1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 01 (Physics Part -1, Class XI)
Module Name/Title	Unit 3, Module 1, Newton's first law of motion Chapter 5, Laws of motion
Module Id	Keph_10501_eContent
Pre-requisites	Kinematics, equations of motion, force ,mass
Objectives	After going through this module, the learners will be able to: • Identify force as cause of motion • Appreciate the work of Newton Aristotle and Galileo's • Conceptualise the relation between mass and inertia • Understand Newton's first law of motion
Keywords	External force, Net force, External unbalanced force, inertia, inertial mass

2. Development Team

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TABLE OF CONTENTS

1. UNIT SYLLABUS

Chapter 5: Laws of Motion

Intuitive concept of force, Inertia, Newton's first law of motion, momentum and Newton's second law of motion, impulse, Newton's third law of motion.

Law of conservation of linear momentum and its applications.

Equilibrium of concurrent forces, Static and kinetic friction, laws of friction, rolling friction, lubrication.

Dynamics of uniform circular motion: Centripetal force, examples of circular motion (vehicle on a level circular road, vehicle on banked road).

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 7 Modules

The above unit is divided into seven modules as follows:

Module 1	• Force • Inertia • First law of motion
Module 2	• Momentum • Second law • Impulse • F = ma • Constant and variable force
Module 3	• Third law • Conservation of linear momentum and its applications
Module 4	• Types of forces(tension, normal, weight …) • Equilibrium of concurrent forces • FBD
Module 5	• Friction • Coefficient of friction • Static Friction • Kinetic Friction • Rolling Friction • Role of friction in daily life
Module 6	• Dynamics of circular motion • Centripetal force • Banking of roads
Module 7	• Using laws of motion to solve problems in daily life

MODULE 1

3. WORDS YOU MUST KNOW

- Rest: A body is said to be at rest if it does not change its position with respect to its surroundings.
- Motion: A body is said to be at rest if it does not change its position with respect to its surroundings.
- Velocity: Time rate of change of displacement in a particular direction is called velocity.
- Uniform motion: When a body covers equal displacement in equal intervals of time, its motion is said to be a uniform motion.
- Momentum: Impact capacity of a moving body: p = mv
- Acceleration: Time rate of change of velocity in a particular direction is called acceleration.
- Vector: A quantity with both magnitude and direction. In physics, there are many physical quantities which have both magnitude and direction.
- Vector Algebra: Part of mathematics dealing with addition subtraction and multiplication of vectors.

4. INTRODUCTION

In kinematics, we were concerned with description of the motion of a particle in space. We saw the relation between the position, velocity and acceleration of the particle in motion, irrespective of the cause producing it.

In this unit we will study dynamics, - the branch of mechanics which deals with the cause of motion. This course serves as an introduction to the cause of motion.

We will understand how Galileo proved Aristotle’s view of motion wrong. Then Galileo performed certain experiments to study the motion of objects and arrived at the law of inertia. Further, Newton builds on Galileo’s ideas to lay the foundation of the three laws of motion.

We will also visualize real life situations related to the above concept.

5. WHAT CHANGES THE STATE OF MOTION OF BODIES?

Try to imagine following situations

- To move a football at rest, someone should kick it.

- To throw a stone upwards, one has to give it an upward push.

https://ccsearch.creativecommons.org/photos/c97befe8-3dbc-47a3-9752-b561205ad0f2

- A breeze causes the branches of a tree to swing.
- A strong wind can even move heavy objects.

http://post.jagran.com/rains-bring-down-temperatures-monsoon-may-hit-kerala-in-48-hours-1433393125

- A boat moves in a flowing river without anyone rowing it.

These can help us in relating what makes bodies change their state of motion?

Clearly, some **external agency is required to provide force to move a body from rest. Similarly, an external force is needed to retard or stop motion of a moving body.**

What is a force?

The change in velocity of a body must be due to an interaction of the body with something in its surroundings. **This interaction that causes the body to accelerate is called a force.**

A force is a push or pull that causes an object to change its state of rest or motion.

SI unit of force is called 'newton' denoted by N.

