NEWTONS LAWS OF MOTION

Newton was a major pioneer in the study of the movement or motion of objects. He gave three major laws that are still used in today’s physics. The following are the laws of motion by Sir Isaac Newton.

INTRODUCTION

In the earlier modules, motion of objects have been described mathematically – Kinematics. In this module we want to consider what makes objects to move the way they do; why does it take a long distance to stop a ship once it is motion? Why is it harder to control a car on wet ice than dry concrete?

The answer to these and similar questions is the subject of dynamics of motion

Dynamics – the relationship of motion to the forces that cause it to analyse the principles of dynamics we use the kinematic quantities displacement, velocity, acceleration along with force and mass.

Isaac Newton (1642 -1727) summarized the principles of dynamics in three statements known as Newton’s laws of motion.

FORCE AND MASS

Force – this is what causes motion and changes in motion

A force can be a push or pull, it produces a velocity change of the object on which it acts. The unit for measuring force is newton (N)

Forces are broadly categorized as contact forces or non- contact force.

Examples of contact forces – frictional, tension, normal and air resistance force.

Examples of non-contact force – electric, magnetic and gravitational force

Mass - a measure of a body’s resistance to acceleration or a change in its state of motion when a net force is applied

CONCEPT OF INERTIA

INERTIA is the natural tendency for of an object to maintain a state of rest or to keep moving in uniform motion in a straight line once it is set in motion.

When you try to get ketchup out of a bottle by shaking the bottle, the ketchup in the bottle moves forward, when you jerk the bottle backwards, the ketchup tend to still move forward due to inertia.

If pulled quickly, a table cloth can be removed from underneath of a set dishes. The dishes have the tendency to remain still as long as the friction from the movement of the tablecloth is not too great.

Newton related the concept of inertia to mass.

Mass is a measure of the inertia of a body. Massive bodies have more inertia- more resistance to a change in motion than a less massive object does.

NEWTON’S FIRST LAW OF MOTION

This states that a body will remain in a state of rest or in continuous motion on a straight line unless acted upon by an external force.

This law is also called the law of INERTIA.



Inertia is the natural tendency for a body to remain at rest or in constant motion on a straight line

The law is based on the principle that force is responsible for the starting a termination of motion.

An illustration of this concept is passengers in a bus. Passengers in a bus move forward when the bus suddenly stops. They tend to continue their state until brought to rest by friction or collision. Isaac Newton related the concept of inertia to mass. Mass is therefore defined as the measure of inertia. This statement implies that a massive body has more inertia and more resistance to a change in motion than a less massive object does.

NEWTON’S SECOND LAW OF MOTION

This states that the applied force is directly proportional to the rate of change of momentum.

Taking k as 1

Or,

In vector form, Newton’s second law of motion can be written as

Where

i.e.

Each component of the net force equals the mass multiplied by the corresponding acceleration (ma)

**CONCEPT OF MOMENTUM AND IMPULSE**

**MOMENTUM**:

() of a body in motion is defined as the product of the mass m of the object and its velocity v.

The unit of momentum

The momentum of a body can be defined as the measure of movement of a body. It is also defined as the product of the mass and velocity of the body.

When a force is applied to a body, there will be a change in the velocity of the body which will correspond to a change in the momentum of the body.

For a particular body,

From the second law,

Therefore,

On cross-multiplying,

The expression on the left side i.e. is known as IMPULSE

Momentum is directly proportional to the object's mass and also its velocity. Thus, the greater an object's mass or the greater its velocity, the greater its momentum.

**IMPULSE**:

() of a force is defined as the product of the force and time

with which the force acts

Impulse,

The unit of impulse is Ns.

IMPULSE

Impulse is defined as the change in momentum. It is also defined as the product of force and the time of impact

From,

From,

But,

Therefore,

Also, in calculus notation,

But,

Therefore,

And,

Here “a” is the acceleration.

The above equation shows that by Newton's second law, the acceleration of an object is directly related to the net force and inversely related to its mass.

