UNIT 2

MOTION IN ONE DIMENSION

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to force and uniform motion;
- ✓ develop skill of manipulating problems related to statics and uniform motion;
- ✓ appreciate the interrelatedness of all things;
- ✓ use a wide range of possibilities for developing knowledge of the major concepts within physics.

Introduction

In grade 7 physics, you learnt the basic concepts in motion and identified four different types of motion. You also learnt how to compute derived quantities from the fundamental quantities.

''A moving object has a natural tendency to come to rest''
Aristotle (2500B.C)

This unit presents to you concepts in motion where you just extend your previous knowledge and skills in motion to greater depth.

2.1 Forces in Physics

Activity 2.1

- From your grade 7 physics lessons describe the concept 'Force' in general and 'Force' in physics in particular.
- List the types of force you know.

Force is a very important physical quantity. It is used to describe interactions between different bodies in nature. For example, when you kick a ball, tear a piece of paper, hold your exercise book, walk on the floor, close or open a door, you apply forces.

Frictional force and gravitational force are some of the forces that you deal with in day to day life. Frictional force helps you walk and gravitational force helps in the flow of water from higher level to lower level and in kicking ball up in the air and receiving it back.

What is a force?

Force is a push or pull exerted on a body.
The SI unit of force is newton (N) and it is measured by a device called a newton-meter.

Fig 2.1 Newton-meter

Challenging question

Can you name some effects of forces?

Particularly in physics, the concept of force is used to describe how a body changes its velocity or accelerates. It is not possible to describe a force as we can describe some material object such as a chalk, pen, orange, etc. You can only tell what a force does.

A force has the following major characteristics: **Magnitude**, **point of application** and **direction**. Thus, a force is a vector quantity.

Types of forces

In physics there are a number of different forces that you need to study. These are:

- Gravitational force,
- Friction force
- Magnetic force,
- Electric force,
- Elastic force,
- Forces from collisions,
- Centripetal force,
- Buoyancy.

Activity 2.2

Identifying types of forces. Consider the following four cases

Case 1. Two bar magnets attracting each other.

Case 2. A stone (ball) dropping from air to ground.

Case 3. Pushing and pulling a table on the floor.

Case 4. A box moving (sliding) over another box.

i) What are the basic differences between these forces?

ii) Have you noticed that forces can be exerted on objects in two ways?

a. By a physical contact of two objects.

b. Without physical contact of two objects.

Using Activity 2.2, you can classify forces as **contact forces** and **non-contact forces.**

Contact forces are forces that are exerted only when two objects are in contact. e.g frictional forces and pushing a table.

Other examples of contact forces:

1. The force exerted by a stretched or compressed spring,
2. The upward force exerted by a table on a book resting on it, and
3. The force exerted on a bone by a contracting muscle are some example of contact forces. Mention some other contact forces.

A *non-contact* force is a force applied to an object by another body that is not in contact with it. e.g magnetic forces, gravitational force, and electric force.

The most common examples of a non-contact forces are

i) Gravity (gravitational force)

ii) Magnetic force

iii) Electric force

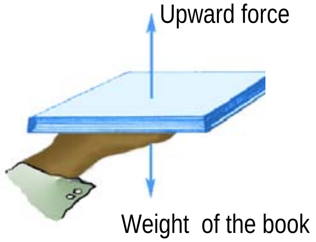
Revising Newton's laws of Motion

Activity 2.3
Discuss the three laws of motion with your friends.

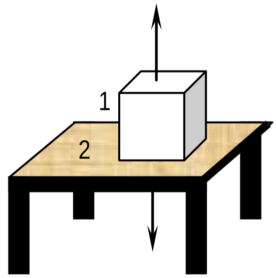
You have learnt **'Newton's first law'** of motion in grade 7. Therefore you remember that an object at rest will not change its position unless a net force causes it to do so.

Newton's first law implies that a net external force must act on an object to speed it up, slow down, or change its direction of motion or to start motion. The first law implies that a force is required to produce change in velocity or acceleration.

From Newton's first law, you observe that the states of **''no motion''** and of **''uniform motion''** are similar as long as there is no net force acting on a body.



a) Holding a book



b) A box resting on a table.

Fig 2.2 Action and reaction forces.