External agency

Can be in contact with the **May exert force on a distant bodies**

(hands, wind) **(Gravitational pull of the Earth, bar magnet attracting a distant iron nail)**

Examples

Contact Forces	**Action-at-a-Distance Forces**
Frictional Force	**Gravitational Force**
Tension Force	**Electrical Force**
Normal Force	**Magnetic Force**
Air Resistance Force	
Spring Force	

6. ARISTOTLE AND GALILEO MECHANICS

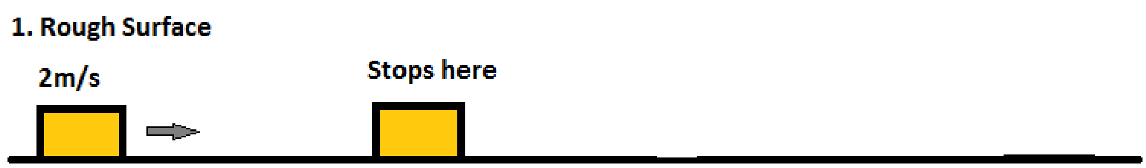
Aristotle's view of Motion:

Objects at rest remains at rest on their own. We don't need to do anything. We don't see a book kept on a table moving up and down on its own. However, a ball rolling on the floor slowly comes to rest. If you stop pedaling a bicycle, it slows down till it stops. i.e. To keep the objects moving, we need to apply a continuous force (a push or a pull).

According to Aristotle an external force is required to keep a body in motion. Left to themselves, all bodies eventually come to rest. Thus, the natural state of a body is at rest.

Galileo's view of Motion:

Galileo found the reason why objects come to stop when left to themselves.



Observation: On a rough surface, the block stopped after covering a small distance.

<u>Observation</u>: On a smooth surface, it travelled a comparatively longer distance.

<u>Observation</u>: On a very smooth surface it travelled a larger distance before coming to stop.

Galileo thought that if the block was stopping on its own, shouldn't it go the same distance and stop? Why does it travel for a longer distance if the surface is smooth? There must be a force on the block that is making it stop." As the force seems to come because of rubbing at the contact, Galileo called it friction force.

Then Galileo concluded: Friction is the reason, why the block stops. Rough surface provides more friction whereas smooth provides less friction and thus the block travels a longer distance on a smooth surface.

The opposing forces such as friction (solids) and viscous forces (for fluids) are always present in the natural world. Forces by external agencies are necessary to overcome the frictional forces to keep bodies in uniform motion.

7. INERTIA

One of Galileo's most famous experiments was his inclined plane experiment. He studied the motion of objects on doubly inclined planes and concluded the following:

- A ball released from rest on one of the planes rolls down and climbs up the other. If the planes are smooth, the final height of the ball is nearly the same as the initial height (a little less but never greater).

- In the **ideal situation**, when friction is absent, the final height of the ball is the same as its initial height.

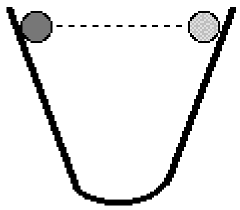
  If there is no friction let us understand Galileo's experiment

  Imagine a doubly inclined rail; curtain rail is a good example bends it in a U shape.

  Drop a small metal ball (cycle ball bearing)

  We find that the final height attained by the ball bearing equals the initial height from where it was dropped.

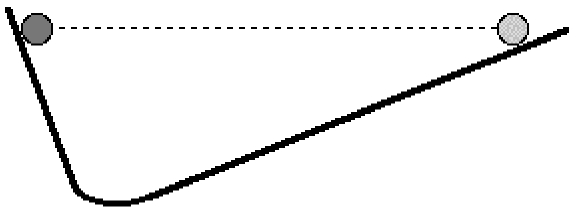
  Final height equals initial height



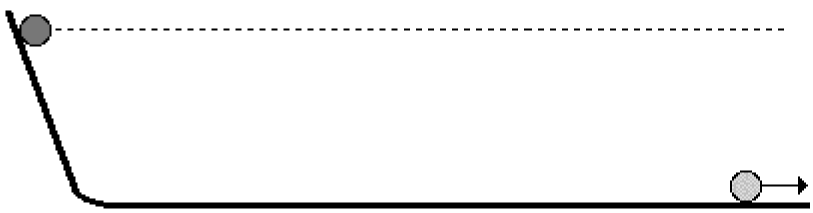
With a steep angle a ball will roll a small distance to attain the original height

As the angle with the horizontal, of the opposing incline is reduced, the ball must roll a farther distance in order to attain the same original height.

