy an object has due to its position above the ground.
- Formula: $E_p=mgh$
    - Where m is the mass, g is the gravitational acceleration (10 m/s²), and h is the height above the ground.
- **Example:** A 30 kg object at a height of 50 meters has a potential energy of 15,000 J.

Mechanical Energy:

- The sum of kinetic and potential energies in a system.

Power

Definition:

- Power is the rate at which work is done or energy is transferred.
- Formula: P=$\frac{W}{t}$
  - Where W is work done and t is the time taken.

Units:

- The SI unit of power is the Watt (W), where 1 W=1 J/s.

Examples:

1. **Car Power:** If a car uses 1500 J of energy in 5 seconds, its power is 300 W.
2. **Water Pump Power:** A pump lifting 500 liters of water (500 kg) through 10 meters in 5 seconds requires 10 kW of power.

Summary: Understanding forces and their effects is crucial for analyzing how objects move and interact. Newton's laws provide the foundation for this understanding, while the concepts of work, energy, and power help describe how forces influence motion and energy changes.