

Unit 3: Dynamics

Textbook Exercise Questions

3.1 Encircle the correct answer from the given choices.

- i. Newton's first law of motion is valid only in the absence of: (LHR 2014, GRW 2015)
(a) Force (b) net force ✓
(c) friction (d) momentum
- ii. Inertia depends upon:
(a) Force (b) net force
(c) mass ✓ (d) velocity
- iii. A boy jumps out of a moving bus. There is a danger for him to fall:
(a) Towards the moving bus (b) Away from the bus
(c) In the direction of motion ✓ (d) Opposite to the direction of motion
- iv. A string is stretched by two equal and opposite forces of 10 N each. The tension in the string is:
(a) Zero (b) 5 N
(c) 10 N ✓ (d) 20 N
- v. The mass of a body
(a) Decreases when accelerated (b) Increases when accelerated
(c) Decreases when moving with high velocity (d) None of the above ✓
- vi. Two bodies of masses m_1 and m_2 attached to the ends of an inextensible string passing over a frictionless pulley such that both move vertically. The acceleration of the bodies is:
(a) $a = \frac{(m_1 - m_2)g}{m_1 + m_2}$ ✓ (b) $a = \frac{m_1 g}{m_1 + m_2}$
(c) $a = \frac{(m_1 + m_2)g}{m_1 - m_2}$ (d) $a = \frac{m_2 g}{m_1 + m_2}$
- vii. Which of the following is the unit of momentum?
(a) Nm (b) kgms^{-2}
(c) Ns ✓ (d) Ns^{-1}
- viii. When a horse pulls a cart, the action is on the:
(a) Cart (b) earth
(c) horse (d) earth and cart ✓
- ix. Which of the following material lowers friction when pushed between metal plates? (LHR 2014, 2015)
(a) Water (b) fine marble powder
(c) air (d) oil ✓

3.2 Define the following terms:

i) Inertia

ii) Momentum

iii) Force

iv) Force of friction

v) Centripetal force

i. Inertia

Ans: Inertia of a body is its property due to which it resists any change in its state of rest or of uniform motion.

It depends on the mass of the body. Greater the mass of the body greater will be the inertia. Therefore, we can say that mass is the direct measure of inertia.

ii. Momentum

Ans: Momentum of a body is the quantity of motion it possesses due to its mass and velocity.

The momentum 'P' of a body is given by the product of its mass m and velocity v . Thus

$$P = m \times v$$

Quantity

Momentum is a vector quantity.

Unit

SI unit of momentum is kg ms^{-1} or Ns .

iii. Force

Ans: A force moves or tends to move, stops or tends to stop the motion of a body. The force can also change the direction of motion of a body.

Example

We can open the door either by pushing or pulling the door.

A man pushes the cart. The push may move the cart or change the direction of its motion or may stop the moving cart.

A batsman changes the direction of moving ball by pushing it with his bat.

iv. Force of friction

Ans: The force which opposes the motion of moving objects is called friction.

Friction is force that comes into action as soon as body is pushed or pulled over the a surface.

Factor on which friction depends

In case of solids, the force of friction between two bodies depends upon many factors such as nature of the two surfaces in contact and the pressing force between them.

v. Centripetal force

Ans: Definition

The force which compels a body to move away from circular path is known as centrifugal force. This is reaction of centripetal force.

Example

Consider a stone tied with a string moving in a circle. The necessary centripetal force acts on the stone through the string that keeps it in the move in a circle. According to Newton's

third law of motion, there exists a reaction to centripetal force. Centripetal reaction that pulls the string outward is sometimes the centrifugal force.

3.3 What is the difference between?

i) Mass and weight

Differentiate between Mass and Weight.

Mass	Weight
- Mass of a body is the quantity of matter possessed by the body. - It is a scalar quantity. - It is measured by physical balance. - It remains same everywhere. It does not change with change of place. - Unit of mass is kilogram (Kg). - It is a base quantity. - It can be calculated by using the formula $F = ma$.	- The weight of the body is equal to the force with which earth attracts it. - It is a vector quantity and is toward the center of the earth. - It is measured by spring balance. - It does not remains same at all places because the value of 'g' does remain same at all places. - Unit of weight is Newton (N). - It is a derived quantity. - It can be calculated by using the formula $w = mg$.

ii) Action and reaction

When two bodies come in contact with each other, the force exerted by first body on second body is known as action.

When two bodies come in contact with each other, the force exerted by second body on first body is known as reaction.

iii) Sliding friction and rolling friction

(GRW 2015)

Sliding Friction	Rolling Friction
Frictional force experienced by the body when a body slides over the other body. It is greater than rolling friction	Frictional force experienced by the body when a body rolls over the other body. It is less than sliding friction

3.4 What is the law of inertia?

Ans: Since Newton's first law of motion deals with the inertial property of matter, therefore, Newton's first law of motion is also known as law of inertia.

3.5 Why is it dangerous to travel on the roof of a bus?

Ans: It is dangerous to travel on the roof of a bus because when brakes are applied suddenly, the lower part of body of passenger sitting on its roof comes to rest immediately but due to inertia upper part of his body continues its motion in a straight line and he may fall forward and gets injured if there is no support.

3.6 Why does a passenger moves outward when a bus takes a turn?

Ans: When the bus traveling in a straight line suddenly takes a turn, the passenger in the bus due to inertia tends to continue his motion in the straight line and falls in the forward direction.

3.7 How can you relate a force with the change of momentum of a body?

Ans: See Q.no.6 Long Question

3.8 What will be the tension in a rope that is pulled from its ends by two opposite forces 100 N each?

Ans: The tension in a rope that is pulled from its ends by two opposite forces 100 N each will be 100 N.

3.9 Action and reaction are always equal and opposite then how does a body move?

Ans: Action and reaction are equal in magnitude but opposite in direction. Action and reaction do not act on the same body. Action is applied on one body due to which an equal and opposite reaction is acting on another body. Both of these do not neutralize each other due to which the body will move.

