DAY FOUR

Laws of Motion

Learning & Revision for the Day

- Concept of Forces
- Inertia
- Newton's Laws of Motion
- Impulse
- Principle of Conservation of Linear Momentum
- Free Body Diagram
- Connected Motion
- Equilibrium of concurrent Forces
- Friction

Concept of Forces

A push or a pull exerted on any object, is defined to be a force. It is a vector quantity. Thus, we denote it with an arrow over it, just as we do for velocity and acceleration. Force can be grouped into two types:

- **Contact forces** are the forces that act between two bodies in contact, e.g. tension, normal reaction, friction etc.
- **Non-contact forces** are the forces that act between two bodies separated by a distance without any actual contact. e.g. gravational force between two bodies and electrostatic form between two charges etc.

Inertia

The inability of a body to change by itself its state of rest or state of uniform motion along a straight line is called inertia of the body.

As inertia of a body is measured by the mass of the body. Heavier the body, greater the force required to change its state and hence greater is its inertia. inertia obviously three types (i) inertia of rest (ii) inertia of motion (iii) inertia of direction.

Newton's Laws of Motion

First Law of Motion (Law of Inertia)

It states that a body continues to be in a state of rest or of uniform motion along a straight line, unless it is acted upon by some external force the change the state. This is also called law of inertia.

If $F = 0, \Rightarrow v = \text{constant} \Rightarrow a = 0$

- This law defines force.
- The body opposes any external change in its state of rest or of uniform motion.
- It is also known as the **law of inertia** given by Galileo.

Linear Momentum

It is defined as the total amount of motion of a body and is measured as the product of the mass of the body and its velocity. The momentum of a body of mass m moving with a velocity $\mathbf{v}$ is given by $\mathbf{p} = m\mathbf{v}$.

Its unit is kg-ms^{-1} and dimensional formula is [ML T^{-1}]

Second Law of Motion

The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.

According to second law, $F \propto \frac{dp}{dt}$ or $F = k\frac{dp}{dt}$

where, k is constant.

as, $\frac{dp}{dt} = \frac{d}{dt}(mv) = ma$ or $\frac{m\,dv}{dt} = ma$

i.e., second law can be written as

$$F = \frac{dp}{dt} = ma$$

The SI unit of force is newton (N) and in CGS system is dyne.

$$1\text{ N} = 10^5\text{ dyne}$$

Impulse

Impulse received during an impact is defined as the product of the average force and the time for which the force acts.

Impulse, $\mathbf{I} = \mathbf{F}_{av}\,t$

Impulse is also equal to the total change in momentum of the body during the impact.

Impulse, $\mathbf{I} = \mathbf{p}_2 - \mathbf{p}_1$

Impulse = Change in momentum

Third Law of Motion

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

$$\mathbf{F}_{12} = -\mathbf{F}_{21}$$

- Action and reaction are mutually opposite and act on two different bodies.
- The force acting on a body is known as action.
- When a force acts on a body, then the reaction acts normally to the surface of the body.

Principle of Conservation of Linear Momentum

It states that if no external force is acting on a system, the momentum of the system remains constant.

According to second law of motion, $\mathbf{F} = \frac{d\mathbf{p}}{dt}$

If no force is acting, then $\mathbf{F} = 0$

$\therefore \quad \frac{d\mathbf{p}}{dt} = 0 \Rightarrow \mathbf{p} = \text{constant}$ or $m_1v_1 = m_2v_2 = \text{constant}$

Applications of Principle of Conservation of Linear Momentum

The propulsion of rockets and jet planes is based on the principle of conservation of linear momentum.

- Upward thrust on the rocket, $F = -\frac{u\,dm}{dt} - mg$ and if effect of gravity is neglected, then $F = -\frac{u\,dm}{dt}$.
- Instantaneous upward velocity of the rocket

  $$v = u\ln\left(\frac{m_0}{m}\right) - gt$$

  and neglecting the effect of gravity

  $$v = u\ln\left(\frac{m_0}{m}\right) = 2.303\,u\log_{10}\left(\frac{m_0}{m}\right)$$

  where, m_0 = initial mass of the rocket including that of the fuel,

  u = initial velocity of the rocket at any time t,

  m = mass of the rocket left,

  v = velocity acquired by the rocket,

  $\frac{dm}{dt}$ = rate of combination of fuel.
- **Burnt out speed** of the rocket is the speed attained by the rocket when the whole of fuel of the rocket has been burnt. Burnt out speed of the rocket

  $$v_b = u\log_e\left(\frac{m_0}{m_r}\right) = 3.303\,u\log_{10}\left(\frac{m_0}{m_r}\right)$$

Apparent Weight of a Boy in a Lift

Actual weight of the body is mg. Here we consider the apparent weight of a non stading in a moving lift.

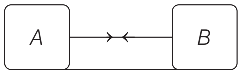
- If lift is accelerating upward at the rate of acceleration a, then apparent weight of the body is $R = m(g + a)$.
- If lift is accelerating downward at the rate of acceleration a, then apparent weight of the body is $R = m(g - a)$
- If lift is moving upward or downward with constant velocity, then apparent weight of the body is equal to actual weight.

Free Body Diagram

A free body diagram (FBD) consists of a diagramatize representation of a single body or sub-system of bodies isolated from its surroundings showing all forces acting on it.

While sketching a free body diagram the following points should be kept in mind.

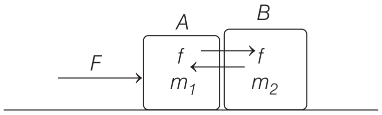
- Normal reaction (N) always acts normal to the surface on which the body is kept.



- When two objects A and B are connected by a string, the tension for object A is towards B and for object B, it is towards A.

Connected Motion

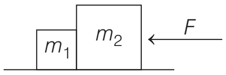
- If two blocks of masses m_1 and m_2 are placed on a perfectly smooth surface and are in contact, then



Acceleration of the blocks, $a = \dfrac{F}{m_1 + m_2}$

and the contact force (acting normally) between the two blocks is $f = m_2 a = \dfrac{F\,m_2}{(m_1 + m_2)}$.

- A block system is shown in the figure

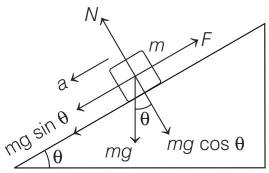


Acceleration of the blocks $a = \dfrac{F}{m_1 + m_2}$

Contact force between two blocks

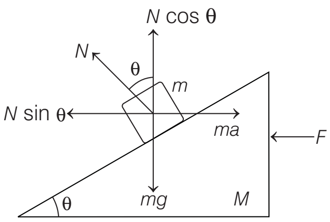
$$f = m_1 a = \frac{m_1 F}{(m_1 + m_2)}$$

- For a block of mass m placed on a fixed, perfectly smooth inclined plane of angle θ, the forces acting on the block are as shown in the figure. Obviously, here $a = g\sin\theta$



- If a block of mass m is placed on a smooth movable wedge of mass M, which in turn is placed on smooth surface, then a force **F** is applied on the wedge, horizontally.

