Unit 2: Friction force and Newton's laws of motion

By the end of this unit, the learner should be able to perform experiments involving
Newton's laws of motion and friction force.

2.0. Introduction

Every day, we interact with forces. The forces can cause different effects such as change in motion, pressure as well as turning moments on an object. The effects of force on motion of a body are summarized by Newton's three laws of motion. In this unit, we will investigate each of these laws in details.

2.1 Newton's First law of motion

Review on force

A force is anything that can cause a change to objects. Forces can:

- **change the shape of an object**
- **move or stop an object**
- **change the direction of a moving object.**

The S.I unit of force is the newton (symbol N).

The effects of a force on a body either at rest or in uniform motion summed up under Newton's first law of motion which states that "a body remains in its state of rest or uniform motion in a straight line unless acted upon by an external force". Newton's first law of motion suggest that matter has an in-built reluctance to change its state of motion or rest. For instance, when a moving bus comes to an abrupt stop, the passenger lurch forward, i.e. tend to keep on moving. Likewise, when a bus surge forward, the passengers are jerked backwards, i.e. tend to resist motion. The property of matter to resist change to its state of motion i.e. either to remain at rest or to continue moving in straight line is known as inertia. This explains why cars have seat belts. The seat belts (see Fig. 2.3), hold passengers onto the seat in case the vehicle comes to a stop or decelerates suddenly, preventing them from lurching forward. This reduces any chances of serious injury in case of an accident.

Fig. 2.3: A person wearing safety belt

Alternatively, *an object at rest wants to stay at rest, while an object in motion wants to stay in motion.*

Factors affecting inertia of a body

(a) Mass of a body

The mass of a body is a measure of its inertia. A large mass requires a large force to produce a given acceleration or deceleration than a smaller mass. A larger mass therefore has a greater inertia.

(b) Acceleration of a body

As the acceleration of a body increases so does its tendency to continue at a constant velocity.

(c) Force applied on a body

When the force applied on a body is increased, its tendency to remain at rest is reduced. This would result to movement of the body from its resting state.

(d) Friction acting on a body

The law of inertia states that an object / body will keep moving at a constant velocity unless a force is applied in it. An example of such a force is friction. It is a force that makes a body to slow down. Without it, the body would continue moving at the same velocity without slowing down.

Exercise 2.1 1.

1. Define the term 'inertia.'
2. State the law of inertia.
3. Briefly explain why wearing safety belts in moving vehicles is very important
4. What physical quantity is a measure of the inertia of a body?
5. Can a force change only the direction of velocity of an object keeping its magnitude constant?
6. State the different types of changes, which a force can bring in a body when applied on it.

2.2 Linear momentum and impulse

Definition of Linear Momentum

The quantity involving both motion and mass of a body is called linear momentum. It is denoted by the letter p and is called momentum in short.The linear momentum of a particle or object of mass *m* moving with a velocity *v* is defined to be the "product of the mass and velocity":

Linear momentum is a vector quantity.

Its SI unit is ***kg .m/s.***

Example 1

A car of mass 600 kg moves with a velocity of 40 m/s. Calculate the momentum of the car.

Solution

Momentum = mass × velocity

= 600 kg × 40 m/s

= 24 000 kg m/s

Example 2

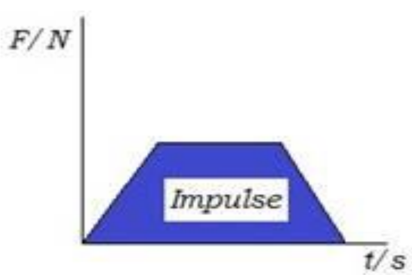
A rubber ball of mass **0.2 kg** strikes a rigid wall with a speed of **10 m/s** and rebounds along the original path with the same speed. Calculate the change in momentum of the ball.

Ans: – 4 kg m/s

Impulse

When a force F acts on an object for a very short time t, it produces an impact, usually referred to as impulse on the object. If a person exerts a force ***F*** on moving an object in time interval Δt the velocity of the object changes. We say that its momentum changes too. An impulse is the product of the force ***F*** and the time interval Δt in which it acts. Its magnitude is $I = F\Delta t$

The S.I unit of impulse is **Newton –Second (Ns).** An impulse can also be equal to the area under the force (F) versus time (t) graph.



Relation between impulse and momentum $\Delta p = F\Delta t = \Delta I$

2.3. Newton's Second Law of Motion

Newton's Second Law of Motion states that "The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of forces."

Let the final velocity becomes v.

Initial momentum $p_i = mu$

Final momentum $p_f = mv$

Change in momentum $\Delta p = p_f - p_i = mv - mu = m(v-u)$

Rate of change of momentum= $\frac{\Delta p}{\Delta t} = \frac{m(v-u)}{t} = ma$

a =acceleration

Therefore the rate of change of momentum= ma

This is another statement of Newton's second law of motion

Where $F \propto ma$

Or $F = ma$

Let a body of mass ***m*** having an initial velocity ***u*** be acted upon by a constant force ***F*** for a time ***t.***

S.I unit of F is **newton (N)**

Definition of one newton

One newton is the force which when it acts on a mass of 1 kg, it gives an acceleration of $1 m/s^2$.

Applying Newton's Second Law

Example 1

Calculate the acceleration produced by a force of 20 N on an object of mass 300 kg.

Solution

$$a = \frac{F}{m} = \frac{20N}{300kg} = 0.0667\ \text{N/s}^2$$

Example2

A ball of mass 0.4 kg starts rolling on the ground at 20 m/s and comes to a stop after 10s. Calculate the force, which stops the ball, assuming it constant in magnitude throughout.

Solution : Given $m = 0.4$ kg, initial velocity $u = 20\ \text{ms}^{-1}$, final velocity $v = 0$ m s^{-1} and $t = 10\text{s}$. So

$$|\mathbf{F}| = m|\mathbf{a}| = \frac{m(v-u)}{t} = \frac{0.4\ \text{kg}\ (-20\ \text{ms}^{-1})}{10\ \text{s}}$$

$$= -0.8\ \text{kg m s}^{-2} = -0.8\ \text{N}$$

Here negative sign shows that force on the ball is in a direction opposite to that of its motion.