SLO 3: Dynamics

3.1 Mass and Weight

3.1.1 Differentiate Between Mass And Weight

- Mass is the actual amount of material contained in a body and is measured in kg. Whereas weight is the force exerted by the gravity on that object (w= mg).
- Mass is independent of everything but weight is different on the earth, moon, and other places due to difference of gravitational pull.
- Mass is the amount of matter present in a body while weight is a measure of how strongly gravity pulls on that matter.
- Mass is an intrinsic property of the body and remains the same wherever the body might be. Weight is a force, (Force = mass x acceleration). The weight of an object is the mass times the acceleration due to gravity. The weight of the body differs from place to place.
- Mass is measured in kilogram (kg) while weight is measured in Newton (N).
- For example, objects weigh lesser on the moon where gravity is lower as compared to that on the Earth. But, the mass of any object remains the same whether on Earth or Moon.

3.1.2 Explain That Mass Of An Object Resists Changes From Its State Of Rest Or Motion

Inertia is the property of an object due to which it tends to continue its state of rest or motion. Inertia is resistance to change the state. The mass of an object is a measure of its inertia. This means that a heavier object (more mass) resists change more while a lighter object (less mass) resists change less.

When a bus starts moving the passengers feel a backward jerk, because their lower part of body moves along the motion of bus but the upper part of the body tends to stay at its initial position of rest. On the other hand, when you stop paddling your bicycle it does not stop at once. The bicycle continues moving. However, the road's friction and air resistance act against its motion and bring it to rest after some time.

3.1.3 Define Gravitational Field Strength

The gravitational field is a space around a mass in which another mass experiences a force due to gravitational attraction. The gravitational field strength is defined as <u>*the gravitational force acting on unit mass*</u>. Thus, mass m on the surface of the Earth exerts a force known as its weight w given by w = mg. where g is the gravitational field strength. Its value is 10 N kg^{-1}. As the value of g varies from place to place and also with altitude, therefore, the value of weight does not remain the same everywhere. The weight cannot be measured by an ordinary balance. A spring balance can be used to measure the weight. The S.I unit of weight is newton (N).

3.1.4 Solve Word Problems Using The Relation w = mg

Questions are available on worksheets.

3.2 Force

3.2.1 Describe The Concept Of Force With Its SI Unit

Force is required to change the position, state or shape of an object. An object at rest needs a force to get moving; a moving object needs a force to come in rest or change its velocity or direction. The magnitude of a force can be measured using a spring balance.

Definition:
Force is the agent that changes the state of rest or uniform motion of a body. Force can act as pull or push agent. Force produces acceleration. It can produce distortion. Force is a vector.

Unit:
One Newton (1 N) is the amount of force that can produce 1 ms^{-2} acceleration in 1 kg mass.

3.2.2 Define Contact And Non-Contact Forces
A contact force is a force that is exerted by one object on the other at the point of contact. Applied forces (push a pull and twist) are contact forces.

A non-contact force is defined as the force between two objects which are not in physical contact. The non-contact forces can work from a distance. That is why, these are sometimes called as action-at-a-distance. There is always a field linked with a non-contact force. Due to this, non-contact forces are also called field forces.

3.2.3 Identify The Following Forces As Contact And Non-Contact Forces
1. Air resistance: A type of contact force. It is the resistance (opposition) offered by air when an object falls through it.
2. Drag force (push, pull): Drag force is a type of contact force which acts as the resistant force caused by the motion of a body through a fluid. It acts opposite to the relative motion of any object moving with respect to surrounding fluid.
3. Electrostatic force: An electrostatic force acts between two charged objects. The opposite charges attract each other and similar charges repel each other. Electrostatic force is a long-range non-contact force.
4. Force of friction: It is a type of contact force that resists motion when the surface of one object comes in contact with the surface of another.
5. Gravitational force: The gravitational force is an attractive force that exists among all bodies which have mass. It is a long-range non-contact force given by Newton's law of gravitation

$$F_g = G\frac{m_1 m_2}{r^2}$$

where m_1, and m_2, are two masses r distant apart and G is constant of gravitation. Its value is 6.67 x 10^{-11} Nm^2kg^3. The Sun's gravitational force keeps the Earth and all other planets of our solar system in fixed orbits. Similarly, the gravitational force of the Earth keeps the moon in its orbit. It also keeps the atmosphere and oceans fixed to the surface of the Earth.

6. Magnetic force: It is a force which a magnet exerts on other magnets and magnetic materials like iron, nickel and cobalt. Iron pins attracted in the presence of a magnet without any physical contact. Magnetic force between the poles of two magnets can be either attractive or repulsive.
7. Tension (elastic force): A type of contact force experienced by rope when a person or load pulls it.
8. Thrust (driving force): A type of contact force. It is an upward force exerted by a liquid on an object immersed in it. When we try to immerse an object in water, we feel an upward force exerted on the object. This force increases as we push the object deeper into the water. A ship can float in the sea due to this force which balances the weight of the ship.