Activity 2.4

1. Hold up your textbook as show in Fig 2.2 (a)
   - Is there any force acting on the textbook you are holding?
   - Is there any force acting on your hand while you are holding the text?
   - Can you mention the number of forces? What are the forces?

While you are holding the textbook on your palm forces occur in pair.

For every action there is equal and opposite reaction Newton's third law

For any two objects a force that is applied to object 1 due to the action of object 2 is accompanied by a force applied to object 2 due to the reaction of object 1. Fig 2.2 illustrates different action and reaction forces. What are the action and reaction forces in Fig 2.2 b? This idea is described by **Newton's third law**. This law implies that action and reaction forces are equal and opposite.

Challenging question

- State and explain the three Newton's laws of motion.

Check point 2.1

1. How could you explain a force in physics?
2. Describe different types of forces in nature.
3. What are contact forces and non-contact forces?
4. Explain the principles behind the first and third laws of Newton.
5. How would you explain the state of 'no motion' and 'balanced forces'?

2.2 Motion in One Dimension

Motion is one of the most important features of the world around us. Every day, you walk from home to your school and see moving objects in your surroundings. In this unit you will further learn about average speed, velocity, acceleration, uniform motion and uniformly accelerated motion in a straight line. Motion in a straight line is called motion in one dimension. Do you remember what you have learnt in grade 7 about uniform motion and uniformly accelerated motion? (Revise your notes).

Activity 2.5

i) What is motion?
ii) Explain the different types of motion.
iii) What does it mean by "motion in one dimension"? Explain its properties.
iv) Define the following terms:
   - Average speed.
   - Average velocity
   - Acceleration.
   - Uniform motion.
   - Uniformly accelerated motion.

2.2.1 Uniform Motion

Challenging question

What does a uniform motion mean?

The type of motion where the moving object covers equal distance in equal time interval is called **uniform motion.** For uniform motion in a straight line, the speed of a moving body is constant.

Activity 2.6

How long does it take you to move around a foot ball field in your school? Five minutes, ten minutes or more? Record the time required to move around the field at least for three different trials.

Trials	Distance (s)	Time (t)	s/t
1			
2			
3			

The distance around the football field remains constant while for many practical reasons the time may not be constant. Sometimes you walk quickly and another time you may run. Therefore, your speed may not be constant. Similarly the motion of bodies, for example a car or a truck will not be uniform. To describe such kinds of motions we use the concept of average speed.

$$\text{Average speed} = \frac{\text{Total distance travlled}}{\text{Total time taken}}$$

$$v_{av} = \frac{s_T}{t_T}$$

The SI unit of average speed is meter per second (m/s). Other non SI units such as kilometer per hour (km/hr), cm/s, etc. can also be used as units of speed.

The concept used to describe a speed that has direction is called a **velocity.** Velocity tells us how fast a body is moving in a given direction.

Velocity is a vector quantity. It depends on the displacement made between final and initial positions. For examples, if you walk from your home to school and back to home your displacement is zero. But your distance traveled is not zero.

$$\textbf{Average velocity} = \frac{\text{Total displacement}}{\text{Total time}}$$

$$\vec{v}_{av} = \frac{\vec{s}}{t}$$

In section 2.1. you have seen that, if there is no net force acting on an object, it will remain at rest, if it was moving with constant speed in a straight line, it will continue to move with its uniform speed.

Generally, the motion of bodies starts and ceases. Bodies increase in motion or slow down, or change their directions. In all these cases the velocities of moving bodies are changing. The causes of these changes in the state of motion are forces exerted on the bodies. Bodies do not change their states of motion without the action of forces.

Newton's second law of motion describes the interrelations of force and motion.

Example 2.1

A bus is travelling from Addis Ababa to Ambo. It travels 43 km in the first hour, 40 km in the second hour, and 46 km in the thirds hour of its journey .What is its average speed?

Given	Required	Solution
$s_1 = 43$ km, $t_1 = 1$hr	**Speed (v_{av}) =?**	$v_{av} = \frac{\text{total distance}}{\text{total time}}$
$s_2 = 40$km, $t_2 = 1$ hr		$v_{av} = \frac{129\text{km}}{3\text{ hr}}$
$s_3 = 46$ km, $t_3 = 1$ hr		

Total distances $S_T = S_1 + S_2 + S_3 = 129$ km

$\mathbf{v_{av} = 43}$ **km /hr**

Total time taken $t_T = t_1 + t_2 + t_3 = 3$ hr

Example 2.2

A car moved 2.4 km due east for 120 second. What is its average velocity?

