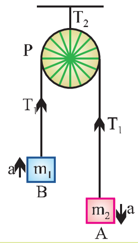


Unit - 3

Newton's Laws Of Motion And Friction

3.1 Inertia

(1) Inherent property of all the bodies by virtue of which they cannot change their state of rest or uniform motion along a straight line by their own is called inertia.

(2) Two bodies of equal mass possess same inertia because it is a factor of mass only.

3.2 Linear Momentum

(1) Linear momentum of a body is the quantity of motion contained in the body.

(2) It is measured as the product of the mass of the body and its velocity *i.e.*, Momentum = mass × velocity.

If a body of mass m is moving with velocity $\vec{v}$ then its linear momentum $\vec{p}$ is given by $\vec{p} = m\vec{v}$.

(3) It is a vector quantity and it's direction is the same as the direction of velocity of the body.

(4) Units : kg-m/sec [S. I.], g cm/sec [C.G. S.]

(5) Dimension : $[MLT^{-1}]$

3.3 Newton's First Law

A body continue to be in its state of rest or of uniform motion along a straight line, unless it is acted upon by some external force to change the state.

(1) If no net force acts on a body, then the velocity of the body cannot change *i.e.*, the body cannot accelerate.

(2) Newton's first law defines inertia and is rightly called the law of inertia. Inertia are of three types :

Inertia of rest, Inertia of motion, Inertia of direction.

3.4 Newton's Second Law

(1) The rate of change of linear momentum of a body is directly proportional to the external force applied on the body and this change takes place always in the direction of the applied force.

(2) If a body of mass m moves with velocity $\vec{v}$ then its linear momentum can be given by $\vec{p} = m\vec{v}$ and if force $\vec{F}$ is applied on a body, then

or $\vec{F} = \frac{d\vec{p}}{dt}$ (K = 1 in C. G. S. and S. I. units)

$\vec{F} = m\vec{a}$ (Force = mass × acceleration)

3.5 Force

(1) Force is an external effect in the form of a push or pulls which :

(i) Produces or tries to produce motion in a body at rest.

(ii) Stops or tries to stop a moving body.

(iii) Changes or tries to change the direction of motion of the body.

(2) Dimension : Force = mass × acceleration

$$[F] = [M][LT^{-2}] = [MLT^{-2}]$$

(3) Units : Absolute units : (i) Newton (S.I.) (ii) Dyne (C.G.S.)

Gravitational units : (i) Kilogram-force (M.K.S.) (ii) Gram-froce (C.G.S.)

(4) $\vec{F} = m\vec{a}$ formula is valid only if force is changing the state of rest or motion and the mass of the body is constant and finite.

(5) if m is not constant $\vec{F} = \frac{d}{dt}(m\vec{v}) = m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt}$.

(6) No force is required to move a body uniformaly along a straight line.

$\vec{F} = ma$, $\therefore$ $\vec{F} = 0$ (As $a = 0$)

(7) When force is written without direction then positive force means repulsive while negative force means attractive.

(8) Out of so many natural forces nuclear force is strongest while gravitational force weakest.

(9) **Central force :** If a position dependent force is always directed towards or away from a fixed point it is said to be central otherwise non-central.

(10) **Conservative or non-conservative force :** If under the action of a force the work done in a round trip is zero or the work is path independent, the force is said to be conservative otherwise non-conservative.

Example : Conservative force : Gravitational force, electric force, elastic force.

Non-conservative force : Frictional force, viscous force.

(11) **Common forces in mechanics :**

(i) **Weight :** Weight of an object is the force with which earth attracts it. (W = mg)

(ii) **Reaction or Normal force :** When a body is placed on a rigid surface, the body experience a force which is perpendicular to the surfaces in contact. Then force is called 'Normal force' or 'Reaction'.

(iii) **Tension :** The force exerted by the end of taut string, rope or chain against pulling (applied) force is called the tension. The direction of tension is so as to pull the body.

(iv) **Spring force :** Every spring resists any attempt to change its length. This resistive force increases with changes in length. Spring force is given by $F = -Kx$; where x is the change in length and K is the spring constant (unit N/m).

3. 6 Equilibrium of Concurrent Force

(1) If all the force working on a body are acting on the same point, then they are said to be concurrent.

(2) A body, under the action of concurrent forces, is said to be in equilibrium, when there is no change in the state of rest or of uniform motion along a straight line.

(3) The condition for the equilibrium of a body is that the vector sum of all the forces acting on the body must be zero.

3.7 Newton's Third Law

To every action, there is always an equal (in magnitude) and opposite (in direction) reaction.

If $\vec{F}_{AB}$ = force exerted on body A by body B (Action) and $\vec{F}_{BA}$ = force exerted on body B by body A (Reaction)

Then according to Newton's third law of motion $\vec{F}_{AB} = -\vec{F}_{BA}$

Example :

(i) A book lying on a table exerts a force on the table which is equal to the weight of the book. This is the force of action.

(ii) Swimming is possible due to third law of motion.

(iii) When a gun is fired, the bullet moves forward (action). The gun recoils backward (reaction).

3.8 Frame of Reference

(1) A frame in which an observer is situated and makes his observations is known as his 'Frame of reference'.

It is associated with a co-ordinate system.

(2) Frame of reference are of two types : (i) Inertial frame of reference (ii) Non-inertial frame of reference.

(i) Inertial frame of reference :

(a) A frame of reference which is at rest or which is moving with a uniform velocity along a straight line is called an inertial frame of reference.

(b) In inertial frame of reference Newton's laws of motion holds good.

(c) Ideally no inertial frame exist in universe. For practical purpose a frame of reference may be considered as inertial it it's acceleration is negligible with respect to the acceleration of the object to be observed.

Example : The lift at rest, lift moving (up or down) with constant velocity.

(ii) Non inertial frame of reference :

(a) Accelerated frame of references are called non-inertial frame of reference.

(b) Newton's laws of motion are not applicable in non-inertial frame of reference.

Example : Car moving in uniform circular motion, lift which is moving upward or downward with some acceleration, plane which is taking off.

3.9 Impulse

(1) When a large force works on a body for very small time interval, it is called impulsive force.

An impulsive force does not remain constant, but changes first from zero to maximum and then from maximum to zero. In such case we measure the total effect of force.

(2) Impulse of a force is a measure of total effect of force.

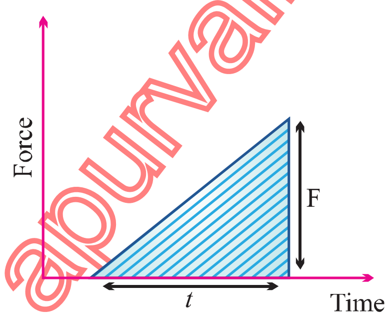
(3) $\vec{I} = \int_{t_1}^{t_2} \vec{F}\, dt.$

(4) Impulse is a vector quantity and its direction is same as that of force.