3.10 A horse pushes the cart. If the action and reaction are equal and opposite then how does the cart move?

Ans: The horse apply action on the road by his feet, the reaction is given by the road on the horse, due to which horse moves. The cart which is tied with the horse will also move.

3.11 What is the law of conservation of momentum?

Ans: The momentum of an isolated system of two or more than two interacting bodies remains constant.

An isolated system is a group of interacting bodies on which no external force is acting. If no unbalanced or net force acts on a system then its momentum remains constant.

3.12 Why is the law of conservation of momentum important?

Ans: Law of conservation of momentum has vast applications and is applicable universally on bigger bodies as well as on atoms and molecules. A system of gun and bullet, rocket and jet engines etc. Work on the principle of law of conservation of momentum.

3.13 When a gun is fired, it recoils. Why?

Ans: Total momentum of the gun and the bullet is zero before the firing. When gun is fired, bullet moves in forward direction and gun recoils to conserve momentum.

3.14 Describe two situations in which force of friction is needed?

Ans:

(i) We cannot write if there would be no friction between paper and the pencil.

(ii) Friction enables us to walk on the ground. We cannot run on a slippery ground. A slippery ground offers very little friction.

3.15 How does oiling the moving parts of a machine lower friction?

Ans: As the friction of liquids is less than friction of solids. So oiling the moving parts of the machines lower the friction.

3.16 Describe ways to reduce friction.

(LHR 2014)

Ans: The friction can be reduced by:

- Making the sliding friction smooth
- Making the fast moving a streamline shape (fish shape) such as car, aeroplanes, etc. this causes the smooth flow of air and thus minimizes air resistance at high speeds.
- Lubricating the sliding surfaces
- Using ball bearings or roller bearings. Because the rolling friction is lesser than the sliding friction.

3.17 Why rolling friction is less than sliding friction?

(LHR 2013, 2014)

- We know that greater the points of contact between two surfaces, greater will be the friction and vice versa. Since the points of contact between surfaces in case of rolling are

less than points of contact in case of sliding therefore rolling friction is less than sliding friction.

- There is no relative motion between rolling surfaces.

Unit 3: Dynamics

Long Questions

3.2 NEWTON'S LAWS OF MOTION

Newton's First Law of Motion

Q.1 State and Explain Newton's First law of motion (GRW 2011, 2012, 2014)

Ans: A body continues in its state of rest or of uniform motion in a straight line provided no net force acts on it.

Explanation for rest

Newton's first law of motion deals with bodies which are either at rest or moving with uniform speed in straight line. According to first law of motion, a body at rest remains at rest provided no net force act on it. This part of the law is true as we observe that objects do not move by themselves unless someone moves them.

Example

A book lying on a table remains at rest as long as no net force acts on it.

Explanation for motion

Similarly, a moving object does not stop moving by itself. A ball rolled on a rough ground stops earlier than that rolled on smooth ground. It is because rough surface offer greater friction. If there would be no force to oppose the motion of the body would never stop.

Example

When its engine of a car moving with uniform velocity is turned off it stops gradually because a net force of friction is acting in the opposite direction causes to stop it.

Law of inertia

Since Newton's first law of motion deals with the inertial property of matter, therefore, Newton's first law of motion is also known as law of inertia.

Example

Passengers standing in a bus fall forward when its driver applies brakes suddenly. It is because the upper parts of the bodies tend to continue their motion, lower parts of their bodies are in contact with the bus stop with it. Hence, they fall forward.

Newton's Second Law of Motion

Q.2 State and Explain Newton's Second law of motion (GRW 2011, LHR 2012, 2013)

Ans: "When a net force acts upon a body, it produces as acceleration in the body in the direction of force and the magnitude of acceleration is directly proportional to the net force and is inversely proportional to the mass of the body".

Mathematical Form

If the force 'F' is acting on the body of mass 'm' then we can write this in the mathematical form as,

$$a \propto F \dots\dots\dots (1)$$

$$a \propto \frac{1}{m} \dots\dots\dots (2)$$

From relation (1) and (2), we have

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

Changing the sign of proportionality into the sign of equality

$$a = \text{constant} \times \frac{F}{m}$$

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

In above equation, according to international system of units if $m = 1\text{Kg}$,

$a = 1\text{ms}^{-2}$, $F = 1\text{N}$ then the value of the constant k will be '1'. So the equation can be written as,

$$a = 1 \times \frac{F}{m}$$

$$F = ma$$

This is the mathematical form of Newton's Second law of motion.

Unit of Force

In the System International, the unit of force is Newton, which is represented by the symbol ‘N’.

Newton

“One Newton is that force which produces an acceleration of 1 ms^{-2} in a body of mass 1 Kg ”.

This unit of Newton can also be written as,

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ ms}^{-2}$$

$$1 \text{ N} = 1 \text{ Kgms}^{-2}$$

Q.3 Differentiate between Mass and Weight.

(GRW 2011, 2012, LHR 2014, 2015)

Ans:

Mass	Weight
• Mass of a body is the quantity of matter possessed by the body. • It is a scalar quantity. • It is measured by physical balance. • It remains same everywhere and does not change with change of place. • Unit of mass is kilogram (Kg). • It is a base quantity. • It can be calculated by using the formula $F = ma$. • Mass of a body can never be zero	• The weight of the body is equal to the force with which earth attracts it. • It is a vector quantity and is toward the center of the earth. • It is measured by spring balance. • It does not remain same at all places and varies with the value of 'g'. • Unit of weight is Newton (N). • It is a derived quantity. • It can be calculated by using the formula $w = mg$. • Weight of body can be zero

Newton's Third Law of Motion

Q.4 State and Explain Newton's Third law of motion

(LHR 2011, GRW 2013)

Ans: To every action there is always an equal but opposite reaction.

Action and Reaction

Newton's third law of motion deals with the reaction of a body when a force acts on it. Let a body A exerts a force on another body B, the body B reacts against this force and exerts a force on body A. the force exerted by body A on B is the action force whereas the force exerted by B on A is called the reaction force.

