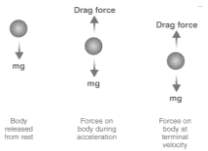
Terminal Velocity

Mechanics

Introduction

In this topic we will discuss the following:

- Definition of terminal velocity.
- Discuss falling objects in a fluid.
- Discuss falling objects in a vacuum.
- Factors that affect falling objects.
- Experiment on terminal velocity.



Definition

- Terminal velocity refers to the **constant maximum downward velocity** that an object reaches when falling in a **fluid** such as air or water.
- A **fluid** is any substance that can **flow** and does **not** have a fixed shape.
- Examples of fluids include both **liquids** and **gasses**.
- Terminal velocity is attained or it occurs when the **downward force** and the **upward forces** acting on a falling object are **balanced** (equal).

- **Figure 1** shows the forces that act on a falling object in a fluid:

Figure 1

Where:

- **W** = Weight (mg)
- **U** = Upthrust
- **Fr** = Friction Force

Definition

Note:

- The weight (w) of the object can be replaced by gravity (g) or a formula for calculating the weight (mg).

Upthrust

- This refers to the upward force exerted by a fluid on the object when immersed in it.
- This force is also called **buoyant** force.
- It is the force that makes objects float when immersed in a fluid

- According to the Archimedes principle, upthrust can be calculated by the formula:

Upthrust = Weight of the displaced fluid

$$= \rho_{fluid} * V * g$$

Where:

- ρ_{fluid} = density of the fluid
- **V** = Volume of the submerged object
- **g** = acceleration due to gravity

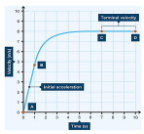
Note: Upthrust and Friction force are also called **resistive forces** in falling objects.

Falling objects in fluids

- As an object falls through a fluid it, experiences **three** forces that affect its motion.
- These forces are:
  a. **Weight (W)** – also called **gravity**, this is the downward force due to the object's mass.
  b. **Fluid resistance** – also called **drag force** or **friction force** (**Fr**), this is the force exerted by the fluid to oppose the motion of the object. This force increases with an increase in the speed of the object, and it also depends on the object's **shape** and **size**.
  c. **Upthrust** – also called **buoyant force**, this is the upward force exerted by the fluid on a falling object. It depends on the volume of the falling object and the density of the fluid.
- As an object is falling through a fluid, it goes through the following stages:
  - At first, the object accelerates due to **gravity (W),** and the resistive forces **(U + Fr)** are low since the speed of the object is low, thus **W> (U + Fr),** As the speed of the object increases, the resistive forces also increases, this opposes the motion of the object as such, acceleration of the object reduces. Finally, the resistive forces (U +Fr) balance with the gravity (W) and the object

Falling objects in fluids

- stops accelerating and falls at a constant speed called terminal velocity, thus **W = U + Fr**.
- The figure below illustrates the velocity time graph of an object falling in a fluid.



Questions:

- Using the graph provided on the left, state the net force (Resultant Force) acting on the object from point A to B.
- A hardwood block with a volume of 0.02 cubic meters is fully immersed in water. Given that the density of the water is 1000 kilograms per cubic meter. Work out the buoyant force acting on the block. (g = 10 m/s)

Falling objects in vacuum

- A vacuum refers to a space that has no matter.
- This means that a vacuum does not contain any air, gas, or liquid.
- In a vacuum, the motion of a falling object is due to **gravity (W),** this is so because in a vacuum we have **no resistive forces** due to the absence of any matter.
- Objects falling in a vacuum will experience the following:

a. **No resistive force:** in a vacuum, there are no fluids as such we have no upthrust and frictional force. The net force acting on the objects is gravity (W).

b. **Constant acceleration:** in a vacuum, the objects fall due to the acceleration of gravity (g) which is 10m/s^2.

c. **Equal falling rate:** all objects will fall at the same rate in a vacuum regardless of their mass or shape. Thus, if a hammer and a feather are dropped from the same height in a vacuum, they will hit the ground at the same time.

Falling objects in vacuum

Questions

Consider a coin and a feather falling inside a vacuum tube as shown below:

- Which object between the coin and the feather will reach the bottom of the tube first?
- Give a reason for your answer.
- State the net force that acts on objects that are falling in a vacuum.
- Sketch a velocity-time graph of an object falling in a vacuum.
- A stone is dropped 100m from a cliff. How long will it take for the stone to reach the ground?

Note: objects that fall due to gravity **only** are said to fall in free fall.

- In free fall we neglect the resistive forces and the object falls due to its weight.

Factors that affect Falling objects.