Given	Required	Solution
s = 2.4 km due east	$\vec{v}_{av} = ?$	$\vec{v}_{av} = \frac{\text{displacement}}{\text{time taken}}$
= 2400 m, due east		$\vec{v}_{av} = \frac{2400\text{m}}{120\text{s}}$ East
t = 120 s		$\vec{v}_{av} = 20$m/s, due East

2.2.2 Uniformly Accelerated Motion

Velocity is a speed with direction

A body that starts to move from rest may increases in motion or slows down or change its direction of motion. In such situations, velocities of moving bodies change. That is, acceleration is produced.

Acceleration is the time rate of change of velocity.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$\Rightarrow \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

$\vec{v}_f$ is final velocity at t_f, $\vec{v}_i$ is initial velocity at t_i

The SI unit of 'a' is m/s^2 (ms^{-2})

If the velocity of a body changes equally for equal interval of time then the motion of the body is said to be *uniformly accelerated motion.*

The phrase **uniformly accelerated motion** means

i. The magnitude of the acceleration is constant (uniform)

ii. The motion is along a straight line. i.e, the direction is fixed. Hence distance and displacement and speed and velocity can be used interchangeably.

Example 2.3

A car starts from rest and reaches a speed of 20 m/s in 5 seconds. What is the acceleration of the car?

Given	Required	Solution
$v_i = 0$ $v_f = 20 m/s$ $t = 5 s$	$\vec{a} = ?$	$\vec{a} = \frac{v_f - v_i}{t} = \frac{20 m/s - 0}{5 s}$ $= 4 (m/s^2)$

Freely Falling Bodies

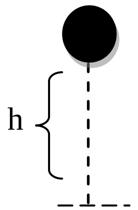


Fig 2.3 Freely falling body

The most common natural example of a uniformly accelerated motion is the motion of a freely falling body. Freely falling body in air means a body which is falling under the action of its weight alone.

For a freely falling bodies you have

$$\vec{v}_i = 0$$

$$\vec{a} = \vec{g} = 9.8 m/s^2, \quad \vec{v}_f = gt$$

$$s = \text{height (h)}$$

Check Point 2.2

1. **What kind of motion is one dimensional motion?**
2. **What is an average speed?**
3. **What is the difference between a speed and a velocity for one dimensional motion?**
4. **What is acceleration?**
5. **Write the equation of acceleration for uniformly accelerated motion.**

2.3 Representation of Uniform Motion and Uniformly Accelerated Motion Using Tables and Graphs

Uniform velocity

When an object moves equal displacement in an equal time interval, then its velocity is said to be uniform velocity or constant velocity.

- Uniform velocity is unchanging velocity.
- If the velocity is uniform then the average and instantaneous velocities are the same.

A motion with constant velocity (i.e constant speed and fixed direction) is said to be **uniform motion**

Uniform motion can be described in v against t and s against t graphs;

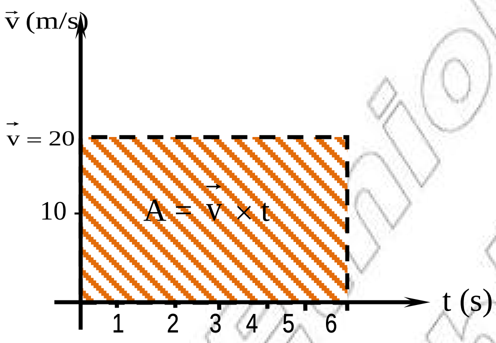


Fig 2. 4 v against t graph for motion with constant velocity.

In Fig 2.4 the v against t graph is given and the slope is a horizontal straight line which shows no change in the velocity as time goes on.

By definition s = v × t = 20 m/s × 6 sec = 120 m. But from Fig, 2.4 the area (A) under the slope equals v × t. ⇒ 20 m/s × 6s= 120 m. This means distance equals the area of the v against t graph.

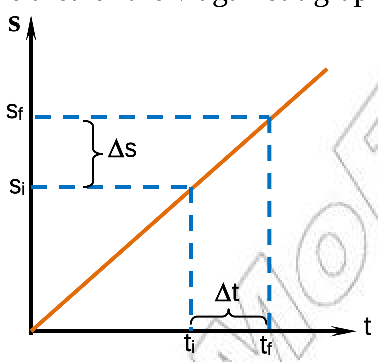


Fig 2.5 s against t graph for motion with constant velocity.