3.2.4 Four Fundamental Forces Of Nature In Terms Of Their Relative Strength
There are four fundamental forces in nature. Every force comes under any of these forces. These are:

1. Gravitational force

The gravitational force is an attractive force that exists among all bodies which have mass. It is a long-range non-contact force given by Newton's law of gravitation

$$F_g = G\frac{m_1 m_2}{r^2}$$

It is the weakest one among all four forces. Being a long-range force, it extends to infinite distance although it becomes weaker and weaker.

2. Electromagnetic Force

It is the force that causes the interaction. between electrically charged particles. Electrostatic and magnetic forces come under this category. These are long-range forces. The areas in which these forces act are called electromagnetic fields. Electromagnetic forces are stronger than gravitational and weak nuclear forces. This force causes all chemical reactions. It binds together atoms, molecules and crystals etc. At macroscopic level, it is a possible cause of friction between different surfaces in relative motion.

3. Strong Nuclear Force

It holds the atomic nuclei together by binding the protons and neutrons in the nucleus over coming repulsive electromagnetic force between positively charged protons. It is also a short-range force with the order of 10^{-14} m. If the distance between nucleons increases beyond this range, this force ceases to act.

4. Weak Nuclear Force

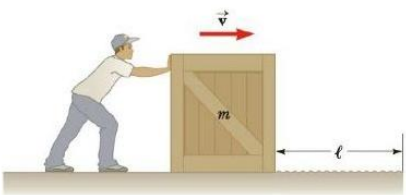
Weak nuclear force is responsible for the disintegration of a nucleus. Radioactive decay of atoms occurs due to weak nuclear force. However, weak nuclear force is stronger than the gravitational force but weaker than the electromagnetic force. It is a short-range force of the order 10^{-17} m. For example, the weak nuclear force executes the β-decay (beta decay) of a neutron, in which a neutron transforms into a proton. In the process, a β-particle (electron) and an uncharged particle called antineutrino are emitted.

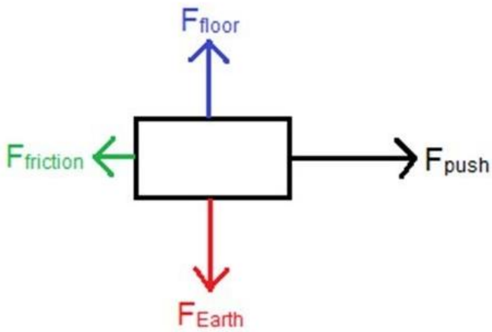
3.2.5 Mention The Role Of Pakistani Scientists In Proving The Weak Forces And The Electromagnetic Force Are Unified

A Pakistani scientist Dr. Abdus Salam along with Sheldon Glashow and Steven Weinberg were awarded in 1979 Nobel Prize in Physics for their contributions to the unification of the weak nuclear force and electromagnetic force as electroweak force. Although these two forces appear to be different in everyday phenomena, but the theory models them as two different aspects of the same force. Its effects are observed for the interactions taking place at very high energy.

3.2.6 Represent The Forces Acting On A Body Using A Free-Body Diagram

External forces acting on an object may include friction, gravity, normal force, drag, tension in a string or a human force due to pushing or pulling. Free-body diagrams are used to show the relative magnitudes and





directions of all the forces acting on an object in a given situation. In other words, a free-body diagram is a special example of the vector diagrams. Usually, the object is represented by a box and the force arrows are drawn outward from the center of the box in the directions of forces. The length of a force arrow (line) reflects the magnitude of the force and the arrow head indicates the direction in which the force acts. Each force is labelled to indicate the exact type of force.

3.3 Newton's Laws of Motion

3.3.1 Explain Newton's Laws Of Motion

Sir Isaac Newton gave three laws of motion that explain how and why objects move. These are basic laws in physics.

Newton's First Law Of Motion:

A body continues its state of rest or of uniform motion in a straight line unless an external force acts on it.

- Objects at rest stay at rest.
- Objects in motion keep moving at the same speed and direction.
- A force is needed to change this state.

Newton's Second Law Of Motion:

when a net force acts on a body it produces acceleration in the direction of force. The acceleration is directly proportional to force and inversely proportional to mass of body.

$$a \propto F$$

$$a \propto \frac{1}{m}$$

$$a \propto \frac{F}{m}$$

$$a = k\frac{F}{m}$$

For k = 1,

$$F = ma$$

Newton's Third Law Of Motion:

To every action, there is an equal and opposite reaction.