What if the opposing incline is made horizontal?

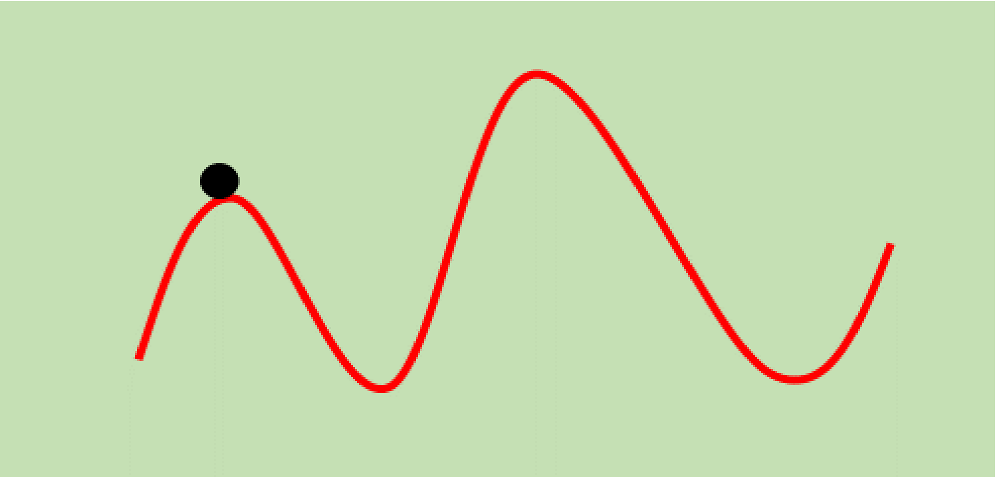


However, when the slope of the second plane is zero (i.e. horizontal) the ball travels an infinite distance and would never come to stop.



See the figure below

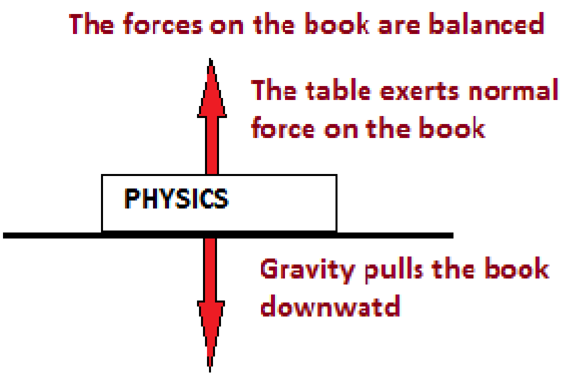
How high would a ball reach in this case?



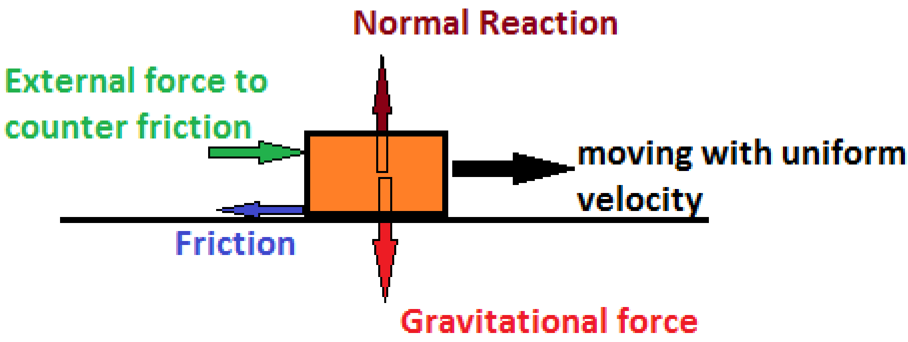
Will the ball reach the second lowest level?