Relation between Action and Reaction

Newton has expressed action and reaction in his third law of motion. Action is always accomplished by a reaction force and the two forces must always be equal and opposite. It is to remember that "action" and "reaction" do not act on the same body but they act on two different bodies.

Example 1

Consider a book lying on a table as shown in figure. The weight of the book is acting on the table in the downward direction. This is the action. The reaction of the table acts on the book in the upward direction.

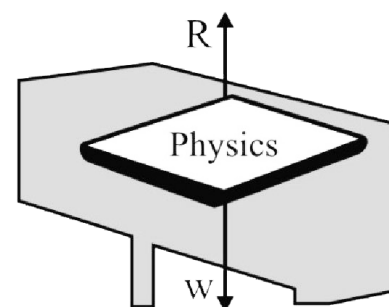


Figure 3.8: Action of the book and reaction on it.

Example 2

Take an air – filled balloon. When the balloon is set free, the air inside it rushes out and the balloon moves forward. In this example, the action is by the balloon that pushes the air out of it when set free. The reaction of the air which escapes out from the balloon acts on the balloon. It is due to this reaction of the escaping air that moves the balloon forward.

Example 3

A rocket moves on the same principle. When its fuel burns, hot gases escape out from its tail with a very high speed. The reaction of these gases on the rocket causes it to move opposite to the gases rushing out of its tail.

Figure 3.10: A Rocket taking off

Tension and Acceleration in a String

Q.5 Explain the tension in the string. If two bodies of masses m_1 and m_2 are hanging from the two ends of a string which is passing over a pulley, find the values of tension and acceleration in it.

(LHR 2013, GRW 2015)

Ans: The force which is exerted by the string on the body when it is subjected to a pull is called the tension in the string. It is a reaction force of the weight and it is usually denoted by T . The weight acts downwards while tension T in the string is acting upwards at the block. If the object is at rest, the magnitude of tension is equal to weight.

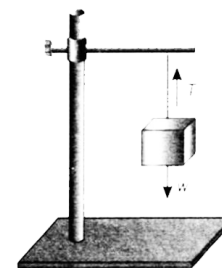


Figure 3.11: Weight of the block pulls the string downwards

Motion of Bodies connected by a string

There are two cases of motion of bodies connected by a string.

(i) When the bodies move vertically

(ii) When one body moves vertically and the other moves horizontally

Case-I

When the Bodies Move Vertically (Atwood machine)

Suppose two bodies A and B having masses m_1 and m_2 respectively are connected to two ends of an inextensible string which passes over a frictionless pulley. If m_1 is greater than m_2 , then the body A will move downward and the body B will move upward. The body A being heavier must be moving downwards with some acceleration. Let this acceleration be a . At the same time, the body B attached to the other end of the string moves up with the same acceleration a . as the pulley is frictionless, hence tension will be the same throughout the string. Let the tension in the string be T .

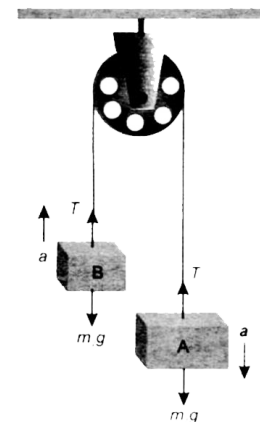


Figure 3.12: Bodies attached to the ends of a string that passes over a frictionless pulley.

Forces acting on the body A

As the body A is moving downward, the resultant force acting on it is downward due to which acceleration a is produced in it.

Net force acting on body A = $F_1 = m_1g - T$

According to Newton's second law of motion;

$$m_1g - T = m_1a \quad \dots\dots\dots (1)$$

As the body B is moving upward, the resultant force acting on it is upward due to which acceleration a is produced in it.

Net force acting on body B = $F_2 = T - m_2g$

According to Newton's second law of motion;

$$T - m_2g = m_2a \quad \dots\dots\dots (2)$$

Calculation of Acceleration

By adding equation (1) and equation (2), we have

$$m_1g - T + T - m_2g = m_1a + m_2a$$

$$m_1g - m_2g = m_1a + m_2a$$

$$(m_1 - m_2)g = (m_1 + m_2)a$$

$$\frac{(m_1 - m_2)g}{m_1 + m_2} = a$$

$$\text{OR} \quad a = \frac{(m_1 - m_2)g}{m_1 + m_2} \quad \dots\dots\dots (3)$$

Calculation of Tension

$$\frac{T - m_2g}{m_1g - T} = \frac{m_2a}{m_1a}$$

$$\frac{T - m_2g}{m_1g - T} = \frac{m_2}{m_1}$$

$$m_1(T - m_2g) = m_2(m_1g - T)$$

$$m_1T - m_1m_2g = m_1m_2g - m_2T$$

$$m_1T + m_2T = m_1m_2g + m_1m_2g$$

$$(m_1 + m_2)T = 2m_1m_2g$$

$$T = \frac{2m_1m_2g}{m_1 + m_2}$$

The above arrangement is also known as Atwood machine. It can also be used to find the acceleration due to gravity by equation (3)

$$g = \frac{m_1 + m_2}{m_1 - m_2} a$$

Case-II

When One Body Moves Vertically and the Other Moves Horizontally

Two bodies A and B having masses m_1 and m_2 respectively are connected to an inextensible string which passes over the pulley as shown in figure. The body A moves vertically downward with an acceleration a . The body B moves on the horizontal smooth surface towards the pulley with the same acceleration a . As the pulley is frictionless, hence tension T will be the same throughout the string.

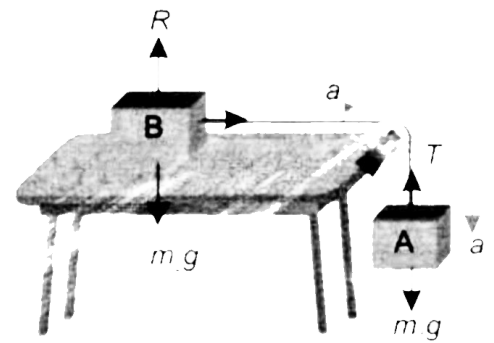


Figure 3.13: Motion of masses attached to a string that passes over a frictionless pulley.