  The acceleration of the wedge and the block is

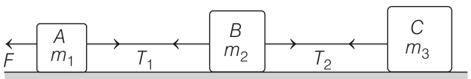


$$a = \frac{F}{(M + m)}$$

Force on the block, $F = (M + m)a = (M + m)g\tan\theta$

- For a block system shown in the figure, acceleration of the system

$$a = \frac{F}{m_1 + m_2 + m_3}$$



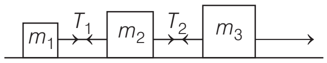
Tension in the string,

$$T_1 = (m_2 + m_3)a = \frac{F(m_3 + m_2)}{(m_1 + m_2 + m_3)}$$

and tension $T_2 = m_3 a = \dfrac{F\,m_3}{m_1 + m_2 + m_3}$

- For a block system shown in the figure, acceleration of the system

$$a = \frac{F}{m_1 + m_2 + m_3}$$



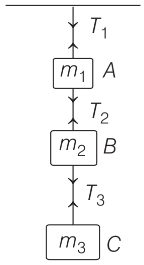
Tension in the string,

$$T_1 = \frac{m_1 F}{m_1 + m_2 + m_3} \quad \text{and} \quad T_2 = \frac{(m_1 + m_2)F}{m_1 + m_2 + m_3}$$

- For a block system suspended freely from a rigid support as shown in the figure, the acceleration of the system $a = 0$.

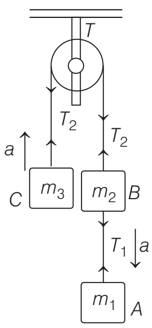
  String tension,

$$T_1 = (m_1 + m_2 + m_3)g$$
$$T_2 = (m_2 + m_3)g$$
and $$T_3 = m_3 g$$



- For a block system and a pulley as shown in the figure, value of the acceleration of the system

$$a = \frac{(m_1 + m_2 - m_3)g}{(m_1 + m_2 + m_3)}$$



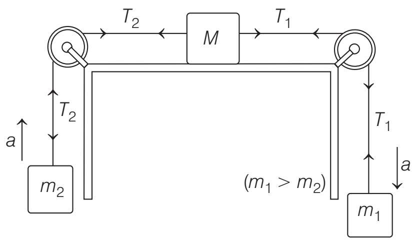
Tension, $T_1 = \dfrac{2m_1 m_3 g}{(m_1 + m_2 + m_3)}$

Tension, $T_2 = \dfrac{2m_3(m_1 + m_2)g}{(m_1 + m_2 + m_3)}$

and tension T

$$T = 2T_2 = \frac{4m_3(m_1 + m_2)g}{(m_1 + m_2 + m_3)}$$

- For the pulley and block arrangement as shown in the figure, we have



Net acceleration,

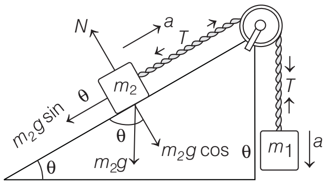
$$a = \frac{\text{Net accelerating force}}{\text{Total mass}} = \frac{(m_1 - m_2)g}{(m_1 + m_2 + M)}$$

Tension, $T_1 = m_1(g - a) = \dfrac{(M + 2m_2)m_1 g}{(M + m_1 + m_2)}$

and Tension, $T_2 = m_2(g + a)$

$$= \frac{(M + 2m_1)m_2 g}{(M + m_1 + m_2)}$$

- For the system of block and pulley, with a smooth inclined plane as shown in the figure, we have



Net acceleration,

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

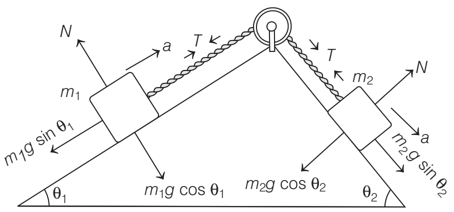
if $m_1 g > m_2 g \sin\theta$

and $a = \dfrac{(m_2 \sin\theta - m_1)g}{m_1 + m_2}$, if $m_1 g < m_2 g \sin\theta$

and tension in the string

$$T = m_1(g - a) = \frac{m_1 m_2 (1 + \sin\theta)}{(m_1 + m_2)}$$

- For a pulley and block system on a smooth double inclined plane as shown in the figure, we have



Net acceleration, $a = \dfrac{(m_2 \sin\theta_2 - m_1 \sin\theta_1)g}{(m_1 + m_2)}$,

for $\theta_2 > \theta_1, m_2 > m_1$

and tension in the string,

$$T = \frac{m_1 m_2 (\sin\theta_1 + \sin\theta_2)g}{(m_1 + m_2)}$$

Equilibrium of Concurrent Forces

If a number of forces act at the same point, they are called concurrent forces.

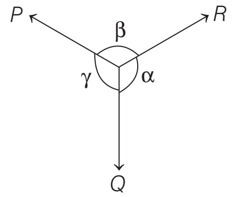
The necessary condition for the equilibrium of a body under the action of concurrent forces is that the vector sum of all the forces acting on the body must be zero.

Mathematically for equilibrium,

$$\Sigma \mathbf{F}_{net} = 0 \text{ or } \Sigma F_x = 0, \Sigma F_y = 0$$

and $\Sigma F_z = 0$

Lami Theorem For three concurrent forces in equilibrium position.



$$\frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma}$$

Friction

Whenever an object actually slides or rolls over the surface of another body or tends to do, so a force opposing the relative motion starts acting between these two surfaces in contact. It is known as friction or the force due to friction. Force of friction acts in a tangential direction to the surfaces in contact.

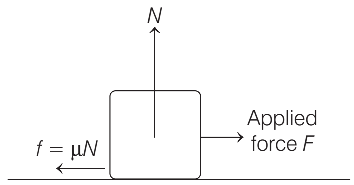
Types of Friction

The four types of friction are given below

1. **Static Friction** It is the opposing force that comes into play when one body is at rest and a force acts to move it over the surface of another body.

   It is a self adjusting force and is always equal and opposite to the applied force.

2. **Limiting Friction** It is the limiting (maximum) value of static friction when a body is just on the verge of starting its motion over the surface of another body.



   The force of limiting friction f_l between the surfaces of two bodies is directly proportional to the normal reaction at the point of contact. Mathematically,

$$f_l \propto N = \mu_l N \Rightarrow \mu_l = \frac{f_l}{N}$$

   where, μ_l is the **coefficient of limiting friction** for the given surfaces in contact.

3. **Kinetic Friction** It is the opposing force that comes into play when one body is actually slides over the surface of another body. Force of kinetic friction f_k is directly proportional to the normal reaction N and the ratio $\dfrac{f_k}{N}$ is called **coefficient of kinetic friction** μ_k, value of μ_k is slightly less than $\mu_e (\mu_k < \mu_l)$.

   Whenever limiting friction is converted into kinetic friction, body started motion with a lurch.

4. **Rolling Friction** It is the opposing force that comes into play when a body of symmetric shape (wheel or cylinder or disc, etc.) rolls over the surface of another body. Force of rolling friction f_r is directly proportional to the normal reaction N and inversely proportional to the radius (r) of the wheel.

   Thus, $$f_r \propto \frac{N}{r} \quad \text{or} \quad f_r = \mu_r \frac{N}{r}$$

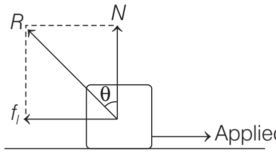
   The constant μ_r is known as the **coefficient of rolling friction** μ_r has the unit and dimensions of length. Magnitudewise $\mu_r << \mu_k$ or μ_l.

- The value of rolling friction is much smaller than the value of sliding friction.
- Ball bearings are used to reduce the wear and tear and energy loss against friction.

