Newton's laws of motion.

Mechanics

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Introduction

- The laws of motion developed by **Sir Isaac Newton** explain the connection (relationship) between physical objects and the forces that act on these objects.
- These laws explain how objects move in response to applied forces.
- In this topic we are going to:
  a. Describe Newton's laws of motion.
  b. Illustrate inertia.
  c. Discuss the Law of conservation of linear momentum.

Newton’s laws of motion

- We have **three** Newton’s law’s of motion that describe the behaviour of objects in relation to force acting on the objects.
- Below are Newton’s laws of motion:
  1. **Newton’s First law of motion** – *also called the **law of Inertia**.*
  2. **Newton’s Second law of motion** – *Force = mass * acceleration.*
  3. **Newton’s Third law of motion** – *action and reaction.*

Newton’s First Law of Motion

- This law states that “ *a body continues in its state of rest or uniform motion in a straight line unless compelled upon by some external force to act otherwise*”.

OR

- It states that “*an object at rest will remain at rest, and an object in motion will continue moving at constant velocity unless acted upon by an external force*”
- This law is also called the **law of inertia**.

Newton’s First Law of Motion

- The word **inertia** refers to the *tendency of an object to resist changes in its state of motion.*
- It is a property of matter that keeps objects in their current motion state.
- This tells us that if a given body is resting, it will remain resting unless a certain force makes it move. And that if a given body is in motion, it will continue its motion in a straight line and at constant speed unless a certain force acts on it to alter its motion.

Examples where Newton’s First law of motion is shown:

- **A book on a table:** the book will not move by itself unless an external force such as a push acts on it.
- **A passenger moving in a vehicle:** when a car suddenly stops , the passenger larch forward, this is because the body (passenger) was in motion and wants to continue moving even if the car stops.
- **A ball rolling on the ground:** the ball will continue rolling until friction or another force such a wall or a person stops it.

Demonstrating Newton's First law of motion.

Experiment One: A body at rest.

The materials that will be required are:

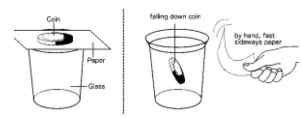
- A coin
- Beaker
- A smooth Card board

Procedure

a. Place the coin on the card board.
b. Place the card board with the coin on top of a beaker.
c. Pull the card board slowly and observe what happens to the coin.
d. Repeat the experiment but this time pull the card board away suddenly.
e. Observe what happens to the coin

Observation

- When the card is pulled slowly the coin moves together with the card, maintain its state of motion (resting).
- But when the card is pulled suddenly, the coin is left behind and it appears to stay put, then drops vertically down into the beaker. – *this shows that the coin tried to maintain its state of motion (resting) but it was pulled downwards by an external force (gravity).*



Demonstrating Newton's First law of motion.

Experiment Two: A body in motion.

The materials that will be required are:

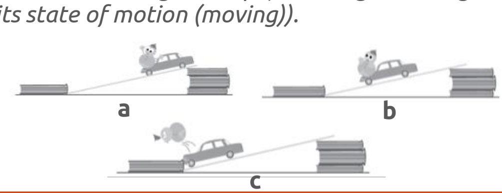
- A wooden track
- Slanted runway
- Trolley
- A stopper

Procedure

a. Place a wooden block at one end of the trolley, and a stopper at the lower end of the slanted runway.
b. Allow the trolley to move down on the slanted runway.
c. Observe what happens to the wooden block once the trolley is stopped by the stopper.

Observation

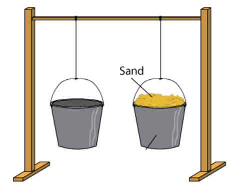
- Upon the trolley colliding with the stopper, the wooden block slides off and continues moving in the direction in which the trolley was moving – *this shows that the wooden block is resisting to stop (resisting to change its state of motion (moving)).*



Mass and Inertia

- In this section we look at the relationship between mass of an object and its inertia.
- **Mass** refers to the **quantity of matter** in a given object while, **inertia** refers to the **reluctance** of a body to change its state of motion.
- In Newton's First law of motion, the greater the mass of an object, the greater the inertia of such object.
- As such when it comes to Newton's First law, we can define ***mass of a given object as the measure of its inertia***.

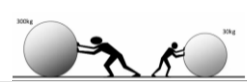
- The figure below shows two buckets, one filled with sand and the other empty.



Quick questions:

- Which bucket will be easier to move to one side so that it swings?
- Give a reason for your answer.

Mass and Inertia



- Below is an experiment to demonstrate the effect of mass on inertia.

The materials that will be required are:

- Strings, a 100g mass
- Hooks, 20g mass

Procedure:

a. Suspend the 100g mass on a hook using a string.
b. Push the 100g mass towards one side and let it swing.
c. Try to stop the mass from moving.
d. Repeat the experiment using the 20g mass.
e. Observe which mass was easier to start and stop moving.