Forces acting on the body A

As the body A is moving downward, therefore, weight $m_1 g$ is greater than the tension T in the string.

Net force acting on body A = $m_1 g - T$

According to Newton's second law of motion;

$$m_1 g - T = m_1 a \quad \dots\dots\dots (1)$$

Forces acting on the body B

Now consider the motion of the body B. Three forces are acting on it.

- (i) Its weight $w_2 = m_2 g$ of the body B acting downward
- (ii) The upward reaction R on the horizontal surface acting on the body B in the upward direction.
- (iii) Tension T on the string pulling the body in the horizontal direction over the smooth surface. As the body B is not moving vertically, therefore, vertical forces cancel each other and their resultant is zero. The only remaining force T due to which the body B is moving in the horizontal direction with acceleration ' a '.

Hence according to Newton's second law of motion,

$$T = m_2 a \quad \dots\dots\dots (2)$$

Calculation of Acceleration

Adding equation (1) and (2)

$$m_1 g - T + T = m_1 a + m_2 a$$

$$m_1 g = (m_1 + m_2) a$$

$$a = \frac{m_1 g}{m_1 + m_2}$$

Calculation of Tension

In order to find the value of T , put the value of a in equation (2), we have

$$T = m_2 \times \frac{m_1 g}{m_1 + m_2}$$
$$T = \frac{m_1 m_2 g}{m_1 + m_2} \quad \dots\dots\dots (4)$$

Force and the Momentum

Q.6 How you can prove that rate of change in momentum of a body is equal to the applied force? Or Derive the relation between momentum and force. (LHR 2015)

Ans: When a force acts on a body, it produces an acceleration in the body and will be equal to the rate of change of momentum of the body.

Suppose a force 'F' acts on a body of mass 'm' moving with initial velocity ' v_i ' which produces an acceleration a in it. This changes the velocity of body to ' v_f ' after time t . If P_i and P_f be the initial momentum and final momentum of the body related to initial and final velocities, Then,

Momentum of the body having velocity $v_i = P_i = mv_i$

Momentum of the body having velocity $v_f = P_f = mv_f$

Change in momentum = final momentum – initial momentum
 $= P_f - P_i = mv_f - mv_i = m(v_f - v_i)$

Rate of change in momentum = $\frac{P_f - P_i}{t} = \frac{mv_f - mv_i}{t}$

Rate of change in momentum = $m \frac{v_f - v_i}{t}$

Since $\frac{(v_f - v_i)}{t}$ is the rate of change of velocity equal to acceleration produced by the force F .

Rate of change of momentum = ma

According to Newton's second law of motion,

$$F = ma$$

$\therefore$ Rate of change of momentum = F

Rate of change of momentum of a body is equal to the applied force on it and the direction of change of in momentum is in the direction of the force.

Hence when a force acts on a body, it produces an acceleration in the body and will be equal to the rate of change of momentum of the body.

This is statement of Newton's second law of motion in terms of momentum.

Law of Conservation of Momentum

Q.7 State and explain Law of conservation of Momentum. (GRW 2013, LHR 2014)

Ans: The momentum of an isolated system of two or more than two interacting bodies remains constant.

An isolated system is a group of interacting bodies on which no external force is acting. If no unbalanced or net force acts on a system then its momentum remains constant.

Example

Consider the example of an air-filled balloon. In this case, balloon and the air inside it form a system. Before releasing the balloon, the system was at rest and hence the initial momentum of the system was zero. As soon as the balloon is set free, air escapes out of it with some velocity. The air coming out of it possesses momentum. To conserve momentum, balloon moves in the direction opposite to the air coming out of it.

Mathematical Explanation

Consider an isolated system of two spheres of masses m_1 and m_2 as shown figure. They are moving in a straight line with initial velocities u_1 and u_2 respectively, such that u_1 is greater than u_2 . Sphere of mass m_1 approaches the sphere of mass m_2 as they move.

Initial momentum of mass $m_1 = m_1u_1$

Initial momentum of mass $m_2 = m_2u_2$

Total momentum of the system before collision = $m_1u_1 + m_2u_2$

After sometime mass m_1 hits m_2 with some force. According to Newton's third law of motion, m_2 exerts an equal and opposite reaction force on m_1 . Let their velocities become v_1 and v_2 respectively after collision.

Final momentum of mass $m_1 = m_1v_1$

Final momentum of mass $m_2 = m_2v_2$

Total momentum of the system after collision = $m_1v_1 + m_2v_2$

Total momentum of system before collision = total momentum of system after collision

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

The above equation states that the momentum of the isolated system before and after collision remains the same, which is the law of conservation of momentum.

Application of Law of Conservation of Momentum

This law is applicable universally i.e. true not only for bigger bodies but also for atoms and molecules.

Example

Consider a system of gun and a bullet. Before firing, the velocity of the bullet as well as that of the gun was zero. Therefore, the total momentum of both the objects was also zero. We can write it as,

Total momentum of gun and bullet before firing = 0

When the gun is fired, the bullet shoots out of the gun and acquires momentum. To conserve momentum the gun recoils backward. Now according to the law of conservation of momentum, the total momentum of the gun and bullet will also be zero after the gun is fired. Let m be the mass of the bullet and v be its velocity on firing the gun; M be the mass of the gun and V be the velocity with which it recoils. Thus the total momentum of the gun after firing will be:

The momentum of the gun and bullet after the gun is fired = $M V + m v$

According to the law of conservation of momentum

Total momentum before firing = Total momentum after firing

$$M V + m v = 0$$

OR $M V = - m v$

Hence $V = - \frac{m}{M} v$

The above equation gives the velocity V of the gun. Here negative sign indicates that the velocity of the gun is opposite to the velocity of the bullet. That is why the shoulder is pressed hard during firing. Since the mass of the gun is much larger than the bullet, therefore, the recoil is much smaller than the velocity of the bullet.