Angle of Friction

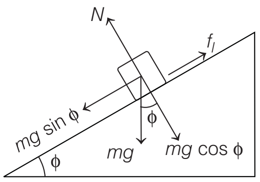
Angle of friction is defined as the angle θ which the resultant R of the force of limiting friction f_l and normal reaction N, subtends with the normal reaction.

The tangent of the angle of friction is equal to the coefficient of friction. i.e. $\mu = \tan\theta$



Angle of Repose

Angle of repose is the least angle of the inclined plane (of given surface) with the horizontal such that the given body placed over the plane, just begins to slide down, without getting accelerated.



The tangent of the angle of repose is equal to the coefficient of friction.

Hence, we conclude that angle of friction is (θ) equal to the angle of repose (ϕ).

In limiting condition, $f_1 = mg \sin\phi$

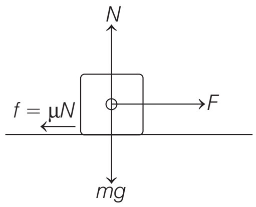
$$\Rightarrow \quad N = mg\cos\phi$$

$$\frac{f_1}{N} = \tan\phi$$

$$\therefore \quad \frac{f_1}{N} = \mu_s = \tan\phi$$

Acceleration of a Block on Applying a Force on a Rough Surface

- Acceleration of a block on a horizontal surface is as shown in the figure.



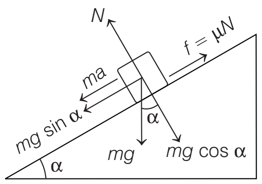
$$a = \frac{F - f}{m} = \frac{F - \mu mg}{m}$$

$$= \frac{F}{m} - \mu g$$

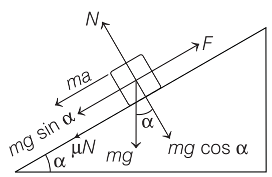
where, μ = coefficient of kinetic friction between the two surfaces in contact.

- Acceleration of block sliding down a rough inclined plane as shown in the figure is given by

$$a = g(\sin\alpha - \mu\cos\alpha)$$



- Retardation of a block sliding up a rough inclined plane as shown in the figure is $a = g(\sin\alpha + \mu\cos\alpha)$



DAY PRACTICE SESSION 1

FOUNDATION QUESTIONS EXERCISE

1 A ship of mass 3×10^7 kg initially at rest is pulled by a force of 5×10^4 N through a distance of 3 m. Assume that the resistance due to water is negligible, the speed of the ship is

(a) $1.5\,ms^{-1}$ (b) $60\,ms^{-1}$ (c) $0.1\,ms^{-1}$ (d) $5\,ms^{-1}$

2 An open knife edge of mass 200 g is dropped from height 5 m on a cardboard. If the knife edge penetrates distance 2 m into the cardboard, the average resistance offered by the cardboard to the knife edge is

(a) 7 N (b) 25 N
(c) 35 N (d) None of these

3 A body with mass 5 kg is acted upon by a force $F = (-3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ N. If its initial velocity at $t = 0$ is $v = (6\hat{\mathbf{i}} - 12\hat{\mathbf{j}})$ m/s. The time at which it will just have a velocity along the Y-axis is

(a) never (b) 10 s (c) 2 s (d) 15 s

4 A block of mass m is moving on a wedge with the acceleration a_0. The wedge is moving with the acceleration a_1. The observer is situated on wedge. The magnitude of pseudo force on the block is

(a) ma_0 (b) ma_1 (c) $m\sqrt{a_0^2 + a_1^2}$ (d) $m\left(\dfrac{a_1 + a_0}{2}\right)$

5 A machine gun fires 10 bullets/s, each of mass 10 g, the speed of each bullet is $20\,cms^{-1}$, then force of recoil is

(a) 200 dyne (b) 2000 dyne
(c) 20 dyne (d) None of these

6 A body, under the action of a force $\mathbf{F} = 6\hat{\mathbf{i}} - 8\hat{\mathbf{j}} + 10\hat{\mathbf{k}}$, acquires an acceleration of 1 ms^{-2}. The mass of this body must be → CBSE AIPMT 2009

(a) $2\sqrt{10}$ kg (b) 10 kg (c) 20 kg (d) $10\sqrt{2}$ kg

7 A disc of mass 100 g is kept floating horizontally in air by firing bullets, each of mass 5g with the same velocity at the same rate of 10 bullets/s. The bullets rebound with the same speed in opposite direction, the velocity of each bullet at the time of impact is

(a) $196\,cms^{-1}$ (b) $9.8\,cms^{-1}$
(c) $98\,cms^{-1}$ (d) $980\,cms^{-1}$

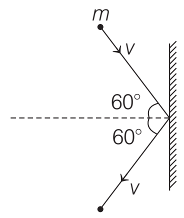
8 A boat of mass 40 kg is at rest. A dog of mass 4 kg moves in the boat with a velocity of 10 ms^{-1}. What is the velocity of boat?

(a) $4\,ms^{-1}$ (b) $2\,ms^{-1}$ (c) $8\,ms^{-1}$ (d) $1\,ms^{-1}$

9 A body of mass 0.25 kg is projected with muzzle velocity 100 m/s from a tank of mass 100 kg. What is the recoil velocity of the tank?

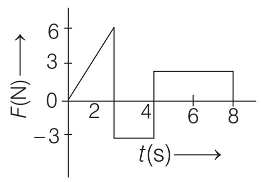
(a) 5 m/s (b) 25 m/s (c) 0.5 m/s (d) 0.25 m/s

10 A rigid ball of mass m strikes a rigid wall at 60° and gets reflected without loss of speed as shown in the figure. The value of impulse imparted by the wall on the ball will be → NEET 2016



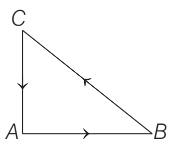
(a) mv (b) $2mv$ (c) $mv/2$ (d) $mv/3$

11 The force F acting on a particle of mass m is indicated by the force-time graph shown below. The change in momentum of the particle over the time interval from 0 to 8 s is → CBSE AIPMT 2014



(a) 24 N-s (b) 20 N-s (c) 12 N-s (d) 6 N-s

12 Three forces start acting simultaneously on a particle moving with velocity **v**. These forces are represented in magnitude and direction by the three sides of a triangle ABC (as shown). The particle will now move with velocity



(a) less than **v**
(b) greater than **v**
(c) |**v**| in the direction of largest force BC
(d) **v** remaining unchanged

13 You are marooned on a frictionless horizontal plane and cannot exert any horizontal force by pushing against the surface. How can you get off

(a) by jumping
(b) by rolling your body on the surface
(c) by splitting or sneezing or throwing any object
(d) by throwing an object in opposite direction

14 A bullet of mass 10 g moving horizontal with a velocity of 400 m/s strikes a wood block of mass 2 kg which is suspended by light inextensible string of length 5 m. As result, the centre of gravity of the block found to rise a vertical distance of 10 cm. The speed of the bullet after it emerges of horizontally from the block will be → NEET 2016

(a) 100 m/s (b) 80 m/s (c) 120 m/s (d) 160 m/s

15 An explosion breaks a rock into three parts in a horizontal plane. Two of them go off at right angles to each other. The first part of mass 1 kg moves with a speed of 12 ms^{-1} and the second part of mass 2 kg moves with 8 ms^{-1} speed. If the third part flies off with 4 ms^{-1} speed, then its mass is ➜ NEET 2013

(a) 3 kg (b) 5 kg (c) 7 kg (d) 17 kg

16 A lift is moving down with acceleration a. A man in the lift drops a ball inside the lift. The acceleration of the ball as observed by the man in the lift and a man standing stationary on the ground are respectively