- Forces always occur in pairs.
- If object A pushes B, object B pushes A with equal force in the opposite direction.

3.3.2 State The Limitations Of Newton's Laws Of Motion

Although Newton's laws explain most everyday motion, they do not apply in all situations.

1. Not Valid at Very High Speeds: Newton's laws fail when objects move close to the speed of light. Einstein's theory of relativity must be used instead. Example: Motion of particles in particle accelerators.
2. Not Accurate at Atomic or Subatomic Levels: do not apply to very small particles like electrons or protons. In such cases, quantum mechanics is used. Example: Behavior of electrons in an atom.
3. Do Not Explain the Cause of Force: these describe how motion changes but not why a force exists.

4. Not Applicable in Non-Inertial (Accelerating) Frames: only work in inertial frames (non-accelerating or constant velocity frames). They fail in rotating or accelerating frames unless corrected with fictitious forces (like centrifugal force). Example: Motion observed inside a rotating merry-go-round.

3.3.3 Identify The Effect Of Force On Velocity Of A Body Acting In The

- Same Direction: Increases the speed of the object (accelerates it). Velocity increases in the same direction.
- Opposite Direction: Decreases the speed of the object (decelerates it). May eventually bring it to a stop or reverse its direction.
- Perpendicular Direction: Changes the direction of motion, but not the speed. This results in circular or curved motion.

3.3.4 Determine The Resultant Of Two Or More Forces Acting Along Same Straight Line

The resultant force is the net force acting on a body when two or more forces act along the same straight line. It is basically the sum of all forces acting on a body.

$$R = F_1 + F_2 + F_3 + \cdots + F_n$$

3.3.5 Identify Those Objects Falling In The Presence Of A Resistive Force May Reach A Terminal (Constant) Velocity

Terminal velocity is the maximum constant speed an object reaches while falling through a fluid (like air or water), when the resistive force equals the weight of the object. At terminal velocity:

- Net force = 0
- Acceleration = 0
- Object falls at a steady speed

The resistive force is usually air resistance or fluid friction acting opposite to the direction of motion. Objects That Reach Terminal Velocity:

1. Parachutist (Skydiver): Falls quickly at first. Air resistance increases with speed. Eventually, resistance = weight → falls at terminal velocity.
2. Rain Drops: Small mass but high surface area. Reach a constant speed while falling through air.
3. Feathers, Paper, Leaves: Large surface area causes high air resistance. They quickly reach terminal velocity and fall slowly.
4. Balls Falling in Water or Oil: The viscous resistance in liquids acts against motion. The object eventually falls with constant speed.

Any object falling in a fluid (like air or water) will eventually reach terminal velocity if resistive forces are strong enough to balance the weight of the object.

3.4 Momentum

3.4.1 Define Momentum With Its Units

The momentum of an object is equal to the mass multiplied by the velocity of the object.

Momentum = mass x velocity

P = mv

A mass unit is multiplied by a velocity unit to provide a momentum unit. This is consistent with the equation for momentum. The SI unit of momentum is kilogram meter per second ($kgms^{-1}$) or Newton Second (Ns).

3.4.2 Explain The Relationship Between Force And Momentum

"Change in momentum is equal to the force multiplied by the time interval for which it was applied"

Consider a body of mass m, moving with initial velocity v_i. A force F acts on the body to produce acceleration a, therefore the final velocity after time t will become v_f. Since mass is constant, then change in velocity due to force applied will result in change in momentum.

$$P_i = mv_i$$

$$P_f = mv_f$$

$$change\ in\ momentum = \Delta P = P_f - P_i$$

$$\Delta P = mv_f - mv_i$$

$$\Delta P = m(v_f - v_i)$$

Dividing both sides by Δt

$$\frac{\Delta P}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$$

$$\frac{\Delta P}{\Delta t} = \frac{m\Delta \text{v}}{\Delta t}$$

We know that rate of change of velocity is acceleration. So,

$$\frac{\Delta P}{\Delta t} = ma$$

And according to Newton's second law, $F = ma$

$$F = \frac{\Delta P}{\Delta t}$$

Which is the rate of change in momentum. Thus, we can say that force is the rate of change in momentum.

3.4.3 Describe Impulse With Examples

Impulse is the effect of a force acting on an object for a short time. It causes a change in momentum.

Impulse = Force × Time

J = F × t

It is also equal to the change in momentum:

Impulse = ΔP = m (v − u)

The unit of impulse is Newton – Second (Ns)

Examples:

1. Catching a Fast Ball: A cricketer moves his hands backward while catching. This increases time and reduces the force (impulse is the same).
2. Jumping on Sand Pit: Athletes land on sand to reduce injury. Sand increases time of impact, reducing force.
3. Airbags in Cars: Airbags increase the time of collision. This reduces the impact force on passengers.
4. Boxer Moving Back: A boxer moves his head back when punched. It increases reaction time, reducing the force felt.
5. Hammering a Nail: A hammer applies a large force in a short time. This impulse drives the nail into wall.