The velocity at a given instant of time can be found from the s against t graph by determining the slope of the graph. The slope of a graph at any point is equal to $\frac{s_f - s_i}{t_f - t_i}$. $= \frac{\Delta s}{\Delta t}$

Let us start with motion at constant velocity. Consider the v against t graph, Fig 2.6. This graph represents the velocity of a car traveling along a straight level road in a direction of north. For the first 2 hours, the car maintains a constant speed of 40 km/hr, then remains at zero velocity for 1 hour, and finally moves opposite in direction to its original velocity (a negative velocity) at 80 km/hr in a direction due south. What information does this graph give?

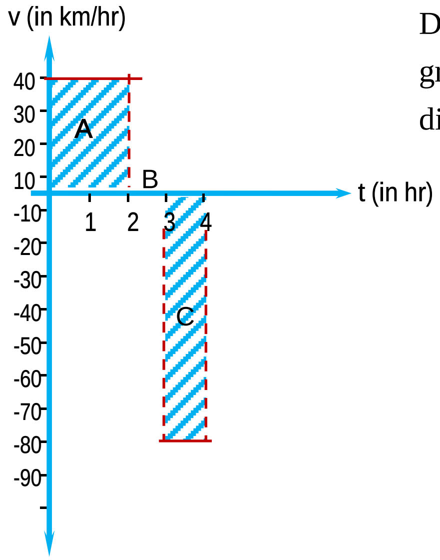


*Fig 2.6 **v against t** graph a car traveling along a straight, level road in a constant direction.*

During the first 2 hours (section A of the graph), When the speed is 40 km/hr the displacement is

$$\vec{s} = \vec{v} \times t$$

$$= 40 \text{ km/hr north} \times 2 \text{ hr}$$

$$= 80 \text{ km, north}$$

The graph does not tell where the car starts, but only that its position changes by 80 km during the 2 hours travel. As you can see, this 80 km is represented by the area under section A.

During the third hour (section B of the graph), the velocity is zero and there is no change in the position of the car, so the area under B is zero.

During the third hour (section C of the graph), the velocity is 80 km/hr due south for 1 hour. The displacement in C is – 80 km /hr × 1hr or 80 km south. This -80 km is represented by the area under section C of the graph.

The total displacement for the 4 hours is zero. The distance traveled by the car, however, is the sum of the magnitude of the displacements and equals

$$(80km) + (80km) = 160km.$$

The s against t graph in Fig 2.6 is a straight line graph, whose slope = $\frac{\Delta \vec{s}}{\Delta t}$. But by definition, $\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$. Hence slope equals velocity in the s against t graph.

Fig 2.7. is a graph of s against t, for the above object, whose v against t is shown in Fig. 2.6

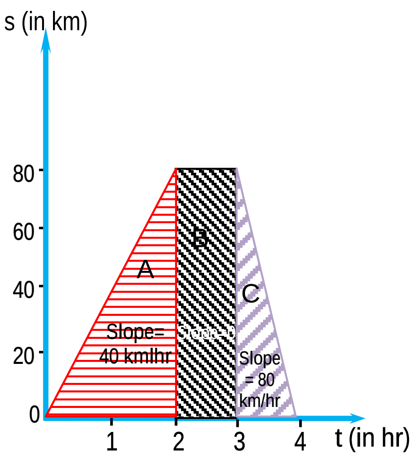


Fig 2.7 $\vec{s}$ against t graph

In section A of the graph, distance increases uniformly with time, in section B, there is no change in distance; and, finally, in section C the displacement is downward rather than upward. Since the negative displacement is equal in magnitude to the positive displacement, the net, or total, displacement is zero. Thus, we see that the velocity for a given time can be found by determining the slope of the displacement time curve for that interval of time.