Application in Rocket or Jet engine

Rocket or Jet engine also works on this same principle. In both of them, gases are produced at a high temperature due to the burning of fuel. These gases rush out with large momentum. Therefore the rockets or jet engines gain an equal and opposite momentum. This enables them to move with very high velocities.

3.3 FRICTION

Q.8 Define friction. Explain cause of friction and derive its mathematical formula.

Ans: The force which opposes the motion of moving objects is called friction.

Cause of friction

No surface is perfectly smooth. A surface that appears smooth has pits and bumps that can be seen under a microscope. A magnified view of a surface in contact shows the gaps and contacts between them. The contact points between the two surfaces form a sort of cold welds. These cold welds resist the surfaces from sliding over each other. Adding weight over the upper block increases the force pressing the surfaces together which increases the resistance. Thus greater the pressing force, greater will be the friction between sliding surfaces.

Mathematical Derivation

Friction is equal to the applied force that tends to move a body at rest. This friction at rest is called static friction. It increases with the applied force. Friction can also be increased to a certain maximum value. It does not increase beyond this. This maximum value of friction

is known as force of limiting friction (F_s). It depends on the normal reaction (pressing force) between the two surfaces in contact. The ratio between the force of limiting friction F_s and the normal reaction R is constant. This constant is called the coefficient of friction and is represented by μ .

Thus
$$\mu = \frac{F_s}{R}$$

Or
$$F_s = \mu R$$

If m is the mass of the block, then for horizontal surface;

$$R = mg$$

Hence
$$F_s = \mu mg$$

Friction is desirable

Friction is needed to walk on the ground. It is risky to run on wet floor with shoes that have smooth soles. Athletes use special shoes that have extraordinary ground grip. Such shoes prevent them from slipping while running fast. To stop bicycle we apply brakes. The rubber pads pressed against the rims provide friction. It is the friction that stops the bicycle.

Rolling Friction

Q.9 Explain the rolling friction.

Ans: Wheel as greatest invention

The most important invention in the history of mankind was a wheel. The first thing about a wheel is that it rolls as it moves rather than to slide. This greatly reduces the friction.

Less friction in Rolling Friction

When axle of a wheel is pushed, the force of friction between the wheel and the ground at the point of contact provides the reaction force. The reaction force acts at the contact points of the wheel in a direction opposite to the direction of the applied force. The wheel rolls without rupturing the cold welds. That is why this rolling friction is extremely small than sliding friction. The fact that rolling friction is less than sliding friction is applied in ball bearing to reduce losses due to friction.

Necessary Road Grip

The wheel would not roll on pushing it if there would be no friction between the wheel and the ground. Thus, friction is desirable for wheels to roll over a surface. It is dangerous to drive on a wet road because the friction between the road and the tyres is very small. This increases the chance of slipping the tyres from the road. The threading of tyres is designed to increase friction. Thus, threading improves road grip and make it safer to drive even on wet road.

Sliding Friction in Brakes

A cyclist applies brakes to stop his/her bicycle. As soon as brakes are applied, the wheels stop rolling and begin to slide over the road. Since sliding friction is much greater than rolling friction, the cycle stops very quickly.

Braking and Skidding

Q.10 Explain the roll of friction in Braking and explain the Skidding.

Ans: The wheels of a moving vehicle have velocity components:

- (i) Motion of wheel along the road
- (ii) Rotation of wheels about their axis

To move a vehicle on the road as well as to stop a moving vehicle requires friction between its tyres and the road.

Example

If the road is slippery or the tyres are worn out then the tyres instead of rolling, slip over the road. The vehicle will not move if the wheels start slipping at the same point on the slippery

road. Thus for the wheels to roll, the force of friction (gripping force) between the tyres and the road must be enough that prevents them from slipping.

Similarly to stop a car quickly, a large force of friction between the tyres and the road is needed. But there is a limit to this force of friction that tyres can provide.

Skidding

If the brakes are applied too strongly, the wheels of the car will lock up (stop turning) and the car will skid due to its large momentum. It will lose its directional control that may result in an accident. In order to reduce the chance of skidding, it is advisable not to apply brakes too hard that lock up their rolling motion especially at high speeds. Moreover, it is unsafe to drive a vehicle with worn out tyres.

3.4 UNIFORM CIRCULAR MOTION

Centripetal Force

Q.11 Define centripetal force and centripetal acceleration and derive the mathematical relation for centripetal force and acceleration.

Ans: A force that keeps a body to move in a circle is known as centripetal force.

Explanation

Consider a body tied at the end of a string moving with uniform speed in a circular path. A body has the tendency to move in a straight line due to inertia. The string to which body is tied keeps it to move in a circle by pulling the body towards the center of the circle. The string pulls the body perpendicular to its motion. The pulling force continuously changes the direction of motion and remains towards the center of the circle. This center seeking force is called the centripetal force. It keeps the body to move in a circle. Centripetal force always acts perpendicular to the motion of the body.

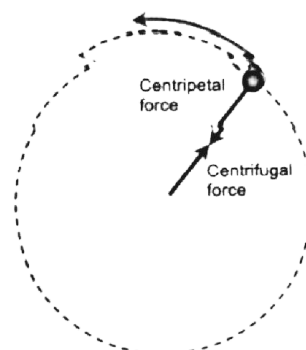


Figure 3.28: Centripetal force acting on the stone and the centrifugal force acting on the

Examples

- (i) A stone is tied to one end of a string rotating in a circle. The tension in the string provides the required centripetal force. It keeps the stone to remain in the circle. If the string is not strong enough to provide the necessary tension, it breaks and the stone moves away along the tangent to the circle.
- (ii) The moon revolves around the Earth. The gravitational force of the Earth provides required centripetal force.

Mathematical Formula

If an object of mass m is moving with velocity v in a circle of radius r , the magnitude of centripetal force F_c acting on it can be found by using the following equation.

$$F_c = \frac{mv^2}{r}$$

Centripetal acceleration

The acceleration produced by the centripetal force which is always directed towards the center of the circle is known as centripetal acceleration. It is represented by a_c .