(5) Dimension : $[MLT^{-1}]$

(6) Units : Newton second or Kg-ms^{-1} (S. I.) and Dyne second or gm cm s^{-1} (C.G. S.)

(7) Force-time graph- Impulse is equal to the area under F-t curve.



I = Area between curve and time axis = $\frac{1}{2}Ft$

(8) If F_{av} is the average magnitude of the force, then

$$I = \int_{t_1}^{t_2} F dt = F_{av} \int_{t_1}^{t_2} dt = F_{av} \Delta t$$

(9) From Newton's second law, $\vec{F} = \frac{d\vec{p}}{dt}$

or $\int_{t_1}^{t_2} F dt = \int_{p_1}^{p_2} d\vec{p} \Rightarrow \vec{I} = \vec{p}_2 - \vec{p}_1 = \Delta\vec{p}$

i.e., The impulse of a force is equal to the change in momentum.

This statement is known as Impulse momentum theorem.

(10) *Examples.* Hitting, kicking, catching, jumping, diving, collision etc.

In all these cases an impulse acts, $I = \int F\,dt = F_{av}.\ \Delta t = \Delta p$ = constant So if time of contact A t is increased, average force is decreased (or diluted) and vice-versa.

(i) In catching a ball a player by drawing his hands backwards increases the time of contact and so, lesser force acts on his hands and his hands are saved from getting hurt.

(ii) China wares are wrapped in straw or paper before packing.

3.10 Law of Conservation of Linear Momentum

If no external force acts on a system (called isolated) of constant mass, the total momentum of the system remains constant with time.

(1) According to this law for a system of particles $\vec{F} = \frac{d\vec{p}}{dt}$

In the absence of external force $\vec{F} = 0$ then $\vec{p}$ = constant.

i.e., $\vec{p} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \dots$ = constant.

(2) Law of conservation of linear momentum is independent of frame of reference though linear momentum depends on frame of reference.

(3) Practical applications of the law of conservation of linear momentum

(i) When a man jumps out of a boat on the shore, the boat is pushed slightly away from the shore,

(ii) A person left on a frictionless surface can get away from it by blowing air out of his mouth or by throwing some object in a direction opposite to the direction in which he wants to move,

(iii) Recoiling of a gun-Tor bullet and gun system, the force exerted by trigger will be internal so the momentum of the system remains unaffected.

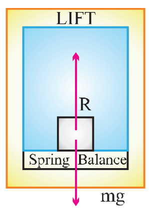
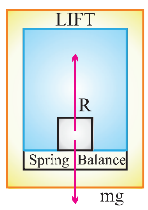
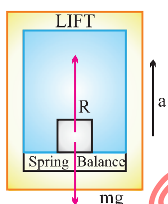
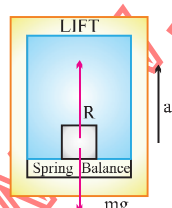
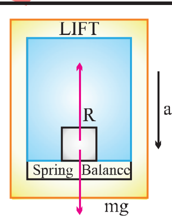
3.11 Free Body Diagram

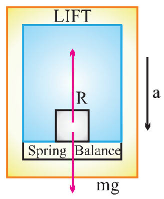
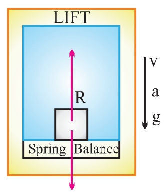
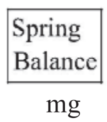
In this diagram the object of interest is isolated from its surroundings and the interactions between the object and the surroundings are represented in terms of forces.

3.12 Apparent Weight of a Body in a Lift

When a body of mass m is placed on a weighing machine which is placed in a lift, then actual weight of the body is mg.

This acts on a weighing machine which offers a reaction R given by the reading of weighing machine. The reaction exerted by the surface of contact on the body is the apparent weight of the body.

Condition	Figure	velocity	Acceleration	Reaction	Conclusion
Lift is at rest		$v = 0$	$a = 0$	$R - mg = 0$ $\therefore R = mg$	Apparent weight = Actual weight
Lift moving upward or downward with constant velocity		v = constant	$a = 0$	$R - mg = 0$ $\therefore R = mg$	Apparent weight = Actual weight
Lift accelerating upward at the rate of 'a'		v = variable	$a < g$	$R - mg = ma$ $\therefore R = m(g+a)$	Apparent weight > Actual weight
Lift accelerating upward at the rate of 'g'		V = variable	$a = g$	$R - mg = mg$ $R = 2mg$	Apparent weight = 2 Actual weight
Lift accelerating downward at the rate of 'a'		V = variable	$a < g$	$mg - R = ma$ $\therefore R = m(g - a)$	Apparent weight < Actual weight

Lift accelerating downward at the rate of 'g'		V = variable $a = g$	$mg - R = mg$ $R = 0$	Apparent weight = Zero (weightlessness)
Lift accelerating downward at the rate of $a(> g)$		V = variable $a > g$	$mg - R = ma$ $R = mg - ma$ $R = -ve$	Apparent weight negative means the body will rise from the floor of the
				Lift and stick to the ceilling of the lift.

3.13 Acceleration of Block on Horizontal Smooth Source

(1) When a pull is acting at an angle (θ) to the horizontal (upward)

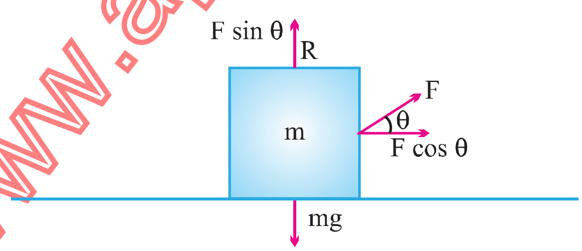
$$R + F \sin\theta = mg$$

$$\Rightarrow \quad R = mg - F \sin\theta$$

and

$$F \cos\theta = ma$$

$$a = \frac{F\cos\theta}{m}$$



3.14 Acceleration of Block on Smooth Inclined Plane

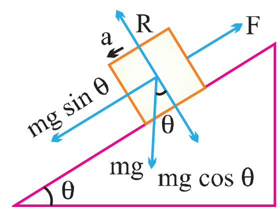
(1) When inclined plane is at rest.

Normal reaction $R = mg \cos\theta$

Force along a inclined plane $F = mg \sin\theta$

$$ma = mg \sin\theta$$

$$a = g \sin \theta$$

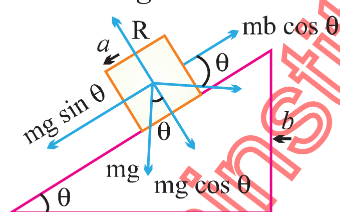


(2) When a inclined plane given a horizontal acceleration '*b*'. Since the body lies in an accelerating frame, an inertial acts on it in the opposite direction.