Galileo thus concluded that the state of rest and state of uniform linear motion are equivalent. i.e. in both the cases, there is no net force acting on the body. This statement can be also understood in following manner:

- An object at rest will remain at rest unless and until an external unbalanced force compels it to change its state. For example: Net force acting on the book is zero.



- An object in motion will not change its velocity spontaneously. That is, if something is moving along at a constant speed in a straight line, it will continue to move along at the same constant speed in the same straight line. On its own, it will not speed up, slow down, or change direction. For example: external force is applied to counter frictional force. Here also net force acting on the block is zero.



- **If net external force is zero**, **a body at rest remains at rest and a body in motion continue to move with uniform velocity**.
- **This inherent property of a body to maintain its state of rest or of uniform motion in the absence of external force is known as 'Inertia'**.
- Inertia means 'resistance to change'.
- All objects have a tendency to resist change in their state of rest or motion. This tendency to resist any change varies with mass of a body. Mass of a body is the measure of its inertia. **A heavier body has more inertia in comparison to a lighter body as more force is required to move a heavier body from rest than the lighter one.**
- **Inertia is not mass, it is not a measure of mass –but a body's ability to remain at rest or continue in uniform motion along a line depends on mass.**

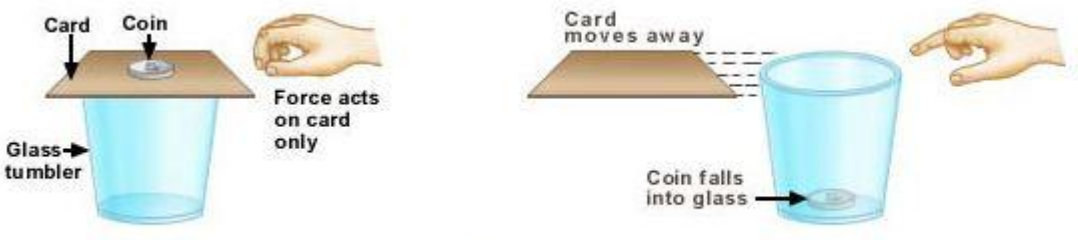
- http://nroer.gov.in/home/video/details/5699f75981fccb15fb213076 (video on inertia)

TYPES OF INERTIA:

(a) Inertia of Rest

Let us consider following examples to understand inertia of rest, where a body offers reluctance to change its state of rest.

- ❖ When the cardboard is given a sudden jerk, the coin falls into the glass. This is because the inertia of coin maintains its state of rest and falls into the glass (due to gravity) when the card moves away.



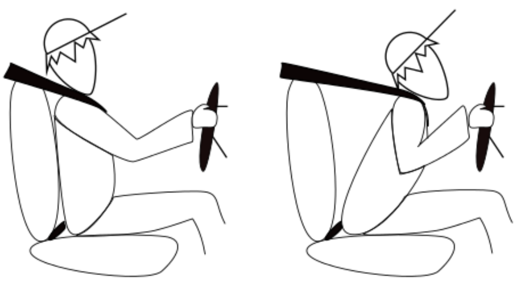
Experiment to demonstrate inertia

- A football will remain at rest unless it is kicked by an external force to change its state of rest.