(a) g, g (b) $g-a, g-a$ (c) $g-a, g$ (d) a, g

17 A balloon with mass m is descending down with an acceleration a (where, $a < g$). How much mass should be removed from it, so that its starts moving up with an acceleration a? ➜ CBSE AIPMT 2014

(a) $\frac{2ma}{g+a}$ (b) $\frac{2ma}{g-a}$ (c) $\frac{ma}{g+a}$ (d) $\frac{ma}{g-a}$

18 A spring balance is attached to the ceiling of lift. A man hangs his bag on the string and the balance reads 49 N, when the lift is stationary. If the lift moves downwards with an acceleration of 5 ms^{-2}. The reading of the spring balance would be

(a) 24 N (b) 74 N (c) 15 N (d) 49 N

19 A person of mass 60 kg is inside a lift of mass 940 kg and presses the button on control panel. The lift starts moving upwards with an acceleration 1.0 m/s^2. If $g = 10\ m/s^2$, the tension in the supporting cable is ➜ CBSE AIPMT 2011

(a) 9680 N (b) 11000 N (c) 1200 N (d) 8600 N

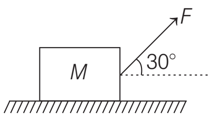
20 The mass of a lift is 2000 kg. When the tension in the supporting cable is 28000 N, then its acceleration is ➜ CBSE AIPMT 2009

(a) 30 ms^{-2} downwards (b) 4 ms^{-2} upwards
(c) 4 ms^{-2} downwards (d) 14 ms^{-2} upwards

21 The ratio of the weight of a man in a stationary lift and when it is moving downwards with uniform acceleration a is 3 : 2, then the value of a is

(a) $\frac{3}{2}g$ (b) $\frac{g}{3}$
(c) g (d) $\frac{2}{3}g$

22 A block of mass 10 kg is kept on a horizontal surface. A force F is acted on the block as shown in figure. For what minimum value of F, the block will be lifted up?

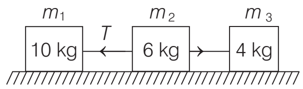


(a) 98 N (b) 49 N
(c) 200 N (d) None of these

23 Two blocks of masses $m_1 = 4$ kg and $m_2 = 2$ kg are connected to the ends of a string which passes over a massless, frictionless pulley. The total downward thrust on the pulley is nearly

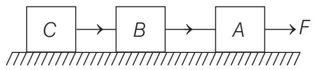
(a) 27 N (b) 54 N
(c) 2.7 N (d) None of these

24 Three blocks of masses m_1, m_2 and m_3 are placed on a horizontal frictionless surface. A force of 40 N pulls the system, then calculate the value of T, if $m_1 = 10$ kg, $m_2 = 6$ kg, $m_3 = 4$ kg.



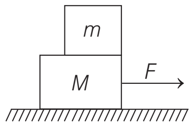
(a) 40 N (b) 20 N (c) 10 N (d) 5 N

25 Three identical blocks of masses $m = 2$ kg are drawn by a force $F = 10.2$ N with an acceleration of 0.6 ms^{-2} on a frictionless surface, then what is the tension (in N) in the string between the blocks B and C?



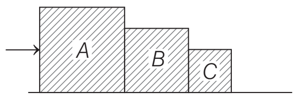
(a) 9.2 N (b) 7.8 N (c) 4 N (d) 9.8 N

26 The mass m is placed on a body of mass M. There is no friction. The force F is applied on M and it moves with acceleration a. Then, the net force on the top body is



(a) F (b) ma
(c) $F - ma$ (d) None of these

27 Three blocks A, B and C of masses 4 kg, 2 kg and 1kg, respectively, are in contact on a frictionless surface as shown. If a force of 14 N is applied on the 4 kg block, then the contact force between A and B is



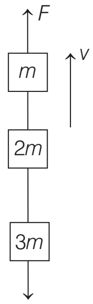
(a) 6 N (b) 8 N (c) 18 N (d) 2 N

28 A spring balance is attached to the ceiling of a lift. A man hangs his bag on the spring and the spring reads 49 N, when the lift is stationary. If the lift moves downward with an acceleration of 5 ms^{-2}, the reading of the spring balance will be

(a) 24 N (b) 74 N (c) 15 N (d) 49 N

29 Three blocks with masses m, $2m$ and $3m$ are connected by string as shown in the figure. After an upward force F is applied on block m, the masses move upward at constant speed v.

What is the net force on the block of mass $2m$? (g is the acceleration due to gravity) ➜ NEET 2013



(a) Zero (b) 2 mg
(c) 3 mg (d) 6 mg

30 A marble block of mass 2 kg lying on ice when given a velocity of 6 m/s is stopped by friction in 10 s. Then, the coefficient of friction is

(a) 0.01 (b) 0.02 (c) 0.03 (d) 0.06

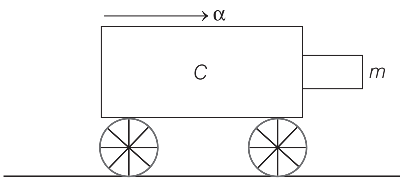
31 A block of mass 4 kg is kept on a rough horizontal surface. The coefficient of static friction is 0.8. If a force of 19 N is applied on the block parallel to the floor, then the force of friction between the block and floor is

(a) 32 N (b) 18 N (c) 19 N (d) 9.8 N

32 The upper half of an inclined plane of inclination θ is perfectly smooth while lower half is rough. A block starting from rest at the top of the plane will again come to rest at the bottom, if the coefficient of friction between the block and lower half of the plane is given by ➞ NEET 2013

(a) $\mu = \frac{1}{\tan\theta}$ (b) $\mu = \frac{2}{\tan\theta}$ (c) $\mu = 2\tan\theta$ (d) $\mu = \tan\theta$

33 A block of mass m is in contact with the cart C as shown in the figure. ➞ CBSE AIPMT 2010



The coefficient of static friction between the block and the cart is μ. The acceleration α of the cart that will prevent the block from falling satisfies

(a) $\alpha > \frac{mg}{\mu}$ (b) $\alpha > \frac{g}{\mu m}$ (c) $\alpha \geq \frac{g}{\mu}$ (d) $\alpha < \frac{g}{\mu}$

34 Which one of the following statements is incorrect? ➞ NEET 2018

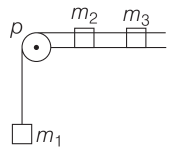
(a) Frictional force opposes the relative motion
(b) Limiting value of static friction is directly proportional to normal reaction
(c) Rolling friction is smaller than sliding friction
(d) Coefficient of sliding friction has dimensions of length

35 A block A of mass m_1 rests on a horizontal table. A light string connected to it passes over a frictionless pulley at the edge of table and from its other end another block B of mass m_2 is suspended. The coefficient of kinetic friction between the block and the table is μ_k. When the block A is sliding on the table, the tension in the string is

(a) $\frac{(m_2 - \mu_k m_1)g}{(m_1 + m_2)}$ (b) $\frac{m_1 m_2 (1 + \mu_k)g}{(m_1 + m_2)}$

(c) $\frac{m_1 m_2 (1 - \mu_k)g}{(m_1 + m_2)}$ (d) $\frac{(m_2 + \mu_k m_1)g}{(m_1 + m_2)}$