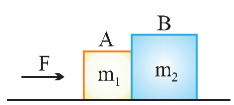
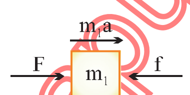
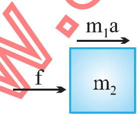
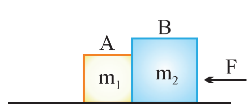
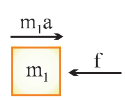
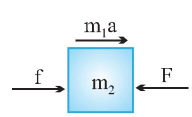
Normal reaction $\qquad R = mg \cos \theta + mb \sin \theta$

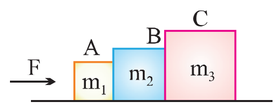
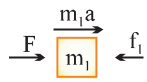
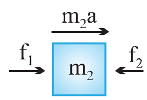
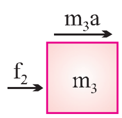
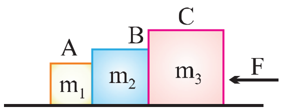
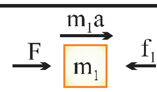
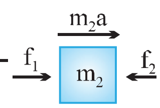
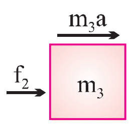
and $\qquad ma = mg \sin \theta - mb \cos \theta$

$$a = g \sin \theta - b \cos \theta$$

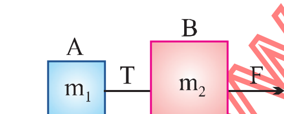
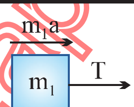
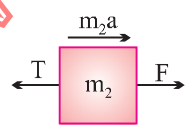
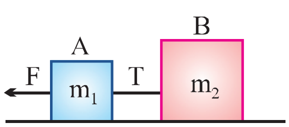
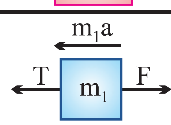
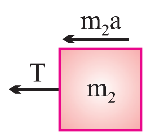


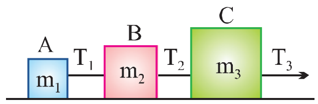
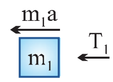
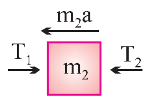
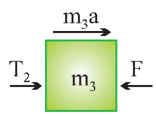
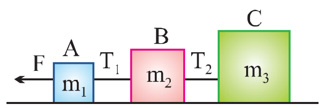
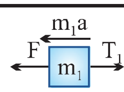
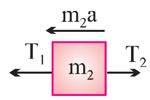
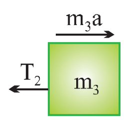
3.15 Motion of Block in Contact

Condition	Free body diagram	Equation	Force and acceleration
		$F - f = m_1 a$	$a = \dfrac{F}{m_1 + m_2}$
		$f = m_2 a$	$f = \dfrac{m_2 F}{m_1 + m_2}$
		$f = m_1 a$	$a = \dfrac{F}{m_1 + m_2}$
		$F - f = m_2 a$	$f = \dfrac{m_1 F}{m_1 + m_2}$

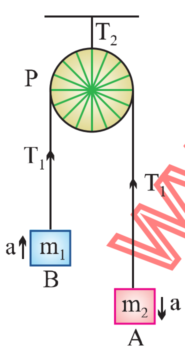
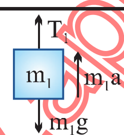
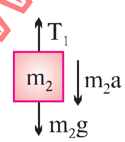
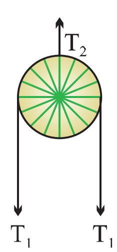
	  	$F - f_1 = m_1 a$ $f_1 - f_2 = m_2 a$ $f_2 = m_3 a$	$a = \frac{F}{m_1 + m_2 + m_3}$ $f_1 = \frac{(m_2 + m_3)F}{m_1 + m_2 + m_3}$ $f_2 = \frac{m_3 F}{m_1 + m_2 + m_3}$
	  	$f_1 = m_1 a$ $f_2 - f_1 = m_2 a$ $F - f_2 = m_2 a$	$a = \frac{F}{m_1 + m_2 + m_3}$ $f_1 = \frac{m_1 F}{m_1 + m_2 + m_3}$ $f_2 = \frac{(m_1 + m_2)F}{m_1 + m_2 + m_3}$

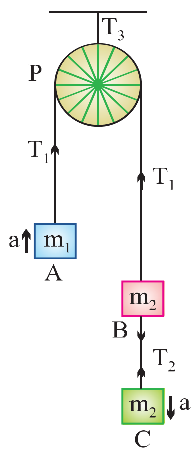
3.16 Motion of Blocks Connected by Mass Less String

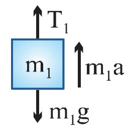
Condition	Free body diagram	Equation	Tension and acceleration
	 	$T = m_1 a$ $F - T = m_2 a$	$a = \frac{F}{m_1 + m_2}$ $T = \frac{m_1 F}{m_1 + m_2}$
	 	$F - T = m_1 a$ $T = m_2 a$	$a = \frac{F}{m_1 + m_2}$ $T = \frac{m_2 F}{m_1 + m_2}$

		$T_1 = m_1 a$	$a = \dfrac{F}{m_1 + m_2 + m_3}$
		$T_2 - T_1 = m_2 a$	$T_1 = \dfrac{m_1 F}{m_1 + m_2 + m_3}$
		$F - T_2 = m_3 a$	$T_2 = \dfrac{(m_1 + m_2)F}{m_1 + m_2 + m_3}$
		$F - T_1 = m_1 a$	$a = \dfrac{F}{m_1 + m_2 + m_3}$
		$T_1 - T_2 = m_2 a$	$T_1 = \dfrac{(m_2 + m_3)F}{m_1 + m_2 + m_3}$
		$T_2 = m_3 a$	$T_2 = \dfrac{m_3 F}{m_1 + m_2 + m_3}$

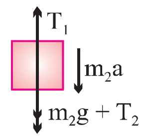
3.17 Motion of Connected Block over A Pulley

Condition	Free body diagram	Equation	Tension and acceleration
		$m_1 a = T_1 - m_1 g$	$T_1 = \dfrac{2m_1 m_2}{m_1 + m_2} g$
		$m_2 a = m_2 g - T_1$	$T_2 = \dfrac{4m_1 m_2}{m_1 + m_2} g$
		$T_2 = 2T_1$	$a = \left[\dfrac{m_2 - m_1}{m_1 + m_2}\right] g$

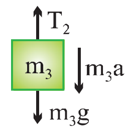




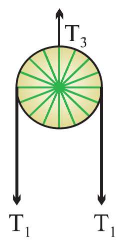
$m_1 a = T_1 - m_1 g$ $\qquad T_1 = \frac{2m_1[m_2 + m_3]}{m_1 + m_2 + m_3}g$