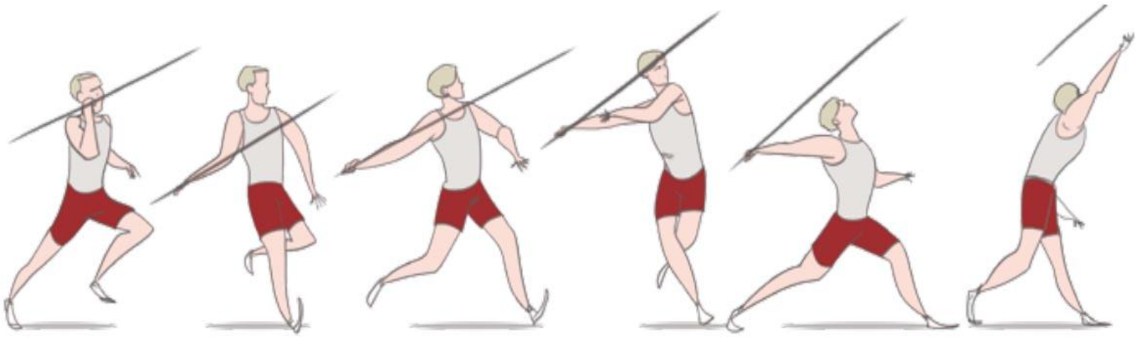
(b) Inertia of Motion

The following examples will help us to understand inertia of motion, where a body offers reluctance to change its state of motion.

- When the bus suddenly stops, the passengers in the bus tend to fall forward. This is because the feet of the passengers stop due to friction (between feet and the floor). As our body allows some relative displacement between the different parts, the feet stop with the bus whereas the rest of the body continues to move forward because of inertia of motion.



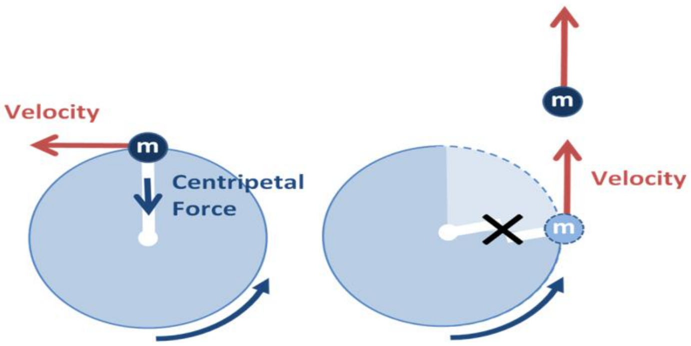
❖ In Javelin throw, an athlete runs certain distance before releasing the javelin. In this way, the athlete gains certain speed and due to inertia of motion he is able to throw it far.



(c) Inertia of Direction

Bodies in motion can offer resistance to change their direction of motion. Following examples can help us understand this property.

❖ Consider a stone tied to the end of a string being whirled in a circle. We know that the velocity of the stone at any instant is along the tangent to the circle at that instant (from uniform circular motion). When the string is released, the stone flies off tangentially due to inertia of direction. i.e. it continue moving along the direction at that instant.



❖ Similarly the sparks from a metal grinder (used to cut and shape metals) come out tangentially. Due to the inertia of direction, the sparks fly off tangentially.

We have taken examples of inertia of rigid bodies. What about non- rigid bodies – fluids i.e. liquids and gases?

We know that **liquids** possess definite volume and take the shape of the container. Liquids in a container at rest remain at rest. If we churn some liquid in a beaker with a glass rod and remove the glass rod, we see the liquid gradually comes to rest. Internal friction (i.e. viscous force) between the layers of the liquid stops the relative motion. Thus, to keep the liquid rotating, we need to churn the glass rod. Thus, Liquids also possess inertia.

Gases do not have definite volume and shape. However, when a gas is transferred to a container, it is observed that the gas molecules do not settle but remain in motion. However at room temperature, the gas molecules are in continuous random motion. Only at absolute zero, all the molecular motion ceases. i.e. we do not talk of gas molecules at rest. More information related to it will be covered in Kinetic theory of gases. Since all matter has mass and inertia is a measure of mass. Thus all matter possesses property of inertia.

8. NETWON'S FIRST LAW OF MOTION:

Newton built on Galileo's ideas and laid the foundation of Newtonian mechanics in terms of three laws of motion. Galileo's law of inertia was his starting point which he formulated as the first law of motion:

> **"Everybody (in solid, liquid or gaseous state) continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external unbalanced force to act otherwise."**

The state of rest or uniform linear motion both imply zero acceleration.

However, gravity is everywhere. On Earth, an object is at rest or in uniform linear motion, not because there are no forces acting on it, but because the various external forces add up to zero net external force.