This implies that acceleration of an object depends on two things, force and mass.

Note: If you apply more force to a body, it accelerates at a higher rate

Note: more mass (load) requires more force to achieve the necessary acceleration.

In the above equation regarded as Newton’s second law of motion, the force is assumed to be constant.

If the supposed constant force is applied at different times to two (2) different bodies of masses m1 and m2 and producing accelerations of a1 and a2 respectively on the two bodies,

From

Since the applied force is constant

However, if the mass and velocity are both functions of time, the resultant force is defined as

From the above equations, newton’s second law can also be stated as “when a force is applied to a body the body begins to move (or accelerate) and the magnitude of the acceleration depends on the magnitude of the force”

Also it could be stated as “the force required to move two or more bodies is dependent on the mass of the bodies and the heavier the object, the more force is required to move it”

Note: If a body is fired at an initial velocity (u) and the body hits an object and bounces back with a velocity (v), the change in momentum will be a summation of the two momenta.

But

PRINCIPLE OF THE CONSERVATION OF LINEAR MOMENTUM

This principle states that During collision in which colliding objects are not acted upon by an external applied force, the sum of total linear momentum of two (or more) bodies before collision is equal to the total linear momentum after collision.

Case 1: For two bodies A and B

Case 2: For two bodies A and B that collide and move with a common velocity after collision

For any array of several objects, the total momentum is the sum of the individual momenta.

If the net external force acting on a system of bodies is zero, then the momentum of the system remains constant that is, the total momentum before and after is constant.

**THE LAW OF CONSERVATION OF LINEAR MOMENTUM**

Total initial momentum “p” of a system of n bodies of masses moving with initial velocities respectively is given as …

During collision, some of the bodies may fuse together or break apart. The system after collision produces m number of particles with a final momentum given as

Each body of mass m, moves with velocity

The law of conservation of momentum implies that total initial momentum equals total final momentum

If the motion is in three dimensions, the above equation becomes

CLASSES OF COLLISION

Collision is any strong interaction between bodies that last a relatively short time ranging from: car accidents, neutrons hitting atomic nuclei to a close encounter of a spacecraft with the planet Saturn.

There are two classes of collision which are elastic and inelastic. The law of conservation of linear momentum is conserved in both classes of collision.

Elastic Collision:

If the forces between colliding bodies are much larger than any external forces, we can neglect the external forces entirely and treat the bodies as an isolated system. For such a system, the total momentum before and after collision is the same; conserved

If the forces between the bodies are so that no mechanical energy is lost or gained in the collision, the total kinetic energy of the system is the same before and after collision. Such a collision is called elastic collision, both momentum and kinetic energy are conserved

In this collision the kinetic energy is conserved. That is the sum of initial Kinetic Energy is equal to the sum of final Kinetic Energy. If several particles are involved in the collision, such that the particle of mass m1 has initial speed of u1 before the collision and speed v1 after the collision, the elastic equation can be written as

In an elastic collision the colliding particles do not disintegrate or join together. In this collision both momentum and (kinetic) energy are conserved.

Inelastic Collision: In an inelastic collision, The Kinetic Energy is not conserved because some of the kinetic energy may be converted into other forms of energy such as heat, sound, radiation or any other form of energy.

A completely inelastic collision between two objects is a collision in which the two objects stick together after the collision and move off together as one body.

The implication is that,

A collision where the total kinetic energy after collision is less than that before collision is called inelastic collision.

An inelastic collision in which the bodies stick together and move as one body after collision is called completely inelastic collision.

COEFFICIENT OF RESTITUTION

The coefficient of restitution (e) for a particular collision describes the extent to which the collision is elastic or completely inelastic. The coefficient of restitution is defined for only 1 dimensional collision for two bodies.