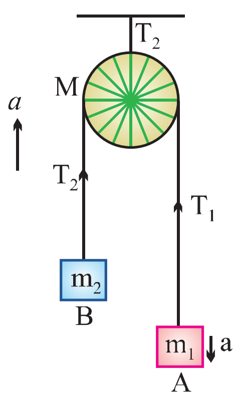
$m_2 a = m_2 g + T_2 - T$ $\qquad T_2 = \frac{2m_1 m_3}{m_1 + m_2 + m_3}g$

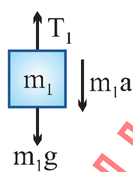


$m_3 a = m_3 g - T_2$ $\qquad T_3 = \frac{4m_1 m_3}{m_1 + m_2 + m_3}g$



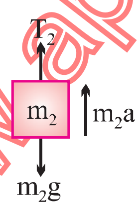
$T_3 = 2T_1$ $\qquad a = \frac{[(m_2 + m_3) - m_1]g}{m_1 + m_2 + m_3}$





$m_1 a = m_1 g - T_1$ $\qquad a = \frac{m_1 + m_2}{m_1 + m_2 + \frac{M}{2}}$

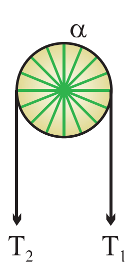
$m_2 a = T_2 - m_2 g$ $\qquad T_1 = \frac{m_1\left[2m_2 + \frac{M}{2}\right]}{m_1 + m_2 + \frac{M}{2}}g$



Torque

$= (T_1 - T_2)R = 1\alpha$

$(T_1 - T_2)R = 1\frac{a}{R}$



$(T_1 - T_2)R = \frac{1}{2}$ $\qquad T_2 = \frac{m_2\left[2m_1 + \frac{M}{2}\right]}{m_1 + m_2 + \frac{M}{2}}g$

$MR^2\frac{a}{R}$

$T_1 - T_2 = \frac{Ma}{2}$

3.18 Friction (Introduction)

If we slide or try to slide a body over a surface the motion is resisted by a bonding between the body and the surface. This resistance is represented by a single force and is called friction.

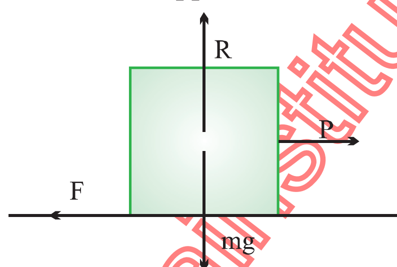
The force of friction is parallel to the surface and opposite to the direction of intended motion.

3.19 Types of Friction

(1) Static friction : The opposing force that comes into play when objects are at rest.

(i) In this case static friction F = P.

(ii) Static friction is a self-adjusting force because it changes itself in accordance with the applied force.



(2) Limiting friction : The maximum value of static friction upto which body does not move is called limiting friction.

(i) The magnitude of limiting friction between any two bodies in contact is directly proportional to the normal reaction between them.

$$F_1 \propto R \text{ or } F_1 = u_s R$$

(ii) Direction of the force of limiting friction is always opposite to the direction in which one body is at the verge of moving.

(iii) Coefficient of static friction :

(a) μ_s is called coefficient of static friction.

(b) Dimension : $[M^0L^0T^0]$

(c) Unit : It has no unit.

(d) Value of μ_s lies in between 0 and 1

(e) Value of μ depends on material and nature of surfaces in contact.

(f) Value of μ does not depend upon apparent area of contact.

(3) **Kinetic or dynamic friction :** If the applied force sets the body in motion, the friction opposing the motion is called kinetic friction.

(i) Kinetic friction depends upon the normal reaction friction.

$F_k \propto R$ or $F_k = \mu_k R$ where μ_k is called the coefficient of kinetic friction.

(ii) Kinetic friction is always lesser than limiting friction $F_k < F_1$, ... $\mu_k < \mu_s$

Thus we require more force to start a motion than to maintain it against friction. This is because when motion has actually started, irregulrities of one surface have little time to get locked again into the irregularities of the other surface.

(iv) Types of kinetic friction : (a) Sliding friction (b) Rolling friction

- Rolling friction is directly proportional to the normal reaction (R) and inversely proportional to the radius (r) of the rolling cylinder or whell.

$$F_{\text{Rrolling}} = \mu_r \frac{R}{r}$$

μ is called coefficient of rolling friction. It would have the dimensions of length and would be measured in *metre*.

- Rolling friction is often quite small as compared to the sliding friction.
- In rolling the surfaces at contact do not rub each other.
- The velocity of point of contact with respect to the surface remains zero all the times.

3.20 Graph Between Applied Force and Force of Friction

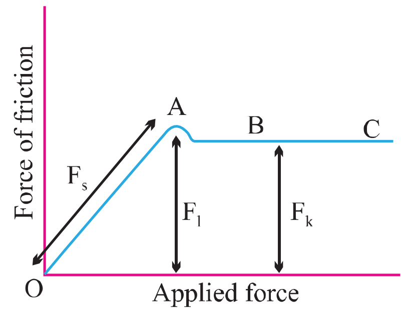
(1) Part OA = static friction (F_s).

(2) At point A = limiting friction (F_1).

(3) Beyond A, the force of friction is seen to decrease slightly.

The portion BC = kinetic friction (F_k).

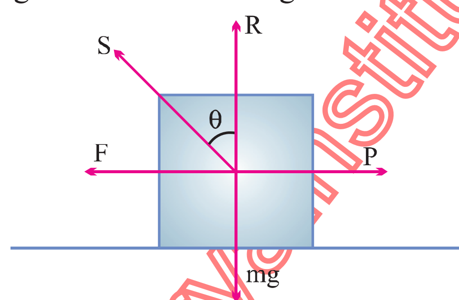
(4) As the portion BC of the curve is parallel to x axis therefore kinetic friction does not change with the applied force.



3.21 Angle of Friction

Angle of friction may be defined as the angle which the resultant limiting friction and normal reaction makes with the normal reaction.

By definition angle θ is called he angle of friction $\tan\theta = \frac{F}{R}$



$\therefore$ $\tan\theta = \mu$ [As we know $\frac{F}{R} = \mu$]

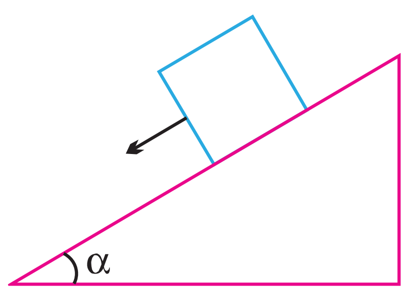
or $\theta = \tan^{-1}(\mu)$

3. 22 Angle of Repose

Angle of repose is defined as the angle of the inclined plane with horizontal such that a body placed on it is just begins to slide.