According to Newton's second law of motion, the direction of this acceleration is along the direction of the centripetal force F_c , i.e., perpendicular to the velocity and directed towards the centre of the circle.

$$F_c = ma_c$$

So,

$$ma_c = \frac{mv^2}{r}$$

So,
$$a_c = \frac{v^2}{r}$$

Dependence

The above equation shows that centripetal force of the body moving in a circular path depends upon:

- Mass m of the body
- Square of its velocity

Unit 3: Dynamics

Multiple Choice Questions

- Laws of motion was presented by:**
(a) Einstein (b) Newton
(c) Galileo (d) Archimedes
- Isaac Newton described the laws of motion in his famous book:**
(a) Qanoon-ul-Masoodi (b) Principia Mathematica
(c) Kitab-ul-Astralab (d) Al-Manazir
- The laws of motion established the relationship between motion and -----:**
(a) Force (b) Torque
(c) Acceleration (d) Momentum
- First law of motion is also known as law of -----:**
(a) Torque (b) Acceleration
(c) Inertia (d) None of these
- of a body is the direct measure of inertia:**
(a) Mass (b) Energy
(c) Momentum (d) All of above
- The characteristic of a body due to which it tends to retain its state of rest or of uniform motion is known as:**
(a) Weight (b) Force
(c) Inertia (d) Momentum
- is the agency which changes or tends to change the state of rest or of uniform motion of a body:**
(a) Weight (b) Force
(c) Inertia (d) Momentum
- Law of inertia is actually the ----- law of motion:**
(a) First (b) Second
(c) Third (d) Fourth
- When a force is applied on the body, ----- is produced in the body:**
(a) Weight (b) Acceleration
(c) Energy (d) None of the above
- The acceleration produced in a moving body is always in the direction of applied -----:**
(a) Velocity (b) Force
(c) Speed (d) Momentum
- If mass of the body is doubled while keeping the force constant, then acceleration will be:**
(a) One half (b) doubled
(c) One fourth (d) Four times
- If force applied on the body is doubled while keeping the mass constant, then acceleration will be:**
(a) One half (b) doubled
(c) One fourth (d) Four times

13. **SI unit of force is:**
 (a) Kilogram (b) Dynes
 (c) newton (d) Pound
14. **When a force of 8 newton is applied on a body of mass 2 kg, then the acceleration produced will be:**
 (a) 16 ms^{-2} (b) 4 ms^{-2}
 (c) 0.4 ms^{-2} (d) 160 ms^{-2}
15. **1 N = ----- (GRW 2014)**
 (a) kgms^{-2} (b) kgms^{-1}
 (c) $\text{kgm}^2\text{s}^{-1}$ (d) $\text{kg}^2\text{ms}^{-2}$
16. **Action and reaction are equal in magnitude but opposite in direction is known as ----- law of motion:**
 (a) First (b) Second
 (c) Third (d) Fourth
17. **Walking on road is an example of ----- law of motion:**
 (a) First (b) Second
 (c) Third (d) Fourth
18. **When a block is lying on a smooth surface, its weight is balanced by:**
 (a) Mass (b) Momentum
 (c) Inertia (d) Normal Reaction
19. **The weight of a body of mass 10 kg on earth will be -----:**
 (a) 10 N (b) 1 N
 (c) 100 N (d) 1000 N
20. **The ----- of a body always acting towards the center of the earth:**
 (a) Mass (b) Force
 (c) Velocity (d) Weight
21. **Quantity of matter in a body:**
 (a) Mass (b) Force
 (c) Velocity (d) Weight
22. **The Force with which earth attracts a body towards its centre is known as:**
 (a) Mass (b) Force
 (c) Weight (d) Inertia
23. **The characteristic of a body which determines the magnitude of acceleration produced when a certain force acts upon it:**
 (a) Mass (b) Force
 (c) Inertia (d) Weight
24. **Mass of the body is measured by:**
 (a) Free Fall Apparatus (b) Physical balance
 (c) Spring balance (d) All of above
25. **Weight of the body is measured by:**
 (a) Free Fall Apparatus (b) Physical balance
 (c) Spring balance (d) All of above
26. **Unit of weight is:**
 (a) kg (b) ms^{-1}
 (c) Nm (d) N
27. **----- of a body remains same every where:**
 (a) Weight (b) Acceleration
 (c) Velocity (d) Mass
28. **----- of a body does not remain same every where:**
 (a) Weight (b) Inertia
 (c) Mass (d) All of above
29. **The value of weight of a body of constant mass depends on:**

- (a) Inertia (b) Momentum
(c) Force (d) 'g'
30. Mass is a ----- quantity:
(a) Scalar (b) Vector
(c) Derived (d) Negative
31. Weight is a ----- quantity:
(a) Scalar (b) Vector
(c) Unitless (d) Negative
32. When a block is hanging with the help of a rope then weight of the body is balanced by:
(a) Acceleration (b) Inertia
(c) Displacement (d) Tension
33. There are ----- cases of motion of the body hanging with the help of rope:
(a) 1 (b) 2
(c) 3 (d) 4
34. The tension produced when one body moves vertically and the other moves horizontally is ----- as compared to the tension produced when both bodies move vertically:
(a) Half (b) One fourth
(c) Double (d) Four times
35. Quantity of motion in a body is known as:
(a) Mass (b) Momentum
(c) Velocity (d) Acceleration
36. Product of mass and velocity is known as:
(a) Force (b) Speed
(c) Momentum (d) Acceleration
37. SI unit of Momentum is: (GRW 2013, LHR 2015)
(a) Kgms^{-2} (b) Ns
(c) Kgms^{-1} (d) Both b & c
38. $\text{Kgms}^{-1} = \text{-----}$
(a) N (b) J
(c) Ns (d) W
39. Rate of change of momentum is equal to:
(a) Force (b) Velocity
(c) Acceleration (d) Impulse
40. Direction of the rate of change of momentum is in the direction of:
(a) Acceleration (b) Momentum
(c) Velocity (d) Force
41. The force which resists the motion of one surface on another surface is known as:
(a) Gravity (b) Friction
(c) Weight (d) Repulsion
42. When object is at rest, the force of friction is known as ----- friction:
(a) Static (b) Limiting
(c) Kinetic (d) Dynamics
43. The maximum value of static friction is known as ----- friction:
(a) Static (b) Limiting
(c) Kinetic (d) Dynamics
44. When an object is in motion then the force of friction is known as -----friction:
(a) Static (b) Limiting
(c) Kinetic (d) Dynamics
45. Static friction is ----- than kinetic friction:
(a) Less (b) Quartered
(c) Greater (d) Equal
46. Rolling friction is ----- than Sliding friction:

