Unit 5
Simple Machines

Introduction to Simple Machines

In this unit, you'll explore simple machines, which are fundamental tools that make work easier. Simple machines have been used throughout history to help humans perform tasks more efficiently. Examples include an axe for chopping wood, a knife for cutting, and a pulley for lifting water. These machines help us by changing the way we apply force.

Simple Machines and Their Purposes

Simple machines are devices that use a single force to perform mechanical work. For instance, a stapler uses a single downward force to staple papers together. Simple machines are designed to make physical tasks easier by:

- **Changing the direction of force:** For example, a pulley changes the direction of force. Instead of lifting a load directly upward, you pull down on the rope.
- **Changing the distance over which force is applied:** An inclined plane, like a ramp, allows you to move a heavy object up a longer but easier path rather than lifting it straight up.
- **Multiplying force:** A bottle opener lets you apply a small force to lift a heavy cap.

Simple machines do not create energy but transfer mechanical energy to make work easier. They act as force or speed multipliers, meaning they either make a force stronger or make it easier to move things over a greater distance.

Key Terms:

- **Effort (F):** The force applied to a simple machine.
- **Load (L):** The force exerted by the machine to move or lift an object.

Simple Machines at Home

You encounter simple machines every day. Here are a few examples:

1. **Lever (e.g., a seesaw):** Changes the direction or magnitude of force.
2. **Pulley (e.g., a clothesline):** Changes the direction of force.
3. **Inclined Plane (e.g., a ramp):** Helps to lift heavy objects with less effort.

4. **Wheel and Axle (e.g., a rolling pin):** Reduces friction and makes movement easier.
5. **Wedge (e.g., an axe):** Splits or cuts materials by applying force over a small area.
6. **Screw (e.g., a jar lid):** Converts rotational force into linear force.

Simple Machines at Work

Simple machines are essential in modern technology. They form the basis of more complex machines, such as cars and airplanes. For example, a lever can move heavy objects with less effort, and a bicycle uses levers, wheels, and pulleys to make riding easier.

Classification of Simple Machines

Simple machines are classified into the following types:

1. **Inclined Planes:**
   - **Ramp:** Helps in lifting objects by increasing the distance over which the effort is applied.
   - **Wedge:** Used for cutting or splitting.
   - **Screw:** Converts rotational force into linear force.
2. **Levers:**
   - **Lever:** A rigid bar that pivots around a fulcrum.
   - **Wheel & Axle:** Reduces friction and makes movement easier.
   - **Pulley:** Changes the direction of force.

Categories:

- **Force Multipliers:** Increase the output force (e.g., a claw hammer).
- **Speed Multipliers:** Increase the speed or distance of the load (e.g., a bicycle).
- **Direction Changers:** Change the direction of the force (e.g., a pulley).

Mechanical Advantage, Velocity Ratio, and Efficiency

Mechanical Advantage (M.A): The ratio of the output force to the input force.

M.A=$\frac{Load}{\text{Effort}}$

Velocity Ratio (V.R): The ratio of the distance moved by the effort to the distance moved by the load. V.R=$\frac{Distance\ moved\ by\ effort}{\text{Distance moved by load}}$

Efficiency: Measures how well a machine converts input energy to useful output energy. Efficiency(η)=$\frac{Work\ Output}{\text{Work Input}}$

Example Problems:

1. **Mechanical Advantage Example:** A lever lifts a load of 400 N with an effort of 160 N. The mechanical advantage is: M.A=$\frac{400\ N}{\text{160 N}}$ =2.5
2. **Velocity Ratio Example:** A lever lifts a load with the effort moving 40 cm while the load moves 10 cm. The velocity ratio is: V.R=$\frac{40\ cm}{\text{10 cm}}$ =4
3. **Efficiency Example:** A machine provides 80 J of work output for every 400 J of work input. The efficiency is: η=$\frac{80\ J}{\text{400 J}}$ =0.2 or 20%

Levers:

Definition: A lever is a rigid bar that pivots around a fixed point known as the fulcrum (F). It helps in lifting or moving loads by applying an effort (E). The basic components of a lever include:

- **Fulcrum (F):** The pivot point about which the lever rotates.
- **Effort (E):** The force applied to the lever to move the load.
- **Load (L):** The weight or resistance that needs to be moved.