If α is called the angle of repose.

$\alpha = \theta$ *i.e.*, angle of repose = angle of friction.



UNIT-III (Laws of Motion)

1 Mark Questions

1. A passenger sitting in a car at next, pusher the car from within. The car doesn't move, why ?
2. Give the magnitude and directions of the net force acting on a rain drop falling with a constant speed.
3. Why the passengers in a moving car are thrown outwards when it suddenly takes a turn ?
4. You accelerate your car forward. What is the direction of the frictional force on a package resting on the floor of the car ?
5. What is the purpose of using shockers in a car ?
6. Why are tyres made of rubber not of steel ?
7. Wheels are made circular. Why ?
8. If a ball is thrown up in a moving train, it comes back to the thrower's hands. Why ?
9. Calculate the force acting on a body which changes the momentum of the body at the rate of 1 kg-m/s^2.
10. On a rainy day skidding takes place along a curved path. Why ?
11. Why does a gun recoils when a bullet is being fired ?
12. Why is it difficult to catch a cricket ball than a tennis ball even when both are moving with the same velocity ?
13. The distance travelled by a moving body is directly proportional to time. Is any external force acting on it ?
14. Calculate the impulse necessary to stop a 1500 kg car moving at a speed of 25 ms^{-1}.
15. Lubricants are used between the two parts of a machine. Why ?
16. What provides the centripetal force to a car taking a turn on a level road ?
17. A body is acted upon by a number of external forces. Can it remain at rest ?
18. Bodies of larger mass need greater initial effort to put them in motion. Why ?
19. An athlete runs a certain distance before taking a long jump. Why ?
20. Action and reaction forces do not balance each other. Why. ?

21. The wheels of vehicles are provided with mudguards. Why ?

22. China wares are wrapped in straw paper before packing. Why ?

23. Why is it difficult to walk on a sand ?

24. The outer edge of a curved road is generally raised over the inner edge. Why ?

25. Explain why the water doesn't fall even at the top of the circle when the bucket full of water is upside down rotating in a vertical circle ?

26. Why does a speedy motor cyclist bends towards the centre of a circular path while taking a turn on it ?

27. An impulse is applied to a moving object with a force at an angle of 20° w.r.t. velocity vector, what is the angle between the impulse vector and change in momentum vector ?

2 Marks Questions

28. A man getting out of a moving bus runs in the same direction for a certain distance. Comment.

29. If the net force acting upon the particle is zero, show that its linear momentum remains constant.

30. A force of 36 dynes is inclined to the horizontal at an angle of 60°. Find the acceleration in a mass of 18 g that moves in a horizontal direction.

31. The motion of a particle of mass m is described by $h = ut + 1/2\, gt^2$. Find the force acting on particle. (F = mg)

32. A particle of mass 0.3 kg is subjected to a force of $F = -kx$ with $k = 15$ Nm^{-1} . What will be its initial acceleration if it is released from a point 20 cm away from the origin ?

33. A 50 g bullet is fired from a 10 kg gun with a speed of 500 ms^{-1}. What is the speed of the recoil of the gun.

34. Smooth block is released at rest on a 45° incline and then slides a distance d. If the time taken of slide on rough incline is n times as large as that to slide than on a smooth incline. Show that coefficient of friction. $\mu = \left(1 - \frac{1}{n^2}\right)$.

35. A spring balance is attached to the ceiling of a lift. When the lift is at rest spring balance reads 49 N of a body hang on it. If the lift moves :

(i) Downward

(ii) upward, with an acceleration of 5 ms^{-2}

(iii) with a constant velocity.

What will be the reading of the balance in each case ?

36. It is easier to pull a roller than to push it. Why ? (using vector diagram)

37. A horse cannot pull a cart and run in empty space. Why ? (using diagram)

38. A bob of mass 0.1 kg hung from the ceiling of room by a string 2 m long is oscillating. At its mean position the speed of a bob is 1 ms^{-1}. What is the trajectory of the oscillating bob if the string is cut when the bob is

(i) At the mean position

(ii) At its extreme position.

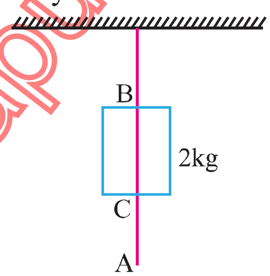
39. Define force of friction. How does ball bearing reduce friction ?

40. Define angle of friction and angle of repose.

41. A block placed on a rough horizontal surface is pulled by a horizontal force F. Let f be the force applied by the rough surface on the block. Plot a graph of f versus F.

42. A mass of 2 kg is suspended with thread AB. Thread CD of the same type is attached.To the other end of 2 kg mass.

(i) Lower end of the lower thread is pulled gradually, hander and hander is the downward direction so as to apply force on AB. Which of the thread will break & why ?



(ii) If the lower thread is pulled with a jerk, what happens ?

43. A block of mass M is held against a rough vertical wall by pressing it with a finger. If the coefficient of friction between the block and the wall is μ and the acceleration due to gravity is g, calculate the minimum force required to be applied by the finger to held the block against the wall ?

3 Marks Questions & Numericals

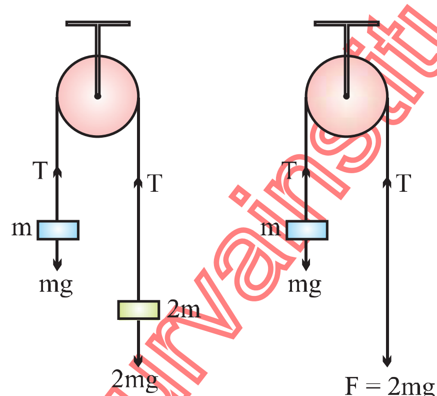
44. A block of mass 500 g is at rest on a horizontal table. What steady force is required to give the block a velocity of 200 cms^{-1} in 4 s ?

45. A force of 98 N is just required to move a mass of 45 kg on a rough horizontal surface. Find the coefficient of friction and angle of friction ?

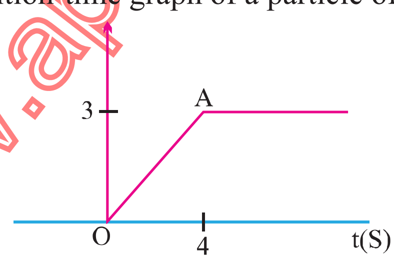
46. Calculate the force required to move a train of 2000 quintal up on an incline plane of 1 in 50 with an acceleration of 2 ms^{-2}. The force of friction per quintal is 0.5 N.

47. A force of 100 N gives a mass m_1, an acceleration of 10 ms^{-2} and of 20 ms^{-2} to a mass m_2. What acceleration must be given to it if both the masses are tied together ?