The first law of motion can, therefore, be simply expressed as:

If the net external force on a body is zero, then it will continue to be in a state of rest or uniform motion along a straight line.

An external force in the above statement is a force exerted from an agency other than the object under consideration.

We use the symbol F to mean force in physics and we use the Greek letter sigma, ∑ read as "the sum of" to express the condition under which Newton's First Law holds, that is:

∑ F=0; the sum of all forces acting on an object is zero. Under this condition the object may be at rest or have a constant velocity
(constant speed in the same direction).

9. PROBLEMS FOR CONCEPTUAL UNDERSTANDING:

1. **Name one factor on which inertia of a body depends.**

   Ans. Mass

2. **A body of mass m is moving with a constant velocity v on a horizontal surface. What is the force exerted on the body?**

   Ans. F = 0

3. **Why bodies of smaller mass require small initial effort to put them in motion?**

   Ans. Lesser the mass, lesser is the inertia.

4. **Why the passengers are thrown backwards when a car suddenly starts?**

   Ans. Due to inertia of rest.

5. **A body is moving with uniform velocity. Can it be said to be in equilibrium?**

   Ans. No net force acts on the body in uniform motion.

6. **A passenger sitting in a car at rest pushes it from within. State whether the force applied by the passenger is internal or external force?**

   Ans. Internal force

7. **A body is acted upon by a number of external forces. Can it still remain at rest?**

   Ans. yes, if the vector sum of all the forces is zero.

8. **In a game of tug of war, two opposing teams are pulling the rope with equal (in magnitude) but opposite forces of 100 N at each end of the rope. What is the net force acting on the rope?**

   Ans. Zero.

9. **What is the magnitude and direction of net force acting on the following:**

   (a) A drop of rain falling down with constant speed?

   (b) A cork of mass 10 g floating on water?

   Ans. Zero in both the cases.

10. **What is the magnitude and direction of net force acting on a piece of stone of mass 0.2 kg, it is in a**

    (a) a stationary train

    (b) a train moving with constant velocity of 40 km/h.

    Ans.

    (a) Net force is acting on a stone is zero.

    (b) Net force on the stone is zero.

SOME MORE EXAMPLES WITH SOLUTION:

EXAMPLE

An astronaut accidentally gets separated out of his small spaceship accelerating in inter stellar space at a constant rate of 100 ms^{-2}. What is the acceleration of the astronaut the instant after he is outside the spaceship? (Assume that there are no nearby stars to exert gravitational force on him.)

SOLUTION

Since there are no nearby stars to exert gravitational force on him and the small spaceship exerts negligible gravitational attraction on him, the net force acting on the astronaut, once he is out of the spaceship, is zero. By the first law of motion the acceleration of the astronaut is zero.

EXAMPLE

When a football is rolling along a grassy field, it does not continue moving forever. What force is acting on it to change its state?

SOLUTION

Force of friction.

EXAMPLE

The amount of force needed to keep a 0.1kg disc moving at a constant speed of 6 m/s on frictionless ice is ___ N

SOLUTION

Zero net force,- because the problem says constant speed. So from the rule of inertia of motion

EXANPLE

Which of these forces is a non-contact force?

a. Force due to air resistance

b. force due to Gravity

c. force due to Friction

d. force caused by tension

SOLUTION

Force due to Gravity, because it acts from a distance

EXAMPLE

When we shake the branch of a mango tree, the mangoes fall down. Why?

SOLUTION

Because of inertia of rest of the mangoes, detaches it from the moving branch or we can say mangoes remain at rest due to inertia of rest and the branch is set into motion. The ripe mango detaches itself from the branch

10. SOME INFORMATION ABOUT THE SCIENTISTS

Aristotle (384 BC – 322 BC)

Interestingly, Aristotle contributed to the history of Science with his methodology and empiricism. He promoted the concept that observation of physical phenomena could ultimately lead to the discovery of natural laws governing those phenomena. Science based on reason but without experimentation, was his natural philosophy.