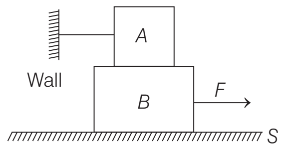
36 A system consists of three masses m_1, m_2 and m_3 connected by a string passing over a pulley P. The mass m_1 hangs freely and m_2 and m_3 are on a rough horizontal table (the coefficient of friction $= \mu$).
The pulley is frictionless and of negligible mass. The downward acceleration of m_1 is
(Assume, $m_1 = m_2 = m_3 = m$) ➞ CBSE AIPMT 2014



(a) $\frac{g(1 - g\mu)}{9}$ (b) $\frac{2g\mu}{3}$

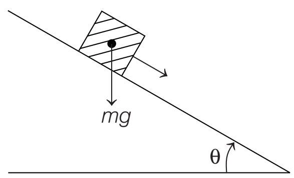
(c) $\frac{g(1 - 2\mu)}{3}$ (d) $\frac{g(1 - 2\mu)}{2}$

37 A block A of mass 100 kg rests on another block B of mass 200 kg and is tied to a wall as shown in the figure. The coefficient of friction between A and B is 0.2 and that between B and the ground is 0.3. The minimum force F required to move the block B is (take, $g = 10 \text{ ms}^{-2}$)



(a) 900 N (b) 200 N (c) 1100 N (d) 700 N

38 A plank with a box on it at one end is gradually raised about the other end. As the angle of inclination with the horizontal reaches 30°, the box starts to slip and slides 4.0 m down the plank in 4.0 s. The coefficients of static and kinetic friction between the box and the plank will be, respectively ➞ CBSE AIPMT 2015



(a) 0.6 and 0.6 (b) 0.6 and 0.5
(c) 0.5 and 0.6 (d) 0.4 and 0.3

39 A block is moving up an inclined plane of inclination 60° with velocity of 20 ms^{-1} and stops after 2.00 s. If $g = 10 \text{ ms}^{-2}$, then the approximate value of coefficient of friction is

(a) 3 (b) 3.3 (c) 0.27 (d) 0.33

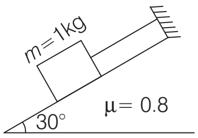
DAY PRACTICE SESSION 2

PROGRESSIVE QUESTIONS EXERCISE

1 A body of mass 2 kg travels according to the law $x(t) = pt + qt^2 + rt^3$, where $p = 3$ m/s, $q = 4\text{ m/s}^2$ and $r = 5\text{ m/s}^3$
The force acting on the body at $t = 2$ s is

(a) 136 N (b) 134 N (c) 158 N (d) 68 N

2 Figure shows a block of mass m kept on an inclined plane with inclination $\theta = 30°$. The tension in the string is

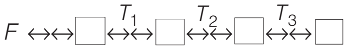


(a) 8 N (b) 10 N
(c) 0.8 N (d) zero

3 Two spheres A and B of masses m_1 and m_2 respectively collide. A is at rest initially and B is moving with velocity v along X-axis. After collision, B has a velocity $\frac{v}{2}$ in a direction perpendicular to the original direction. The mass A moves after collision in the direction

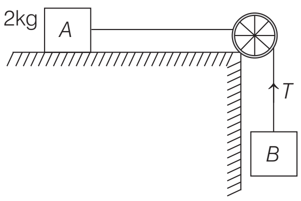
(a) same as that of B (b) opposite to that of B
(c) $\theta = \tan^{-1}\left(\frac{1}{2}\right)$ to the X-axis
(d) $\theta = \tan^{-1}\left(\frac{-1}{2}\right)$ to the X-axis

4 Four blocks of same mass connected by cords are pulled by a force F on a smooth horizontal surface, as shown in the figure. The tensions T_1, T_2 and T_3 will be



(a) $T_1 = \frac{1}{4}F, T_2 = \frac{3}{2}F, T_3 = \frac{1}{4}F$ (b) $T_1 = \frac{1}{4}F, T_2 = \frac{1}{2}F, T_3 = \frac{1}{2}F$
(c) $T_1 = \frac{3}{4}F, T_2 = \frac{1}{2}F, T_3 = \frac{1}{4}F$ (d) $T_1 = \frac{3}{4}F, T_2 = \frac{1}{2}F, T_3 = \frac{1}{2}F$

5 The coefficient of static friction μ_s, between block A of mass 2 kg and the table as shown in the figure is 0.2. What would be the maximum mass value of block B, so that the two blocks do not move? The string and the pulley are assumed to be smooth and massless (take, $g = 10\text{ ms}^{-2}$)

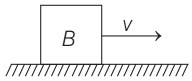


(a) 2.0 kg (b) 4.0 kg (c) 0.2 kg (d) 0.4 kg

6 A block of mass m is placed on a smooth wedge of inclination θ. The whole system is accelerated horizontally, so that the block does not slip on the wedge. The force exerted by the wedge on the block (g is acceleration due to gravity) will be

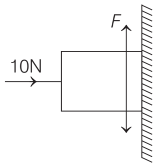
(a) $mg\cos\theta$ (b) $mg\sin\theta$ (c) mg (d) $\frac{mg}{\cos\theta}$

7 A block B is pushed momentarily along a horizontal surface with an initial velocity v. If μ is the coefficient of sliding friction between B and the surface, block B will come to rest after a time



(a) $\frac{v}{g\mu}$ (b) $\frac{g\mu}{v}$
(c) $\frac{g}{v}$ (d) $\frac{v}{g}$

8 A horizontal force of 10 N is necessary to just hold a block stationary against a wall. The coefficient of friction between the block and the wall is 0.2. The weight of the block is

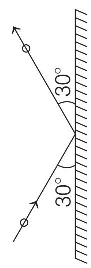


(a) 20 N (b) 50 N
(c) 100 N (d) 2 N

9 A heavy uniform chain lies on a horizontal top of table. If the coefficient of friction between the chain and the table is 0.25, then the maximum percentage of the length of the chain that can hang over one edge of the table is

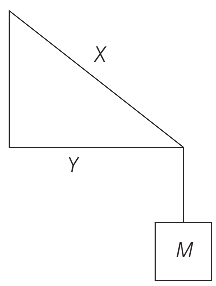
(a) 20% (b) 25%
(c) 35% (d) 15%

10 A 0.5 kg ball moving with a speed of 12 ms^{-1} strikes a hard wall at an angle of 30° with the wall. It is reflected with the same speed and at the same angle. If the ball is in contact with the wall for 0.25 s, the average force acting on the wall is



(a) 48 N (b) 24 N
(c) 12 N (d) 96 N

11 Two rods X and Y are attached to a weight of mass M as shown in figure, then

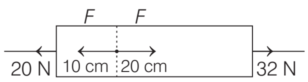


(a) both X and Y experience compression
(b) both X and Y experience extension
(c) Y experiences extension and X compression
(d) Y experiences compression and X extension

12 With what minimum acceleration can a fireman slide down a rope while breaking strength of the rope is $\frac{2}{3}$ of the weight?