48. The pulley arrangement of fig. are identical. The mass of the rope is negligible. In (a) mass *m* is lifted up by attaching a mass (2 m) to the other end of the rope. In (b), *m* is lifted up by pulling the other end of the rope with a constant downward force F = 2 mg. In which case, the acceleration of *m* is more ?



49. Fig. shows the position-time graph of a particle of mass 4 kg. What is the



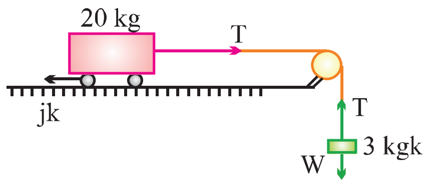
(a) Force on the particle for $t < 0$, $t > 4s$, $0 < t < 4s$?

(b) Impulse at $t = 0$ and $t = 4s$?

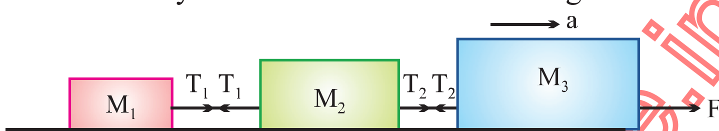
(Consider one dimensional motion only)

50. What is the accleration of the block and trolly system as the fig., if the coefficient of kinetic friction between the trolly and the surface is 0.04 ? Also Calculate friction in the string.

Take g = 10 m/s^2, mass of the string is negligible.



51. Three blocks of masses m_1 = 10 kg, m_2 = 20 kg are connected by strings on smooth horizontal surface and pulled by a force of 60 N. Find the acceleration of the system and frictions in the string.



52. The rear side of a truck is open and a box of 40 kg mass is placed 5m away from the open end. The coefficient of friction between the box and the surface below it is 0.15 on a straight road, the truck starts from rest and accelerates with 2 m/s^2. At what distance from the starting point does the box fall off the truck ? (ignore the size of the box)

53. A block slides down as incline of 30° with the horizontal. Starting from rest, it covers 8 m in the first 2 seconds. Find the coefficient of static friction.

54. A helicopter of mass 2000 kg rises with a vertical acceleration of 15 m/s^2. The total mass of the crew and passengers is 500 kg. Give the magnitude and direction of the :

(i) Force on the floor of the helicopter by the crew and passenger.

(ii) Action of the rotor of the helicopter on the surrounding air

(iii) Force on the helicopter due to the surrounding air (g =10 m/s^2)

55. A rectangular box lies on a rough inclined surface. The coefficient of friction between the surface and the box is (μ). Let the mass of the box be m.

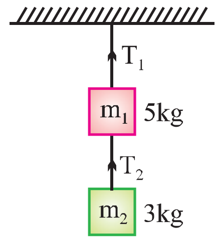
(a) At what angle of inclination θ of the plane to the horizontal will the box just start to slide down the plane ?

(b) What is the force acting on the box down the plane, if the angle of inclination of the plane is increased to $\alpha > \theta$.

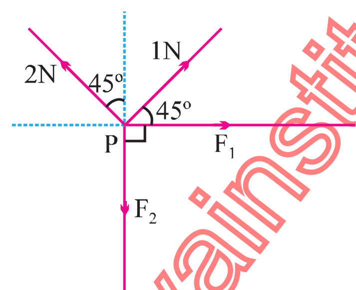
(c) What is the force needed to be applied upwards along the plane to make the box either remain stationary or just move up with uniform speed ?

(d) What is the force needed to be applied upwards along the plane to make the box move up the plane with acceleration a ?

56. Two masses of 5 kg and 3 kg are suspended with help of mass less inextensible string as shown. Calculate T_1 and T_2 when system is going upwards with acceleration m/s^2. (Use $g = 9.8$ m/s^2)



57. There are few forces acting at a Point P produced by strings as shawn, which is at rest, Find the forces F_1 & F_2



58. A hunter has a maching gun that can fire 50g bullets with a velocity of 150 ms^{-1} . A 60 kg tiger springs at him with a velocity of 10 ms^{-1}. How many bullets must the hunter fire into the target so as to stop him in his track ?

59. Two blocks of mass 2 kg and 5 kg are connected by an ideal string passing over a pulley. The block of mass 2 kg is free to slide on a surface inclined at an angle of 30° with the horizontal whereas 5 kg block hangs freely. Find the acceleration of the system and the tension in the string.

60. Show that Newton's second law of motion is the real law of motion.

5 Marks Questions

61. Define the principle of conservation of linear momentum. Deduce the law of conservation of linear momentum from Newton's third law of motion.

62. Why circular roads are banked ? Derive an expression for angle of banking for safe circular turn. Consider that coefficient of friction between the tyre and road is μ.

63. Obtain an expression for minimum velocity of projection of a body at the lowest point for looping a vertical loop.

64. Show that the area under the force-time graph gives the magnitude of the impulse of the given force for the following case when (i) force is constant (ii) variable force.

65. Derive an expression for acceleration of a body down a rough inclined plane ? (Sliding only)

66. With the help of suitable example, explain the terms static friction, limiting friction and kinetic friction. Show that static friction is a self adjusting force. Also plot the graph showing the variation between applied force F and force of friction *f*.

Unit-III (LAWS OF MOTION AND FRICTION)

Solutions

1. For motion, there should be external force.
2. as $\vec{a} = 0$ so $\vec{F} = 0$.
3. Due to inertia of direction.
4. The package in the accelerated car (a non inertial frame) experiences a Pseudo force in a direction opposite to that of the motion of the car. The frictional force on the package which acts opposite to this pseudo force is thus in the same direction (forward) as that of the car.
5. To decrease the impact of force by increasing the time for which force acts.
6. Since coefficient of friction between rubber and road is less than the coefficient of friction between sheet and road.
7. Rolling friction is less than sliding friction.
8. Both during its upward and downward motion, the ball continues to move inertia of motion with the same horizontal velocity as the train. In this period, the ball covers the same horizontal distance as the train and so it comes back to the thrower's hand.
9. As F = rate change of momentum

$$F = 1\text{kg-m/s}^2 = 1\text{N}$$

10. As the friction between the tyres and road reduces on a rainy day.

11. To conserve momentum.

12. Being heavier, cricket ball has higher rate of change of momentum during motion so more force sumed.

13. As $s \propto t$, so acceleration $a = 0$, therefore, no external force is acting on the body.

14. Use formula I = change in momentum = $m(v - u)$

(**Ans**. – 37500 Ns)

15. To reduce friction and so to reduce wear & tear.

16. Force of friction between the tyre and road provides centripetal force.

17. Yes, if the external forces acting on the body can be represented in magnitude and direction by the sides of a closed polygon taken in the same order.