The maximum value of “e” is one (1) for a completely elastic collision and zero (0) for a completely inelastic collision. For other one dimensional (1D) bodies, the value of “e” lies between zero (0) and one (1).

is the relative velocity of the bodies after collision and is the relative velocity of the bodies before collision

APPLICATIONS OF CONSERVATION OF LINEAR MOMENTUM

Rocket Repulsion: The thrust experienced by a rocket can be expressed as the product of the rate of ejection of gases and the velocity

But,

Therefore,

Recoil of A gun: Experiment has shown that the momentum of a gun is equal to the momentum of the bullet fired

NEWTON’S THIRD LAW OF MOTION

This law states that for every reaction there is an equal and opposite reaction.

This law implies that if a body “A” exerts a force (action) on a body “B”, “B” will exert an equal and opposite force (reaction) on A.

The mathematical statement of the law is as follows

Where FAB is the force exerted on body A by body B while FBA is the force exerted on body B by body A.

The negative sign shows that FAB and FBA are in opposite directions.

This law just shows that forces always occur in pairs and one body cannot exert a force aon another body without experiencing a force itself

APPLICATIONS OF THE THIRD LAW OF MOTION

THE ELEVATOR

The elevator is an electro-mechanical device used in lowering or lifting people or goods from floor to floor in a building.

Case 1: When an elevator is ascending at uniform acceleration.

But,

Case 2: ELEVATOR DESCENDING AT A CONSTANT ACCELERATION

Case 3: THE ELEVATOR MOVING AT A CONSTANT VELOCITY

Note: It can be observed from the above equations that

A body experiences weight gain when ascending and

Experiences weight loss when descending

Weight gain or weight loss is given by ma

PULLEY SYSTEM

This is another application of Newton’s Third law of motion.

This system entails two bodies suspended by a light inextensible string over a pulley

Case 1: If m1 > m2

For m1,

For m2,

Adding the two equations above,

From,

But,

On finding the L.C.M,

Case 2: Two bodies connected by a light inextensible string with one hanging and the other on a smooth surface

For m1,

For m2,

On adding,

Therefore,

From,

But,

Therefore,

Case 3: Two bodies connected by a light inextensible string over a pulley with one hanging and the other on a rough horizontal surface

For m1,

For m2,

On adding,

Therefore,

From

But,

Case 4: This comprises two bodies connected by a light inextensible string over a pulley with one hanging and the other on a smooth inclined plane.

For m1,

For m2,

On adding,

Therefore,

From

But,

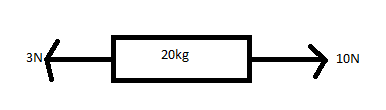
If one body is involved, if the acceleration (a) of the system (the body on the plane) without friction is

If friction is involved,

Case 5: One body on a rough inclined plane and the second body is hanging

For ,

For ,



The diagram above shows a body of mass 20kg under forces 10N and 3N acting in opposite directions. The acceleration of the body is (Answer: 0.35ms-2)

A motorist driving a car of mass 750kg at a speed 108hmh-1, suddenly observes a stationary dog 130m ahead. If he applies a retarding force of 2250N through the brakes, the car will stop (Answer: 10m after hitting the dog)

The principle of conservation of momentum states that during collisions if the net external force acting on a system is zero, the sum of the momentum before collision is equal to the sum of the momentum.

This principle is a direct consequence of Newton’s third law

QUESTIONS

A body A of mass 1.5kg traveling along the positive x-axis with a speed of 4.5m/s, collides with another body B of mass 3.2kg which initially is at rest. As a result of the collision, A is deflected and moves with a speed 2.1m/s in a direction which is at an angle 30 degrees below the x-axis. B is set in motion at an angle theta above the x-axis. Calculate the velocity of B after the collision

A man of mass stands next to a stationary ball of mass on a frictionless surface. He kicks the ball forward along the surface with a speed of 15m/s. Calculate the man’s recoil speed

A hose directs a horizontal jet of water moving with a velocity of , on to a vertical wall. The cross sectional area of the jet is . If the density of water is , calculate the force on a wall assuming that