3.4.4 Solve Word Problems Related To Momentum And Impulse
Worksheet available separately.

3.4.5 State The Law Of Conservation Of Momentum
"The total momentum of an isolated system always remains constant".

Consider a system of two billiard balls A and B of mass m_1 and m_2 are moving in a straight line with velocities u_1 and u_2 respectively where u_1 is greater than u_2. Then,

- Momentum of ball A before collision = m_1u_1
- Momentum of ball B before collision = m_2u_2

Since ball A is faster than ball B, ball A will collide with ball B. Then,

- Momentum of ball A after collision = m_1v_1
- Momentum of ball B after collision = m_2v_2

Where v1 and v2 are velocities of ball A and ball B after collision. According to law of conversation of momentum, the total momentum will remain constant:

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

3.4.6 Solve Word Problems Using The Law Of Conservation Of Momentum
Worksheet available separately.

3.5 Friction

3.5.1 Define Friction
- The force that resists relative motion between two surfaces is called friction.
- Frictional forces are always parallel to the plane of contact between two surfaces and opposite to the direction of the applied force.
- Friction is self-adjusting. It can increase to a certain value known as limiting force (F_s).
- Friction is proportional to normal force $F_S \propto R$.
- The ratio between limiting force and normal reaction R is constant that is represented by coefficient of friction μ. Thus $F_S = \mu R$
- When a body is placed on a surface its weight w acts downward so R = w and so $F_S = \mu mg$
- The coefficient of friction has different values for different surfaces.

3.5.2 Differentiate Between Rolling Friction And Sliding Friction

FEATURE	ROLLING FRICTION	SLIDING FRICTION
Definition	Friction when an object rolls over a surface	Friction when an object slides over a surface
Contact Type	Rolling contact (point or line contact)	Surface contact (entire area)
Friction Force	Less than sliding friction	More than rolling friction
Examples	Wheels of a car, ball rolling on the floor	Pushing a box across the floor
Ease of Motion	Easier to move due to less resistance	Harder to move due to more resistance
Energy Loss	Less heat generated	More heat due to surface rubbing

3.5.3 List Various Methods To Reduce Friction

1. Applying oil, grease, or graphite between surfaces makes them smoother and reduces friction.
2. Smoother surfaces produce less friction than rough ones.
3. Ball bearings reduce sliding friction by converting it into rolling friction, which is much less.
4. Replacing sliding with rolling by using wheels or rollers greatly reduces friction.
5. Objects like cars, airplanes, and boats are given streamlined shapes to reduce air or fluid resistances

3.6 Uniform Circular Motion

3.6.1 Define Centripetal Force

The force required to move a body along a circular path is called Centripetal force. It is denoted by F_c. The centripetal force is always directed towards center of the circular path. It depends on three factors:

(i) the velocity of the object "v"
(ii) the object's distance from the center "r"
(iii) the mass of the object "m".

It is given by relation $F_c = \frac{mv^2}{r}$

Here r is the radius of circle. The velocity of the object is constant and perpendicular to a line running from the object to the center of the circle.

3.6.2 Exemplify Sources Of Centripetal Force During Circular Motion In Terms Of

When an object moves in a circular path, it needs a centripetal force to keep it moving in that path. This force always acts towards the center of the circle. Depending on the situation, the source of this centripetal force can be:

1. Tension

A stone tied to a string and whirled in a circle. The tension in the string provides the centripetal force. If the string breaks, the stone flies off in a straight line (tangent to the circle). Pour about a cup of water in a bucket and tie a string to bucket. Now try rotating the bucket around and up. The water will stick to the bottom of bucket. The force that keeps it stuck is known as centrifugal force and the force you apply against the pull on your arm is known as centripetal force.

2. Frictional Force

A car turning around a circular track. The friction between the tires and the road acts as the centripetal force. Without friction, the car would skid outward. The outer edge or bank of the road is raised to a certain height at the curved part of roads. This provides the centripetal force against the tires of vehicle hence prevents from skidding.

3. Gravitational Force

The Moon revolving around the Earth or a satellite orbiting a planet. The gravitational attraction between the Earth and the Moon provides the centripetal force needed for circular motion. The milk plants in country are using high speed spinners to separate cream from milk. The skimmed milk is heavier whereas the cream is lighter. When the milk is spun at high speed the heavy particles are pushed towards the walls of the spinner. These particles push the lighter particles of cream to the center where from it is collected through a tube.