Observation

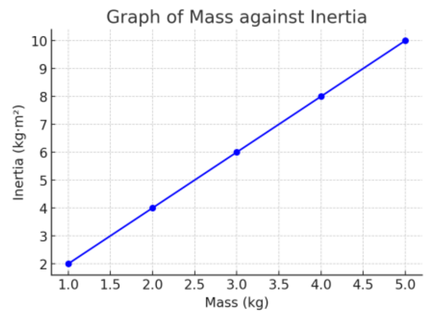
- The 20g mass was easier to start moving and stop moving. The 100g mass was difficult to start or stop moving as it required more force.

Conclusion

- The experiment shows *that **the greater the mass of an object, the greater its inertia***, making it more difficult to alter its motion

Mass and Inertia

- According to Newton's First Law of Motion, the relationship between mass and inertia is a **direct proportional relationship**.
- This means that as the mass of a given object increases, its inertia also increases.
- If we plot a graph of mass against inertia it is going to be a graph of a straight line passing through the origin.
- The graph on the right shows the relationship between mass and inertia of a given object.



Application of Newton's First law of motion

- Below are some of the notable applications of Newton's First law of motion:
  - **a.** **Seatbelts in Cars**: When a car suddenly stops, passengers tend to keep moving forward due to inertia. Seatbelts provide the external force needed to stop the passengers and prevent injury.

  - **b.** **Kicking a Soccer Ball**: A stationary ball stays still until kicked. After being kicked, it continues moving until friction (an external force) or another object stops it.
  - **c.** **Books on a Car Dashboard**: If a car makes a sharp turn, books left on the dashboard will slide off in the original direction of motion. The books want to stay in their straight-line path due to inertia.
  - **d.** **Flying on an Airplane**: When the airplane accelerates or decelerates, passengers feel pushed back into their seats or pulled forward due to inertia, as their bodies resist changes in motion.

Linear Momentum

- The term momentum refers to the **measure of the quantity of motion an object has**.

OR

- Momentum is the product of the **mass** and the **velocity** of a given object.
- Momentum is a **vector quantity** as such it has both **magnitude** and **direction**.
- In physics momentum can be grouped into two: **Linear momentum** and **Angular momentum**.
- The **SI** unit of momentum is **kgm/s**.

- In this class we are going to focus on **Linear momentum** for now.
- Linear momentum refers to the quantity of motion a given object has in a **straight line**.
- In simple terms, Linear momentum refers to ***the motion of an object in a straight line***.
- Linear momentum is given by the formula:

Linear momentum(p) = mass(m)×velocity(v)

$$p = mv$$

Linear Momentum

Example:

a. A ball of mass 4000g moves on a smooth surface with a velocity of 6m/s. Work out the linear momentum of the ball.

Solutions:

***p* = m * v**

m = 4000g to kg = 4kg

v = 6m/s

p = 4kg * 6m/s = 24kgm/s in the direction of velocity.

Example:

b. A paper plane weighing 8 grams is floating due east with a velocity of 0.5m/s. Calculate its momentum.

Solutions:

***p* = m * v**

m = 8g to kg = 0.008kg

v = 0.5m/s

p = 0.008kg * 0.5m/s = 0.004 kgm/s due east.

Linear Momentum

Answer all:

a. State Newton's First law of motion. (1)

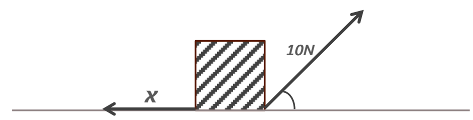
b. Define mass in terms of inertia. (1)

c. An object of mass 1.5kg falls from a height of 3m above the ground to a rest in 2 seconds. Calculate the object's linear momentum. (5)

d. The linear momentum of a body is 40kgm/s and the mass of the object is 5000g. Determine the velocity of the object. (4)

e. A balloon of mass 0.1g is floating due east with a velocity of 0.5mls. Calculate the momentum the balloon. (4)

e. Consider the load being pulled in the figure below:



i. Name the force marked x. (1)

ii. State the components of the 10N force. (2)

Newton's Second Law of Motion

- When force is applied to an object, it can either make the object move if it is resting, stop, or change direction if it is moving.
- This change in the state of motion will affect the object's velocity, which in turn causes a change in the object's **momentum**.
- This change in momentum was summarised in **Newton's second law of motion**.
- This law states that:
- ***"The rate of change of momentum is directly proportional to the resultant force and it takes the direction in which the force acts".***

OR

- ***"The Force F acting on an object of mass m to cause acceleration a is directly proportional to the product of mass and acceleration".***
- Newton's second law mathematically:

$$\textbf{Force (F)} \ \alpha \ \frac{Change\ in\ momentum}{time\ taken}$$

Newton's Second Law of Motion

- But the change in momentum is given by:

  Final momentum – Initial momentum

- Given a body of mass **m** and taking **u** and **v** at the body's initial and final velocities respectively, then we can say:

  Initial momentum = mass * initial velocity = **mu**

  Final momentum = mass * final velocity = **mv**

- So the change in momentum can be given by:

  Change in momentum = **mv – mu**

- Now rate of change of momentum is given by:

  $$\frac{mv - mu}{t} \quad \text{thus:} \quad m(\frac{v-u}{t})$$

- But $\frac{v-u}{t}$ = **a** as such, rate of change of momentum = **ma**
- Now we have:

  Force (F) α **ma**

- Introducing a proportionality constant K, whose value is , thus: **F = Kma**
- Therefore: **F = ma**

Newton's Second Law of Motion

Examples:

a. Calculate the resultant force that causes an object of mass 3000g to accelerate at the rate of 4 m/s^2.