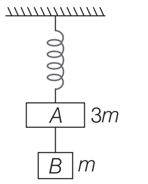
(a) $\frac{2}{3}g$ (b) g (c) $\frac{1}{3}g$ (d) Zero

13 Figure shows a uniform rod of length 30 cm having a mass of 3.0 kg. The strings shown in the figure are pulled by constant forces of 20 N and 32 N. Find the force exerted by 20 cm part of the rod on the 10 cm part. All the surfaces are smooth and the strings and pulleys are light ➔ AFMC 2010



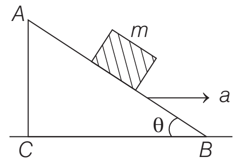
(a) 36 N (b) 12 N
(c) 64 N (d) 24 N

14 Two blocks A and B of masses $3m$ and m respectively are connected by a massless and inextensible string. The whole system is suspended by a massless spring as shown in figure. The magnitudes of acceleration of A and B immediately after the string is cut, are respectively ➔ NEET 2017



(a) $g, \frac{g}{3}$ (b) $\frac{g}{3}, g$ (c) g, g (d) $\frac{g}{3}, \frac{g}{3}$

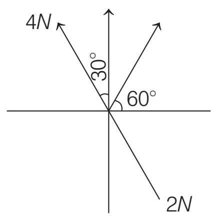
15 A block of mass m is placed on a smooth inclined wedge ABC of inclination θ as shown in the figure. The wedge is given an acceleration a towards the right. The relation between a and θ for the block to remain stationary on the wedge is ➔ NEET 2018



(a) $a = g\cos\theta$ (b) $a = \frac{g}{\sin\theta}$

(c) $a = \frac{g}{\operatorname{cosec}\theta}$ (d) $a = g\tan\theta$

16 Three forces acting on a body are shown in the figure. To have the resultant force only along the y-direction, the magnitude of the minimum additional force needed is ➔ CBSE AIPMT 2008



(a) 0.5 N (b) 1.5 N (c) $\frac{\sqrt{3}}{4}$ N (d) $\sqrt{3}$ N

ANSWERS

SESSION 1	1 (c)	2 (b)	3 (b)	4 (b)	5 (b)	6 (d)	7 (d)	8 (d)	9 (d)	10 (d)
	11 (c)	12 (d)	13 (c,d)	14 (c)	15 (b)	16 (c)	17 (a)	18 (a)	19 (b)	20 (b)
	21 (b)	22 (c)	23 (b)	24 (b)	25 (b)	26 (d)	27 (a)	28 (a)	29 (a)	30 (d)
	31 (a)	32 (c)	33 (c)	34 (d)	35 (b)	36 (c)	37 (c)	38 (b)	39 (c)	
SESSION 2	1 (a)	2 (d)	3 (c)	4 (c)	5 (d)	6 (d)	7 (a)	8 (d)	9 (a)	10 (b)
	11 (d)	12 (c)	13 (d)	14 (b)	15 (d)	16 (a)				

Hints and Explanations

SESSION 1

1 $v^2 = u^2 + 2as$ or $v^2 = 2as$ $[\because u = 0]$ ...(i)

Force on the ship,

$$F = ma \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$v = \sqrt{\frac{2Fs}{m}} = \sqrt{\frac{2 \times 5 \times 10^4 \times 3}{3 \times 10^7}}$$

$$= 0.1 \text{ ms}^{-1}$$

2 Velocity acquired in falling through height h

$$u = \sqrt{2gh} = \sqrt{2 \times 10 \times 5} = 10 \text{ ms}^{-2}$$

Again, $v^2 = u^2 + 2as$,

$\Rightarrow$ $(0)^2 = (10)^2 + 2a \times 2$,

$$a = -\frac{100}{2 \times 2} = -25 \text{ ms}^{-2}$$

This is total retardation due to gravity and cardboard.

$\therefore$ Retardation due to cardboard

$a' = g + a = (10 + 25) \text{ ms}^{-2} = 35 \text{ ms}^{-2}$

Force due to card board $= Ma'$

$= 200 \times 10^{-3} \times 35$

$= 7000 \times 10^{-3} = 7$ N

3 Here, $m = 5$ kg; Force

$$\mathbf{F} = (-3\,\hat{\mathbf{i}} + 4\,\hat{\mathbf{j}})\text{N}$$

So, $\mathbf{a} = \frac{\mathbf{F}}{m} = \left[\frac{-3i}{5} + \frac{4\mathbf{j}}{5}\right]\text{N}$

Final velocity is along y-axis only when its x-component of velocity is zero. So, using $v_x = u_x + a_x t$

$\Rightarrow \quad 0 = 6 - \frac{3}{5} \times t \Rightarrow t = \frac{6 \times 5}{3} = 10\text{ s}$

4 The magnitude and direction of pseudo force depends upon acceleration of frame of reference in which observer is situated. It does not depend upon direction and magnitude of acceleration of the block.

i.e. the magnitude of pseudo force on the block is ma_1.

5 Time taken for 1 bullet $= \frac{1}{n}$

Force = the rate of change of momentum $= mvn$

$= 10 \times 20 \times 10 = 2000$ dyne

6 Here, $\mathbf{F} = 6\hat{\mathbf{i}} - 8\hat{\mathbf{j}} + 10\hat{\mathbf{k}}$

$$|F| = \sqrt{36 + 64 + 100}$$

$$= 10\sqrt{2}\text{ N}$$

$$a = 1\text{ ms}^{-2}$$

$\therefore \quad m = \frac{10\sqrt{2}}{1} \quad [\because F = ma]$

$= 10\sqrt{2}$ kg

7 $2m'vn = mg$

$\therefore$ velocity of each bullet

$v = \frac{mg}{2m'n} = \frac{100 \times 980}{2 \times 5 \times 10} = 980\text{ cms}^{-1}$

8 From law of conservation of linear momentum,

momentum of boat = momentum of dog

$$m_1 v_1 = m_2 v_2$$

Given, $m_1 = 40$ kg

$v_1 = ?$, $m_2 = 4$ kg, $v_2 = 10\text{ ms}^{-1}$

$\therefore \quad 40 \times v_1 = 4 \times 10$

$\Rightarrow \quad v_1 = \frac{4 \times 10}{40} = 1\text{ ms}^{-1}$

9 From law of conservation of momentum

$$m_1 v_1 = m_2 v_2$$

Given, $m_1 = 0.25$ kg, $v_1 = 100$ m/s, $m_2 = 100$ kg

$0.25 \times 100 = 100 \times v$

$v = 0.25$ m/s

10 As we know that, impulse is imparted due to change in perpendicular components of momentum of ball.

$J = \Delta p = mv_f - mv_i$

$= mv\cos 60° - (-mv\cos 60°)$

$= 2mv\cos 60° = 2mv \times \frac{1}{2} = mv$

11 The area under F-t graph gives change in momentum.

For 0 to 2 s, $\Delta p_1 = \frac{1}{2} \times 2 \times 6 = 6$ kg-m/s

For 2 to 4 s, $\Delta p_2 = 2 \times -3 = -6$ kg-m/s

For 4 to 8 s, $\Delta p_3 = 4 \times 3 = 12$ kg-m/s

So, total change in momentum for 0 to 8 s

$\Delta p_{\text{net}} = \Delta p_1 + \Delta p_2 + \Delta p_3$

$= (+6 - 6 + 12)$

$= 12$ kg-m/s $= 12$ N-s

12 Resultant force is zero, as three forces acting on the particle has been represented in magnitude and direction by three sides of a triangle in same order. Hence, by Newton's second law $\left(\mathbf{F} = m\frac{d\mathbf{v}}{dt}\right)$, particle velocity ($\mathbf{v}$) will be same.

13 One can come off the frictionless surface following the law of conservation of momentum i.e. by splitting or sneezing or throwing an object in opposite direction of motion.