18. As F = ma so for given a, more force will be required to put a large mass in motion.

19. So that inertia of motion may help him in his muscular efforts to take a longer jump.

20. As they acts on different bodies.

21. When the wheel rotates at a high speed, the mud sticking to the wheel flies off tangentially, this is due to inertia of direction. If order that the flying mud does not spiral the clothes of passer by the wheels are provided with mudguards .

22. The straw paper between the China ware increases the Time of experiencing the jerk during transportation. Hence impact of force reduces on China wares.

23. Less reaction force.

24. In addition to the frictional force, a component of reaction force also provides centripetal force.

25. Weight of the water and bucket is used up in providing the necessary centripetal force at the top of the circle.

26. So that in addition of the frictional force, the horijontal component of the normal reaction also provides the necessary centripetal forces.

27. Impulse and change in momentum are along the same direction. Therefore angle between these two vectors is zero.

28. Due to inertia of motion.

29. As $$F \propto \frac{dP}{dt}$$

when $$F = 0, \frac{dP}{dt} = 0 \text{ so } P = \text{constant}$$

30. $$F = 36 \text{ dyne at an angle of } 60°$$

$$F_x = F \cos 60° = 18 \text{ dyne}$$

$$F_x = ma_x$$

So $$a_x = \frac{F_x}{m} = 1 \text{ cm/s}^2$$

31. $h = ut + \frac{1}{2}gt^2$

find a by differentiating h twice w.r.t.

$$a = g$$

as F = ma so F = mg (answer)

32. As F = ma so F = $-kx = ma$

$$a = \frac{-kx}{m}$$

for x = 20 cm, $\Rightarrow$ $a = -10$ m/s^2

33. Initial momentum = 0

using conservation of linear momentum

$$mv + MV = 0$$

$$V = \frac{-mv}{M}$$

$\Rightarrow$ $$V = 2 \cdot 5 \text{ m/s}$$

34. When there is no friction, the block slides down the inclined plane with acceleration.

$$a = g \sin \theta$$

when there is friction, the downward acceleration of the block is

$$a' = g (\sin \theta - \mu \cos \theta)$$

As the block slides a distance d in each case so

$$d = \frac{1}{2}at^2 = \frac{1}{2}a't'^2$$

$$\frac{a}{a'} = \frac{t'^2}{t^2} = \frac{(nt)^2}{t^2} = n^2$$

or $$\frac{g\sin\theta}{g(\sin\theta-\mu\cos\theta)}=n^2$$

Solving, we get (Using $\theta = 45°$)

$$\mu=1-\frac{1}{n^2}$$

35. (i) $R = m(g-a)$

weight $= 49$ N

so $m = \frac{49}{9.8} = 5$ kg

$R = 5(9{\cdot}8 - 5)$

$R = 24$N

(ii) $R = m(g+a)$

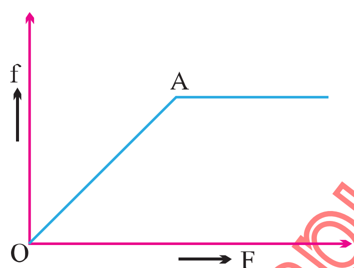
$R = 5(9{\cdot}8 + 5)$

$R = 74$ N

(iii) as $a = 0$ so $R = mg = 49$N

38. (i) Parabolic, (ii) vertically downwards

41.



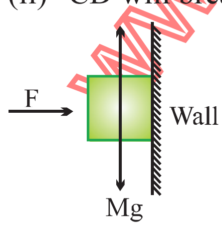
Uuto point A, $f = F$ (50 Long as block is stationary)

beyond A, when F increases, block starts moving f remains constant.

42. (i) Thread AB breaks down

(ii) CD will break.

43.



For the block not to fall $f = Mg$

But $f = \mu R = \mu F$ so

$\mu F = Mg$

$$F = \frac{Mg}{\mu}.$$

44. Use $F = ma$

$$a = \frac{v - u}{t} = \frac{200 - 0}{4} = 50 \text{ cm/s}^2$$

$$F = 500 \times 50 = 25{,}000 \text{ dyne.}$$

45. F = 98 N, R = 45 × 9·8 = 441 N

$$\mu^2 = \frac{F'}{R} = 0.22$$

Angle of friction $\theta = \tan^{-1}\mu = \tan^{-1} 0{\cdot}22 = 12°24'$

46. Force of friction = 0·5 N per quintal

$$f = 0{\cdot}5 \times 2000 = 1000 \text{ N}$$

$$m = 2000 \text{ quintals} = 2000 \times 100 \text{ kg}$$

$$\sin\theta = \frac{1}{50},\ a = 2 \text{ m/s}^2$$

In moving up an inclined plane, force required against gravity

$$= mg\sin\theta = 39200 \text{ N}$$

And force required to produce acceleration $= ma$

$$= 2000 \times 100 \times 2 = 40{,}0000 \text{ N}$$

Total force required = 1000 + 39,200 + 40,0000

= 440200 N.

47. Suppose, a = acceleration produced if m_1 and m_2 are tied together,

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

Let a_1 and a_2 be the acceleration produced in m_1 and m_2, respectively.

$\therefore$ $a_1 = 10 \text{ ms}^{-2}$, $a_2 = 20 \text{ ms}^{-2}$ (given)

Again $m_1 = \frac{F}{a_1}$ and $m_2 = \frac{F}{a_2}$

$\Rightarrow$ $$m_1 = \frac{100}{10} = 10 \text{ ms}^{-2}$$

and $$m_2 = \frac{100}{20} = 5 \text{ ms}^{-2}$$

$\therefore$ $$m_1 + m_2 = 10 + 5 = 15$$

So, $$a = \frac{F}{m_1 + m_2} = \frac{100}{15} = \frac{20}{3}$$

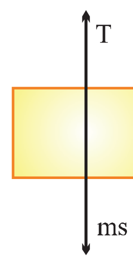
$$= 6.67 \text{ ms}^{-2}$$

48. Case (a) :

$$a = \left(\frac{2m - m}{2m + m}\right)g$$

$$a = \frac{g}{3}$$

Case (b) : FBD of mass *m*



$$ma' = T - mg$$

$$ma' = 2mg - mg$$

$$\Rightarrow \qquad ma' = mg$$

$$a' = g$$

So in case (b) acceleration of *m* is more.

49. (a) For $t < 0$. No force as Particles is at rest.

For $t > 4s$, No force again particle comes at rest.

For $0 < t < 4s$, as slope of OA is constant so velocity constant *i.e.*, $a = 0$, so force must be zero.