Aristotle attempted to explain ideas such as motion and gravity with his theory of elements, an addition to ancient physics that also spread into alchemy and medicine.
The Greek philosopher Aristotle describes a geocentric universe in which the fixed, spherical Earth is at the centre, surrounded by concentric celestial spheres of planets and stars.

There was no attempt by Aristotle to mathematically describe the reality that he observed. He considered mathematics and the natural world to be fundamentally unrelated.

He published a large number of works in fields as diverse as poetry and politics; religion and rhetoric; logic and literary theory; music and metaphysics; and many other fields, centred chiefly around his philosophy.

Aristotle's work was rediscovered by scholars in the Middle Ages and he was proclaimed the greatest thinker of the ancient world. His views became the philosophical foundation of the Catholic Church (in cases where it didn't directly contradict the Bible) and in centuries to come observations that did not conform to Aristotle were denounced as heretic.

Galileo Galilei (1564 - 1642)

Galileo Galilei, born in Pisa, Italy in 1564 was a key figure in the scientific revolution in Europe about four centuries ago.
Galileo proposed the concept of acceleration. From the experiments on motion of bodies on inclined planes or freely falling bodies, he contradicted the Aristotelian notion that a force was required to keep a body in motion, and that heavier bodies fall faster than lighter bodies under gravity. He thus arrived at the law of inertia that was the starting point of the subsequent remarkable work of Isaac Newton.
Galileo’s discoveries in astronomy were equally revolutionary. In 1609, he designed his own telescope (invented earlier in Holland) and used it to make a number of startling observations: mountains and depressions on the surface of the moon; dark spots on the sun; the moons of Jupiter and the phases of Venus.
Galileo advocated the heliocentric theory of the solar system proposed by *Copernicus, which eventually got universal acceptance.

With Galileo came a turning point in the very method of scientific inquiry. Science was no longer merely observations of nature and inferences from them. Science meant devising and doing experiments to verify or refute theories. Science meant measurement of quantities and a search for mathematical relations between them. Not undeservedly, many regard Galileo as the father of modern science.

Isaac Newton (1642 - 1727)

Isaac Newton was born in Woolsthorpe, England in 1642, the year Galileo died.

In 1684, encouraged by his friend Edmund Halley, Newton embarked on writing what was to be one of the greatest scientific works ever published: The Principia Mathematica. In it, he clearly expressed the three laws of motion and the universal law of gravitation, which explained all the three Kepler's laws of planetary motion. The book was packed with a host of path-breaking achievements: basic principles of fluid mechanics, mathematics of wave motion, calculation of masses of the earth, the sun and other planets, explanation of the precession of equinoxes, theory of tides, etc.

In 1704, Newton brought out another masterpiece Opticks that summarized his work on light and colour.

The scientific revolution triggered by Copernicus and steered vigorously ahead by Kepler and Galileo was brought to a grand completion by Newton. Newtonian mechanics unified terrestrial and celestial phenomena. The same mathematical equation governed the fall of an apple to the ground and the motion of the moon around the earth. The age of reason had dawned.

11. SUMMARY

- According to Aristotle (384 BC-322 BC), the Greek thinker, the natural state of a body is at rest.
- Galileo proved Aristotle wrong by stating that a force is necessary to counter the opposing force of friction.

- Newton's work showed that the “natural” state of moving objects in the absence of an opposing force is not rest, but continuous motion.

- Inertia means resistance to change in the state of motion.

- We use the symbol F to mean force in physics and we use the Greek letter sigma, ∑ read as “the sum of” to express the condition under which Newton’s First Law holds, that is:

$\sum F=0$; the sum of all forces acting on an object is zero. Under this condition the object may be at rest or have a constant velocity.

- Force: It is the mutual interaction between two bodies. It is defined as push or pull which changes or tends to change the state of rest or of uniform motion in a straight line.
- Inertia: The resistance of any object to change its state of rest or of motion.
- Law of inertia: A body, by itself, is unable to change its state of rest or uniform motion in a straight line.
- Mass: A measure of the amount of matter in an object. Weight on Earth's surface is based on mass, but an object's mass is the same wherever it is taken.
- Net force: The vector sum of all the forces on a single object.