14 According to the law of conservation of momentum, $p_i = p_f$

$\Rightarrow (0.01) \times 400 + 0 = 2v + (0.01)v' \quad$ ...(i)

Also, velocity v of the block just after the collision is

$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 0.1} = \sqrt{2} \quad$ ...(ii)

$\Rightarrow$ From Eqs. (i) and (ii), we have

$v' \approx 120$ m/s

15 *Concept* Momentum is conserved before and after collision.

We have,

$\mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_3 = 0 \quad [\because p = mv]$

$\therefore \quad 1 \times 12\hat{\mathbf{i}} + 2 \times 8\hat{\mathbf{j}} + \mathbf{p}_3 = 0$

$\Rightarrow \quad 12\hat{\mathbf{i}} + 16\hat{\mathbf{j}} + \mathbf{p}_3 = 0$

$\Rightarrow \quad \mathbf{p}_3 = -(12\hat{\mathbf{i}} + 16\hat{\mathbf{j}})$

$\therefore \quad \mathbf{p}_3 = \sqrt{(12)^2 + (16)^2}$

$= \sqrt{144 + 256} = 20$ kg-m/s

Now, $\quad \mathbf{p}_3 = m_3 v_3$

$\Rightarrow \quad m_3 = \frac{\mathbf{p}_3}{v_3} = \frac{20}{4} = 5$ kg

16 Acceleration of man in left $\mathbf{a}_{\text{man}} = a\hat{\mathbf{k}}$

Acceleration of ball $\Rightarrow \mathbf{a}_{\text{ball}} = g\,\hat{\mathbf{k}}$

Here, $\hat{\mathbf{k}}$ represents downwards direction

$\Rightarrow$ Relative acceleration

$\mathbf{a}_{\text{rel}} = \mathbf{a}_{\text{base}} - \mathbf{a}_{\text{man}} = (g - a)\hat{\mathbf{k}}$

$\therefore$ Acceleration observed by man in lift $= g - a$

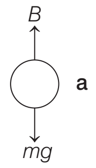
Again for man standing outside

$\mathbf{a}_{\text{man}} = 0\hat{\mathbf{k}}$

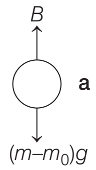
So, $\mathbf{a}_{\text{relative}} = g\hat{\mathbf{k}} - 0\hat{\mathbf{k}} = g\hat{\mathbf{k}}$

$\therefore$ Acceleration observed by man standing outside $= g$

17 Since, balloon is descending



$mg - B = ma \quad$ ...(i)



$B - (m - m_0)g = (m - m_0)a \quad$ ...(ii)

On adding, Eqs. (i) and (ii), we get

$\Rightarrow \quad mg - mg + m_0 g = ma + ma - m_0 a$

$\Rightarrow \quad m_0 = \frac{2ma}{g + a}$

18 When lift is stationary,

$R = mg$

$49 = m \times 9.8$

$\Rightarrow \quad m = \frac{49}{9.8} = 5$ kg

If a is downward acceleration of lift

$R = m(g - a)$

$R = 5(9.8 - 5) = 24$ N

19 Total mass (m) = Mass of lift + Mass of person $= 940 + 60 = 1000$ kg

So, from the free body diagram

$T - mg = ma$

Hence, $T - 1000 \times 10 = 1000 \times 1$

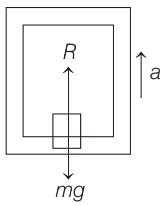
$T = 11000$ N

20 Here, lift is accelerating upward at the rate of a.

Hence, equation of motion is written as $R - mg = ma$

$28000 - 20000 = 2000a$

$[\because g = 10\text{ ms}^{-2}]$



$\Rightarrow \quad a = \frac{8000}{2000} = 4\text{ ms}^{-2}$ upwards

21 According to the question

$$\frac{3}{2} = \frac{mg}{m(g - a)}$$

$3g - 3a = 2g \Rightarrow a = \frac{g}{3}$

22 $F\sin 30° + N = Mg$

The block lifts when $N = 0$

$\therefore \quad F = \frac{10 \times 10}{1/2} = 200$ N

23 Tension

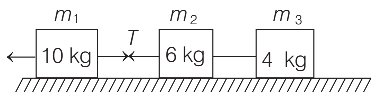
$$T = \frac{2m_1m_2}{m_1 + m_2} g = \frac{2 \times 4 \times 2 \times 10}{4+2}$$

$$= \frac{160}{6} = 26.6 \approx 27 \text{ N}$$

Total downward thrust on the pulley

$$= 2T = 2 \times 27 = 54 \text{ N}$$

24



From the relation, $F = ma$

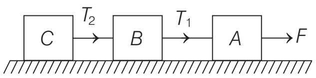
$$a = \frac{F}{m_1 + m_2 + m_3}$$

$$\Rightarrow \quad a = \frac{40}{10+6+4} = 2 \text{ ms}^{-2}$$

$$40 - T = 10 \times 2$$

$$T = 20 \text{ N}$$

25 The system of masses is shown below



From the figure,

$$F - T_1 = ma \quad \text{...(i)}$$

and $$T_1 - T_2 = ma \quad \text{...(ii)}$$

Eq. (i) gives $10.2 - T_1 = 2 \times 0.6$

$$\Rightarrow \quad T_1 = 10.2 - 1.2 = 9 \text{ N}$$

Again from Eq. (ii), we get

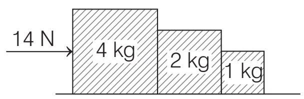
$$9 - T_2 = 2 \times 0.6$$

$$\Rightarrow \quad T_2 = 9 - 1.2 = 7.8 \text{ N}$$

26 Since, no force of friction is present. So, no horizontal force is present on body of mass m. In vertical direction normal force balances weight of the body. Hence, net force on top body must be zero.

27 Acceleration of system

$$= \frac{F_{\text{net}}}{M_{\text{total}}} = \frac{14}{4+2+1} = 2 \text{ m/s}^2$$



The contact force between 4 kg and 2 kg block will move 2 kg and 1kg block with the same acceleration.

So, $F_{\text{contact}} = (2+1)a = 3(2) = 6 \text{ N}$

28 In stationary position,

$$mg = 49$$

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

When lift moves downwards reading of balance

$$T = mg - ma$$

$$= 5(9.8 - 5) = 24.0 \text{ N}$$

29 Since, all the blocks are moving with constant velocity, then the net force on the all blocks will be zero.

30 From equation of motion,

$$v = u - at$$

$$\Rightarrow \quad 0 = u - \mu gt$$

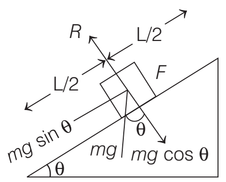
$\Rightarrow$ Coefficient of friction

$$\mu = \frac{u}{gt} = \frac{6}{10 \times 10} = 0.06$$

31 Friction, $f = \mu\, mg = 0.8 \times 4 \times 10 = 32 \text{ N}$

Applied force $F < f$, therefore answer will be (a).

32



The block may be stationary, when

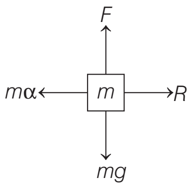
$$mg\sin\theta \cdot L = \mu mg\cos\theta \frac{L}{2}$$

or $$\mu = \frac{mg\sin\theta \cdot L}{mg\cos\theta \frac{L}{2}} = 2\frac{\sin\theta}{\cos\theta}$$

$$= 2\tan\theta$$

Coefficient of friction, $\mu = 2\tan\theta$

33 When cart moves with some acceleration towards right, then a pseudo force ($m\alpha$) acts on block towards left.



This force ($m\alpha$) is action force by a block on cart. Now, block will remain static with respect to cart, if frictional force

$$\mu R \geq mg.$$

$$\Rightarrow \quad \mu m\,\alpha \geq mg \qquad [R = m\alpha]$$

$$\Rightarrow \quad \alpha \geq \frac{g}{\mu}$$

34 The opposing force that comes into play when one body is actually sliding over the surface of the other body is called sliding friction.