- (a) Inertia (b) Momentum
(c) Force (d) 'g'
30. Mass is a ----- quantity:
(a) Scalar (b) Vector
(c) Derived (d) Negative
31. Weight is a ----- quantity:
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(c) Kinetic (d) Dynamics
44. When an object is in motion then the force of friction is known as -----friction:
(a) Static (b) Limiting
(c) Kinetic (d) Dynamics
45. Static friction is ----- than kinetic friction:
(a) Less (b) Quartered
(c) Greater (d) Equal
46. Rolling friction is ----- than Sliding friction:

- (a) Less (b) Quartered
(c) Greater (d) Equal
47. The coefficient of friction has ----- unit:
(a) Newton (b) Dynes
(c) No (d) Kilogram
48. Friction of liquids is ----- than friction of solids:
(a) Less (b) Quartered
(c) Greater (d) Equal
49. Coefficient of friction does not depend upon the ----- between two surfaces:
(a) Area of contact (b) Normal Reaction
(c) Weight (d) Roughness
50. The rolling friction is about ----- times smaller than sliding friction:
(a) 10 (b) 50
(c) 100 (d) 1000
51. Friction in the human joints is much reduced due to the presence of:
(a) Bones (b) Muscles
(c) Fluid (d) Gas
52. Value of coefficient of friction (μ_k) depends upon:
(a) Nature of the surfaces (b) Area of contact
(c) Force (d) All of above
53. The Rotation of water sprinkler is an example of ----- law of motion:
(a) First (b) Second
(c) Third (d) Fourth
54. A spider web remains intact due to:
(a) Weight (b) Momentum
(c) Tension (d) None of these
55. Momentum of a moving body depends upon its:
(a) Mass (b) Velocity
(c) Weight (d) Both a & b
56. Motion of the rocket is an example of:
(a) First law of motion (b) Law of conservation of Momentum
(c) Law of conservation of Energy (d) Weight
57. Value of coefficient of static friction (μ_s) is usually ----- than coefficient of kinetic friction (μ_k):
(a) Less (b) Quartered
(c) Greater (d) Equal
58. When air is released from an inflated balloon, it shoots off is an example of:
(a) First law of motion (b) Law of conservation of Energy
(c) Weight (d) Law of conservation of Momentum
59. Sliding friction is commonly converted into Rolling friction by the use of:
(a) Ball bearing (b) Oil
(c) Grease (d) Polish
60. The front sides of high speed vehicles, aeroplanes and ships are shaped wedge like to reduce:
(a) Weight (b) Pressure
(c) Speed (d) Friction

ANSWER KEY

Q.	Ans	Q.	Ans	Q.	Ans	Q.	Ans	Q.	Ans	Q.	Ans
1	b	11	a	21	a	31	b	41	b	51	c
2	b	12	b	22	c	32	d	42	a	52	a
3	a	13	c	23	a	33	b	43	b	53	c
4	c	14	b	24	b	34	a	44	c	54	c
5	a	15	a	25	c	35	b	45	c	55	d
6	c	16	c	26	d	36	c	46	a	56	b
7	b	17	c	27	d	37	d	47	c	57	c
8	a	18	d	28	a	38	c	48	a	58	d
9	b	19	c	29	d	39	a	49	a	59	a
10	b	20	d	30	a	40	d	50	c	60	d

Unit 3: Dynamics

Problems

3.1 20 N force moves a body with an acceleration of 2 ms^{-2} . What is its mass?
(LHR 2013)