Classes of Levers:

1. **First-Class Lever:**
   - **Description:** The fulcrum is positioned between the load and the effort.
   - **Examples:** Seesaw, scissors, crowbar.
   - **Mechanical Advantage (IMA):** Can be greater than, equal to, or less than one, depending on the positions of the load and effort.
2. **Second-Class Lever:**
   - **Description:** The load is positioned between the effort and the fulcrum.
   - **Examples:** Wheelbarrow, nutcrackers, bottle opener.
   - **Mechanical Advantage (IMA):** Always greater than one, which means the effort needed is less than the load being lifted.
3. **Third-Class Lever:**
   - **Description:** The effort is applied between the load and the fulcrum.
   - **Examples:** Fishing pole, tweezers, broom.
   - **Mechanical Advantage (IMA):** Always less than one, meaning the effort required is more than the load being moved, but it allows for a greater range of movement.

Calculations Involving Levers:

1. **Mechanical Advantage (M.A):**
   - **Formula:** M.A=$\frac{Load}{\mathrm{Effort}}$
   - This shows how many times the lever amplifies the effort applied.
2. **Velocity Ratio (V.R):**
   - **Formula:** V.R=$\frac{Distance\ from\ Effort\ to\ Fulcrum}{\mathrm{Distance\ from\ Load\ to\ Fulcrum}}$
   - This indicates the ratio of the distance moved by the effort to the distance moved by the load.
3. **Efficiency (η):**
   - **Formula:** η=$\frac{M.A}{\mathrm{V.R}}$ ×100%
   - Efficiency represents how well the lever converts input effort into output work, accounting for losses due to friction.

Example Calculation:

If a load of 200 N is lifted by applying an effort of 80 N on a lever, with the load 10 cm from the fulcrum and the effort 40 cm from the fulcrum:

a) **Velocity Ratio (V.R):**

- V.R=$\frac{40\ cm}{10\ \mathrm{cm}}$ =4

b) **Mechanical Advantage (M.A):**

- M.A=$\frac{200\ N}{80\ \mathrm{N}}$ =2.5

c) **Efficiency (η):**

- η=$\frac{2.5}{4}$×100%=62.5 %

Inclined Plane, Wedge, and Screw

1. Inclined Plane

- **Definition:** An inclined plane is a flat, sloping surface that connects two different heights. It helps in lifting or moving objects by reducing the amount of effort needed.
- **Description:** Imagine a ramp. The longer the ramp, the easier it is to lift the object, although it requires moving the object over a longer distance.
- **Formula for Mechanical Advantage (M.A):** M.A=$\frac{Load}{\mathrm{Effort}}$ Where:

- **Load (L):** The weight or resistance being moved.
- **Effort (E):** The force applied along the inclined plane.

- **Formula for Velocity Ratio (V.R):** V.R=$\frac{Length\ of\ Inclined\ Plane\ (l)}{\text{Height (h)}\backslash}$ This represents how much the distance moved by the effort is compared to the height the load is lifted.

2. Wedge

- **Definition:** A wedge is a tool used to split or separate objects. It has a sharp edge that applies force to a small area, making it effective for cutting or splitting.
- **Description:** Examples include knives, axes, and nails. A wedge works by applying force to its narrow edge, which then spreads apart the materials.
- **Formula for Mechanical Advantage (M.A):** M.A=$\frac{Load}{\text{Effort}}$
- **Formula for Velocity Ratio (V.R):** V.R=$\frac{Penetration\ Length\ (l)}{\text{Thickness (t)}}$ Where:
  - **Penetration Length (l):** The distance the wedge moves into the material.
  - **Thickness (t):** The thickness of the wedge.
- **Formula for Efficiency (η):** η=$\frac{M.A}{\text{V.R}}$ ×100% Efficiency measures how well the wedge converts input effort into output work.