Solution

F = ma

F = ?

m = (3000g/1000g)*1kg = 3kg

a = 4 m/s^2

F = 3kg * 4 m/s^2 **= 12N**

b. A force of 15N makes a body of mass 3kg move. Calculate the average acceleration of the body.

Solution

F = ma

m = 3kg

F = 15N

a = ?

a = F/m

a = 15N/3kg = 5 m/s^2

Applications of Newton's Second Law of Motion

Below are some of the notable applications of Newton's second law of motion:

a. **Vehicle acceleration and braking:** this law explains how force applied by the engine results in the acceleration of a vehicle and how braking forces are calculated.

b. **Crash testing and seat belts:** this law helps in designing safety features such as airbags and seatbelts.

c. Use by engineers to calculate how much force structures like bridges and building must withstand when subjected to various loads.

d. Used in machines like elevators, cranes, and conveyor belts to calculate the force required to lift and move objects of various masses.

e. Used in rockets to determine how much force will be required to accelerate the rocket into space.

Newton's Second Law of Motion

Practice:

a. Define momentum.

b. A ball of mass **0.2kg** is thrown with a velocity of **15m/s**. What is its momentum?

c. If a car with a mass of **1,200,000g** experiences a force of **4,800N**. What is its acceleration?

d. A force of **200N** is applied to an object, causing it to accelerate at **4** $\mathbf{m/s^2}$. What is the mass of the object?

e. A bullet of mass **7** g travels with a velocity of **200** m/s. It hits a tree and penetrates into it. The bullet comes to rest in **0.05** s. Calculate the following:
   i. The distance the bullet travels in the target.
   ii. Average retarding force exerted on the bullet.

Newton’s Third Law of Motion

- When two objects push or pull each other, they create forces that we call **action** and **reaction**.
- These forces are summaries in Newton’s third law of motion.
- This law states that ***“For every action, there is an equal and opposite reaction”***.
- This means that when one object applies a force on a second object, the second object applies an equal but opposite force back on the first object.
- These forces are called **action-reaction force pairs**.
- As such we can also say it states that “***whenever a body exerts a force on another body, this second body exerts an equal but opposite force on the first body***”.

Note:

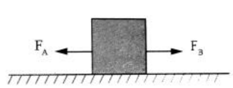
- The action and reaction forces of two objects that are in motion do not necessarily always cancel out each other or produce zero resultant force, they may cause the objects to move in different directions upon contact. **See Figure a**.

Newton’s Third Law of Motion

Note Conti…

- But, when the two forces are acting on the same object, the forces cancel each other out and the object remain in the same place. **See Figure b**.

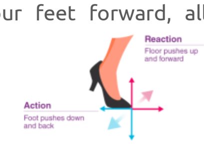
(a) Forces do not cancel each other



(b) Forces cancel each other

Examples of Newton’s third law of motion. (Common experiences due to Newton’s law of motion)

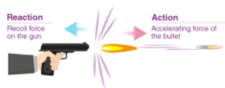
a. **Walking:** When you walk, your feet push backward on the ground, and the ground pushes your feet forward, allowing you to move.



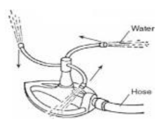
b. **Rocket Propulsion:** The rocket engine pushes exhaust gases downward (action), and the gases push the rocket upward (reaction), allowing it to lift off.

Newton’s Third Law of Motion

c. **Recoil of a Gun:** When a gun is fired, the bullet moves forward (action), and the gun recoils backward (reaction).



d. **Water Sprinkler Action:** Water is forced out of the sprinkler nozzle at high speed in one direction (action). As a reaction to the water being pushed out, the sprinkler head experiences an equal and opposite force, causing it to rotate in the opposite direction (reaction).



e. **Swimming:** A swimmer pushes the water backward with their hands, and the water pushes them forward.

f. **A Ball Hitting the Ground: Action:** When a ball falls and hits the ground, it exerts a force on the ground. **Reaction:** The ground exerts an equal and opposite force on the ball, causing it to bounce back up (depending on the ball's elasticity).

g. **Jumping from a Boat: Action:** When you jump off a boat by pushing the boat backward with your feet. **Reaction:** The boat moves backward as a result of the force you applied, while you move forward into the water.

Demonstrating Newton’s Third Law of Motion

The materials that will be required are:
- Two spring balances and a rigid support

Procedure

a. Label the springs balances **A** and **B** respectively.
b. Hook spring balance **A** to a rigid support and note the readings.
c. Hook spring balance **A** to spring balance **B**.
d. Pull the two spring balances until the reading on spring **A** is as noted in step b.
e. Note the reading on spring balance **B**.

Observation

- The rigid support is being pulled by the spring but it does not move.
- When the springs are hooked they give the same reading.

Conclusion

- The same reading on spring balance A and B shows that the forces being created are equal in size and opposite direction.

NEXT: Collisions