Given Data

Force acting on the body = $F = 20 \text{ N}$

Acceleration of the body = $a = 2 \text{ ms}^{-2}$

Required

Mass of the body = $m = ?$

Solution

From Newton's second law of motion

$$F = ma$$

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

By putting the values, we have

$$m = \frac{20}{2}$$

$$m = 10 \text{ kg}$$

Result

Mass of the body = $m = 10 \text{ kg}$

3.2 The weight of a body is 147 N. What is its mass?
(LHR 2013, 2015)

Given Data

Weight of the body = $w = 147 \text{ N}$

Gravitational acceleration = $g = 10 \text{ ms}^{-2}$

Required

Mass of the body = $m = ?$

Solution

As we know that

$$w = mg$$

So $m = \frac{w}{g}$

By putting the values, we have

$$m = \frac{147}{10}$$

$$m = 14.7 \text{ kg}$$

Result

Mass of the body = $m = 14.7 \text{ kg}$

3.3 How much force is needed to prevent a body of mass 10 kg from falling?

Given Data

Mass of the body = 10 kg

Gravitation acceleration = $g = 10 \text{ ms}^{-2}$

Required

Force required to prevent the body from falling = $R = ?$

Solution

As we know that in stable position,

$$R = w = mg$$

By putting the values, we have

$$R = w = 10 \times 10$$

$$R = 100 \text{ N}$$

Result

Force required to prevent the body from falling = $R = 100 \text{ N}$

3.4 Find the acceleration produced by a force of 100 N in a mass of 50 kg. (GRW 2013)

Given Data

Force acting on the body = $F = 100 \text{ N}$

Mass of the body = $m = 50 \text{ kg}$

Required

Acceleration of the body = $a = ?$

Solution

From Newton's second law of motion

$$F = ma$$

$$\text{So } a = \frac{F}{m}$$

By putting the values, we have

$$a = \frac{100}{50}$$

$$a = 2 \text{ ms}^{-2}$$

Result

Acceleration of the body = $a = 2 \text{ ms}^{-2}$

3.5 A body has weight 20 N. How much force is required to move it vertically upwards with an acceleration of 2 ms^{-2} .

Given Data

Weight of the body = 20 N

Acceleration of the body = $a = 2 \text{ ms}^{-2}$

Gravitational acceleration = $g = 10 \text{ ms}^{-2}$

Normal reaction = $R = w = 20 \text{ N}$

Required

Force acting on the body moving vertical upward = $F = ?$

Solution

As we know that

$$w = mg$$

So $m = \frac{w}{g}$

By putting the values, we have

$$m = \frac{20}{10}$$

$$m = 2 \text{ kg}$$

From Newton's second law of motion

$$F = ma$$

By putting the values, we have

$$F = 2 \times 2$$

$$F = 4 \text{ N}$$

Now net force required to move the body upward

= normal reaction + force producing acceleration

$$= 20 \text{ N} + 4 \text{ N} = 24 \text{ N}$$

Result

Force acting on the body moving vertical upward = $F = 24 \text{ N}$

3.6 Two masses 52 kg and 48 kg are attached to the ends of a string that passes over a frictionless pulley. Find the tension in the string and acceleration in the bodies.

Mass of first body = $m_1 = 52 \text{ kg}$

Mass of second body = $m_2 = 48 \text{ kg}$

Gravitational acceleration = $g = 10 \text{ ms}^{-2}$

Required

Acceleration of the bodies = $a = ?$

Tension in the string = $T = ?$

Solution

When the two bodies are moving vertically then acceleration of the bodies is as,

$$a = \frac{(m_1 - m_2)g}{m_1 + m_2}$$

By putting the values in above equation, we have

$$a = \frac{(52 - 48) \times 10}{52 + 48}$$

$$a = \frac{40}{100}$$

$$a = 0.4 \text{ ms}^{-2}$$

When the two bodies are moving vertically then tension in the string is as,

$$a = \frac{2m_1m_2g}{m_1 + m_2}$$

By putting the values in above equation, we have

$$T = \frac{2 \times 52 \times 48 \times 10}{52 + 48}$$

$$T = \frac{49920}{100}$$

$$T = 499.2 \text{ N} = 500 \text{ N}$$

Result

Acceleration of the bodies = $a = 0.4 \text{ ms}^{-2}$

Tension in the string = $T = 500 \text{ N}$

3.7 Two masses 26 kg and 24 kg are attached to the ends of a string which passes over a frictionless pulley. 26 kg is lying over a smooth horizontal table. 24 kg mass is moving vertically downward. Find the tension in the string and the acceleration in the bodies.

Given Data

Mass of the block moving vertically = $m_1 = 24 \text{ kg}$

Mass of the block moving along table = $m_2 = 26 \text{ kg}$

Gravitational acceleration = $g = 10 \text{ ms}^{-2}$

Required

Acceleration of the bodies = $a = ?$

Tension in the string = $T = ?$

Solution

When one body is moving vertically and other body is moving horizontally then acceleration of the bodies is as,

$$a = \frac{m_1 g}{m_1 + m_2}$$

By putting the values in above equation, we have

$$a = \frac{24 \times 10}{24 + 26}$$

$$a = \frac{240}{50}$$

$$a = 4.8 \text{ ms}^{-2}$$

When the two bodies are moving vertically then tension in the string is as,

$$T = \frac{m_1 m_2 g}{m_1 + m_2}$$

By putting the values in above equation, we have

$$T = \frac{24 \times 26 \times 10}{24 + 26}$$

$$T = \frac{6240}{50}$$

$$T = 124.8 \text{ N} = 125 \text{ N}$$

Result

Acceleration in bodies = $a = 4.8 \text{ ms}^{-2}$

Tension in the string = $T = 125 \text{ N}$

3.8 How much time is required to change 22 Ns momentum by a force of 20 N?

(LHR 2014)

Given Data

Change in momentum = $P_f - P_i = 22 \text{ Ns}$

Force applied = $F = 20 \text{ N}$

Required

Time required = $t = ?$

Solution

As we know that

$$F = \frac{P_f - P_i}{t}$$

$$\text{So } t = \frac{P_f - P_i}{F}$$

By putting the values, we have

$$t = \frac{22}{20}$$

$$t = 1.1 \text{ s}$$

Result

$$\text{Time required} = t = 1.1 \text{ s}$$

3.9 How much is the force of friction between a wood block of mass 5 kg and the horizontal marble floor? The coefficient of friction between wood and marble is 0.6.

Given Data

$$\text{Mass of the block} = m = 5 \text{ kg}$$

$$\text{Coefficient of friction} = \mu_s = 0.6$$

Required

$$\text{Force of friction} = F_s = ?$$

Solution

As we know that

$$F_s = \mu_s mg$$

By putting the values, we have

$$F_s = 0.6 \times 5 \times 10$$

$$F_s = 30 \text{ N}$$

Result

$$\text{Force of friction} = F_s = 30 \text{ N}$$

3.10 How much centripetal force is needed to make a body of 0.5 kg to move in a circle of radius 50 cm with a speed of 3 ms⁻¹? (LHR 2012)

Given Data

$$\text{Mass of the body} = m = 0.5 \text{ kg}$$

$$\text{Radius of the circle} = r = 50 \text{ cm} = 0.5 \text{ m}$$

$$\text{Speed of the body} = v = 3 \text{ ms}^{-1}$$

Required

$$\text{Centripetal force} = F_c = ?$$

Solution

As we know that

$$F_c = \frac{mv^2}{r}$$

By putting the values, we have

$$F_c = \frac{0.5 \times (3)^2}{0.5}$$

$$F_c = 9 \text{ N}$$

Result

$$\text{Centripetal force} = F_c = 9 \text{ N}$$