3. Screw

- **Definition:** A screw is a cylindrical object with a helical thread wrapped around it. It is used to hold things together, lift materials, or create pressure.
- **Description:** A screw moves into a material as it is turned. The distance it moves in one full turn is called the pitch (p).
- **Formula for Mechanical Advantage (M.A):** M.A=$\frac{\pi d}{\text{p}}$ Where:
  - **Diameter (d):** The diameter of the screw.
  - **Pitch (p):** The distance between adjacent threads of the screw.
- **Example:** A screw is commonly used in nuts and bolts, or in devices like bottle openers

Wheel and Axle, and Pulley System

1. Wheel and Axle

- **Definition:** The wheel and axle consist of a large wheel attached to a smaller rod called an axle. This setup helps to multiply force or distance, depending on how it is used.

- **Description:** The wheel turns around the axle. When force is applied to the wheel, the axle turns, and vice versa.
- **Types and Uses:**
  1. **Wheel with Input Force on the Wheel:**
     - **Description:** When force is applied to the wheel, it turns the axle, which can move heavy loads.
     - **Examples:** Screwdriver, drill, windmill, doorknob.
     - **Advantage:** Lifts large loads with less force applied to the wheel, though the wheel must move a longer distance.
  2. **Axle with Input Force on the Axle:**
     - **Description:** When force is applied to the axle, it turns the wheel. This setup usually results in the wheel turning faster.
     - **Examples:** Bicycle, car tires, electric fan.
     - **Advantage:** Provides greater speed but requires more effort to move the wheel.
- **Mechanical Advantage (M.A):** M.A=$\frac{Load}{\text{Effort}}$
- **Velocity Ratio (V.R):** V.R=$\frac{Radius\ of\ the\ Wheel\ (R)}{\text{Radius of the Axle (r)}}$ The wheel covers a larger distance than the axle, providing a mechanical advantage by multiplying force.

2. Pulley System

- **Definition:** Pulleys are wheels with a groove that a rope or cable runs through. They help lift loads by changing the direction of the force applied.
- **Types:**
  1. **Fixed Pulley:**
     - **Description:** The pulley is fixed in one place. It changes the direction of the applied force but does not reduce the effort needed.
     - **Example:** Flagpole.
     - **Advantage:** Easier to pull downward to lift a load.
     - **Disadvantage:** Requires the same amount of force as the load.
  2. **Movable Pulley:**
     - **Description:** The pulley moves with the load. It provides a mechanical advantage by reducing the effort needed to lift the load.
     - **Example:** Construction cranes.
     - **Advantage:** Reduces the effort needed to lift the load.
     - **Disadvantage:** Requires more distance to pull the rope.
  3. **Compound Pulley (Block and Tackle):**

        - **Description:** A combination of fixed and movable pulleys. It reduces the amount of effort required to lift a load significantly.
        - **Example:** Ship's hoist.
        - **Advantage:** Allows lifting heavy loads with less effort.
        - **Disadvantage:** Requires pulling the rope over a longer distance.
- **Mechanical Advantage (M.A) and Velocity Ratio (V.R):**
    - **Fixed Pulley:** M.A = 1 (Effort equals load); V.R = 1.
    - **Movable Pulley:** M.A = 2 (Effort is half the load); V.R = 2.
    - **Compound Pulley:** M.A = Number of rope segments supporting the load; V.R = Number of segments.

In summary, the wheel and axle can be used to either increase speed or force depending on how the effort is applied. Pulleys, on the other hand, help lift loads more easily by changing the direction of the force and, in the case of compound pulleys, significantly reducing the effort required.