(b) Impulse at $t = 0$

Impulse = change in momentum

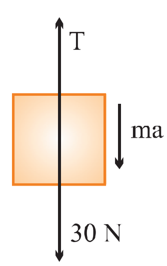
$$I = m(v - u) = 4(0 - 0{\cdot}75) = 3 \text{ kg ms}^{-1}$$

Impulse at $t = 4s$

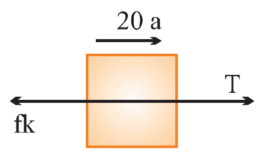
$$I = m(v - u) = 4(0 - 0.75) = -3 \text{ kg ms}^{-1}$$

50. Free body diagram of the block

$$30 - T = 3a \qquad \text{...(i)}$$



Free body diagram of the trolley



$$T - f_k = 20\,a \qquad \ldots\text{(ii)}$$

where $\quad f_k = \mu_k\,N = 0{\cdot}04 \times 20 \times 10 = 8\text{ N}$

Solving (i) & (ii),

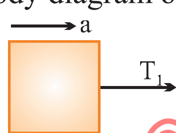
$$a = 0{\cdot}96\text{ m/s}^2 \;\text{ and } T = 27{\cdot}2\text{ N}$$

51. All the blocks more with common acceleration a under the force F = 60 N.

$$F = (m_1 + m_2 + m_3)a$$

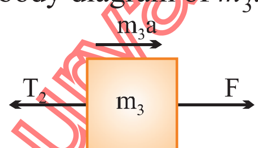
$$a = \frac{F}{(m_1 + m_2 + m_3)} = 1\text{ m/s}^2$$

To determine, $T_1 \rightarrow$ Free body diagram of mass m_1.



$$T_1 = m_1 a = 10 \times 1 = 10\text{ N}$$

To determine, T_2 – Free body diagram of m_3.



$$F - T_2 = m_3 a$$

Solving, we get $\quad T_2 = 30\text{ N}$

52. Force on the box due to accelerated motion of the truck

$$F = ma = 40 \times 2 = 80\text{ N}$$

(in forward direction)

Reaction on the box, $\quad F' = F = 80\text{ N} \quad$ (in backward direction)

Force of limiting friction, $f = \mu R = 0{\cdot}15 \times 40 \times 10 = 60\text{ N}$

Net force on the box in backward direction is $P = F' - f$

$$= 80 - 60 = 20\text{ N}$$

Backward acceleration in the box $= a = \dfrac{P}{m} = \dfrac{20}{40} = 0{\cdot}5\text{ ms}^{-1}$

t = time taken by the box to travel s = 5 m and falls off the truck, then from

$$s = ut + \frac{1}{2}at^2$$

$$5 = 0 \times t + \frac{1}{2} \times 0{\cdot}5 \times t^2$$

$$t = 4{\cdot}47\text{s}$$

If the truck travels a distance x during this time

then $$x = 0 \times 4{\cdot}34 + \frac{1}{2} \times 2 \times (4{\cdot}471)^2$$

$$x = 19{\cdot}98 \text{ m}$$

53. Use $$s = ut + \frac{1}{2}at^2$$

$$a = \frac{2s}{t^2} \text{ as } u = 0$$

$$\mu = \frac{g \sin\theta - a}{g \cos\theta}$$

Putting the value and solving, $\mu =$ 0·11

54. (a) Force on the floor of the helicopter by the crew and passengers

= apparent weight of crew and passengers

= 500 (10 + 15)

= 12500 N

(b) Action of rotor of helicopter on surrounding air is Obviously vertically downwards, because helicopter rises on account of reaction of this force. Thus force of action

= (2000 + 500) (10 + 15)

= 2500 × 25

= 62,500 N

(c) Force on the helicopter due to surrounding air is obviously a reaction. As action and reaction are equal and opposite, therefore

Force of reaction F′ = 62,500 vertically upwards.

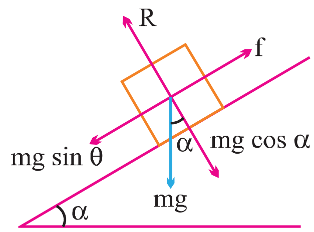
55. (a) When the box just starts sliding

$$\mu = \tan\theta$$

or $$\theta = \tan^{-1}\mu$$

(b) Force acting on the box down the plane

$$= mg\,(\sin\alpha - \mu\cos\alpha)$$



(c) Force needed $mg\,(\sin\alpha + \mu\cos\alpha)$

(d) Force needed $= mg\,(\sin\alpha + \mu\cos\alpha) + ma.$

56. According Newton's second law of motion

(i)
$$T_1 - (m_1 + m_2)g = (m_1 + m_2)a$$
$$T_1 = (m_1 + m_2)(a + g)$$
$$= (5 + 3)\,(2 + 9{\cdot}8)$$
$$T_1 = 94{\cdot}4\text{ N}$$

(ii)
$$T_2 - m_2 g = m_2 a$$
$$T_2 = m_2\,(a + g)$$
$$T_2 = 3(2 + 9{\cdot}8)$$
$$T_2 = 35{\cdot}4\text{ N}$$

57. Using Resolution of forces 1N and 2N and then applying laws of vector addition.

Calculate for F_1 & F_2.

$$F_1 = \frac{1}{\sqrt{2}}.\text{N}\,,\ F_2 = \frac{3}{\sqrt{2}}\text{N}.$$

58. Given m = mass of bullet = 50 gm = 0.50 kg

M = mass of tiger = 60 kg

v = Velocity of bullet = 150 m/s

V = Velocity of tiger = – 10m/s

(∴ It is coming from opposite direction n = no. of bullets fired per second at the tiger so as to stop it.)

$$P_i = 0\text{, before firing} \qquad \text{...(i)}$$

$$P_f = n(mv) + MV \qquad \text{...(ii)}$$

∴ From the law of conservation of momentum,

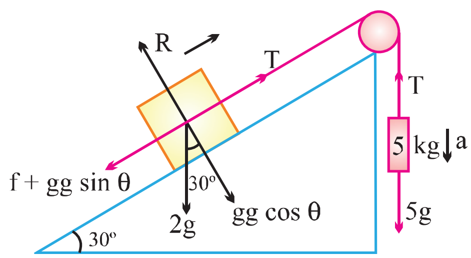
$$P_i = p_f$$

$\Rightarrow \qquad 0 = n(mv) + MV$

$\Rightarrow \qquad n = \frac{MV}{mv}$

$$= \frac{-60\times(-10)}{0.05\times 150} = 80.$$

59.



Let a be the acceleration of the system and T be the Tension in the string.

Equations of motions for 5 kg and 2 kg blocks are

$$5g - T = 5a \qquad \text{...(1)}$$

$$T - 2g \sin\theta - f = 2a \qquad \text{...(2)}$$

where $\quad f =$ force of limiting friction

$= \mu R = \mu\, mg \cos\theta = 0{\cdot}3 \times 2g \times \cos 30°$

Solving **(1)** & **(2)**,

$a = 4{\cdot}87$ m/s^2

T = 24·65 N.

❑❑