Uniformly accelerated motion

The v against t graph for a uniformly accelerated motion is a straight line graph. Fig 2.8 illustrates the graph of a uniformly accelerated motion. From the graph you observe that;

i. Slope = $\frac{\Delta \vec{v}}{\Delta t} \Rightarrow$ slope $= \vec{a}$ (acceleration

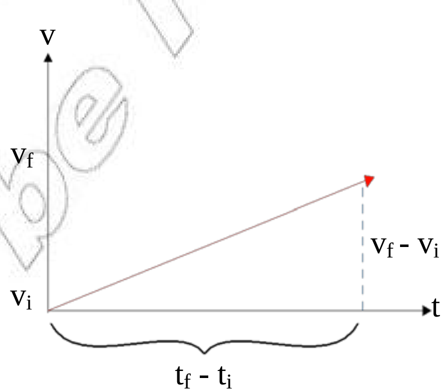


Fig 2.8 v against t graph for changing velocity

ii. The area under the slope of $\vec{v}$ against t graph equals to the displacement of the body. The area (A) under the graph = $\frac{1}{2} \times \Delta t \times \Delta v$. if $v = a\Delta t$, then distance (s) = $\frac{1}{2} at^2$.

Check Point 2.3

1. The motion of a toy is recorded as in table below

t (s)	1	2	3
v (m/s)	10	20	30

a) What is the acceleration of the toy?

b) What is the velocity attained at time t = 10 seconds?

2. A car accelerates from rest to 20 m/s in 5 seconds.

a) What is the acceleration of the car?

b) If it continued accelerating at this rate, how fast would it go after i) 2 seconds? ii) 10 seconds?

3. A car starts from rest and reaches a velocity of 10 m/s in 10 s.

a) Draw the v against t graph for the motion of the car?

b) From the graph find:

i) the slope of the graph.

ii) Area of the v against t graph bounded by the slope, and x- axis.

c) What are the slope and area of v against t graph equal to respectively?

SUMMARY

In this unit you learnt that:

- when two bodies interact with each other, forces are produced between them. Force is a push or a pull exerted between bodies.
- force has magnitude and direction. It is measured by a Newton meter.
- forces are classified as contact and non- contact forces Newton's first law of motion states that a body at rest remains at rest or a body moving with a uniform velocity continues to move at that velocity, unless an external force is applied.
- the states of no motion and uniform motion remain the same in the absence of a force.
- uniform motion in a straight line is illustrated with a constant velocity. The s against t graph uniform motion is a straight line graph.
- the slope of the S against t graph equals the velocity.
- uniformly accelerated motion in a straight line is illustrated with a changing velocity. The v against t graph for an accelerated motion is a straight line.
- the slope of the v against t graph equals the acceleration. The area of the v against t graph equals the distance traveled for the time 't'.

Review Questions and Problems

1. The motion of a car is drawn is v against t graph as in Fig 2.8.

   a) What is the acceleration of the car?

   b) What is the distance travelled by the car in60 s?

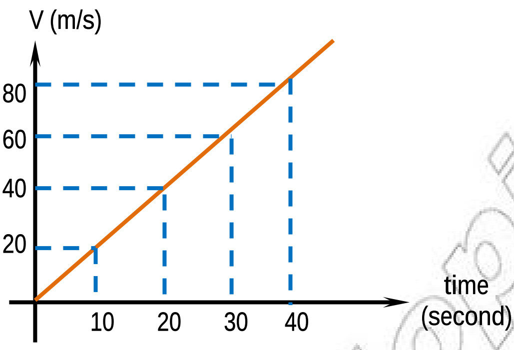


Fig 2.9. v against t graph

2. I rode my bicycle to grandmother's house at 6 km/h in a flat road for 5 min before reach a hill. I went at 2 km/h up the hill for 3minutes. I met a friend and stopped to talk for 5 minutes. I went on at 2 km/h to my grandmother's house. Draw (plot) the v against t graph for this motion.

3. An object is moving along a straight road at the speed of 6 km/h.

   a) How further away is the object every one hour?

   b) How further away is the object every half (½) hr?

   c) How further away is the object every 1/3 hr? Plot (draw) the s against t graph for its motion

4. Athlete Mesert Defar runs at 10 m/s. How long will it take her to go

   a) 1 m b) 5 m c) 20 m d) 100 m

5. Draw a speed v against time graph by guessing of the values of your trip to school this morning. Show how this graph can be used to determine distance.

6. A car traveling due north at 60 km/hr increased its velocity to 80 m/s due south in 20 seconds.

   Draw

   i) speed against time graph,

   ii) acceleration against time graph.