The coefficient of sliding is given as

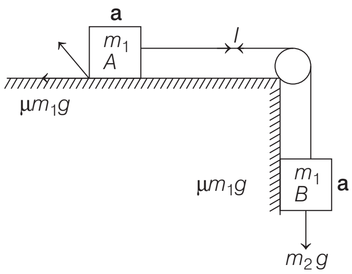
$$\mu_S = \frac{N}{F_{\text{sliding}}}$$

where, N is the normal reaction and F_{sliding} is the sliding force.

As, the dimensions of N and F_{sliding} are same. Thus, μ_S is a dimensionless quantity.

Hence, statement(d) is incorrect.

35



For the motion of both blocks

$$m_2g - T = m_2a \quad \text{...(i)}$$

$$T - \mu_k m_1 g = m_1 a \quad \text{...(ii)}$$

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

For the block of mass m_2,

$$m_2g - T = m_2\left[\frac{m_2 - \mu_k m_1}{m_1 + m_2}\right]g$$

$$T = m_2g - \left[\frac{m_2 - \mu_k m_1}{m_1 + m_2}\right]m_2g$$

$$= m_2g\left[\frac{m_1 + \mu_k m_1}{m_1 + m_2}\right]$$

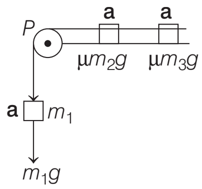
$\Rightarrow$ Tension in the string

$$T = \frac{m_1m_2(1 + \mu_k)g}{m_1 + m_2}$$

36 Acceleration

$$a = \frac{m_1g - \mu(m_2 + m_3)g}{m_1 + m_2 + m_3} = \frac{m[g - 2\mu g]}{3m}$$

$$= \frac{g}{3}(1 - 2\mu)$$



37 Friction force between blocks A and B and between block B and surface will oppose F

$$\therefore \quad F = F_{AB} + F_{BS}$$

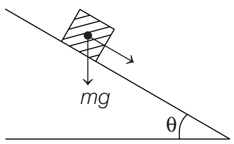
$$= \mu_{AB}M_Ag + \mu_{BS}(m_A + m_B)g$$

$$= 0.2 \times 100 \times 10 + 0.3\,(100 + 200) \times 10$$

$$= 200 + 900 = 1100 \text{ N}$$

This is the required minimum force to move the block B.

38 Given a plank with a box on its one end is gradually raised about the end having angle of inclination is 30°, the box starts to slip and slides down 4 m the plank in 4 s as shown in figure.



The coefficient of static friction,

$$\mu_s = \tan 30° = \frac{1}{\sqrt{3}} = 0.6$$

So, distance covered by a plank,

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

Here, $u = 0$

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

$\therefore \quad 4 = \frac{1}{2}g\,(\sin 30° - \mu_k \cos 30°)(4)^2$

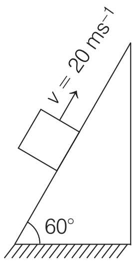
$\Rightarrow \quad 0.5 = 10 \times \frac{1}{2} - \mu_K \times 10 \times \frac{\sqrt{3}}{2}$

$\Rightarrow \quad 5\sqrt{3}\,\mu_k = 4.5$

$\Rightarrow \quad \mu_k = 0.51$

Thus, coefficient of kinetic friction between the box and the plank is 0.51.

39 Retardation $= g\,(\sin 60° + \mu\cos 60°)$



$$= 10\left(\frac{\sqrt{3}}{2} + \mu\frac{1}{2}\right) = 5(\sqrt{3} + \mu)$$

$v = u - at$

$0 = 20 - 5(\sqrt{3} + \mu) \times 2$

$\sqrt{3} + \mu = 2$

$\mu = 2 - 1.732 \approx 0.27$

SESSION 2

1 We have, mass $m = 2$ kg

$x = pt + qt^2 + rt^3$

$\Rightarrow \quad \frac{dx}{dt} = p + 2qt + 3rt^2$

$\frac{d^2x}{dt^2} = 2q + 6rt =$ acceleration (a)

At $t = 2$ s,

$a = 2q + 12r = 2 \times 4 + 12 \times 5$

$= 68 \text{ m/s}^2$

Now, $|\mathbf{F}| = |m\mathbf{a}| = 2 \times 68 = 136$ N

2 We know that, $\tan\alpha = 0.8$

$$\alpha = \tan^{-1}(0.8) = 39°$$

The given angle of inclination is less than angle of repose. So, 1 kg block has no tendency to move. Therefore, $T = 0$.

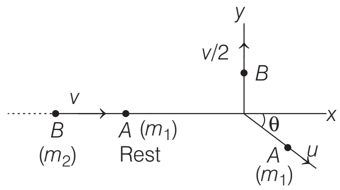
3 Here, $\mathbf{p}_i = m_2 v\hat{\mathbf{i}} + m_1 \times 0$

$$\mathbf{p}_f = m_2 \frac{v}{2}\hat{\mathbf{j}} + m_1 \times \mathbf{v}_1$$

Law of conservation of momentum

$\mathbf{p}_i = \mathbf{p}_f \Rightarrow m_2 v\hat{\mathbf{i}} = m_2\frac{v}{2}\hat{\mathbf{j}} + m_1 \times \mathbf{v}_1$

$\mathbf{v}_1 = \frac{m_2}{m_1}v\,\hat{\mathbf{i}} + \frac{m_2}{m_1}\frac{v}{2}\hat{\mathbf{j}}$



From this equation, we can find $\tan\theta = \frac{y}{x} = \frac{1}{2}, \theta = \tan^{-1}\left(\frac{1}{2}\right)$ to the X-axis.

4 $T_1 = \frac{(m_2 + m_3 + m_4)}{m_1 + m_2 + m_3 + m_4}F$

Given, $m_1 = m_2 = m_3 = m_4 = m$

$\therefore \quad T_1 = \frac{3}{4}\cdot F$

Similarly, $T_2 = \frac{(m_3 + m_4)F}{m_1 + m_2 + m_3 + m_4}$

Given, $m_1 = m_2 = m_3 = m_4 = m$

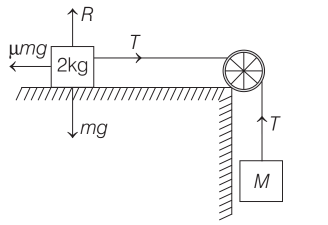
$\therefore \quad T_2 = \frac{1}{2}\cdot F$

Also, $T_3 = \frac{m_4 F}{m_1 + m_2 + m_3 + m_4}$

Given, $m_1 = m_2 = m_3 = m_4 = m$

$\Rightarrow \quad T_3 = \frac{1}{4}F$

5 Let the mass of the block B is M.



In equilibrium, $T = Mg$ …(i)

If block do not move, then $T = f_s$

where, $f_s =$ frictional force

$= \mu_s R = \mu_s mg$

$\therefore \quad T = \mu_s\, mg$ …(ii)

Thus, from Eqs. (i) and (ii), we have

$Mg = \mu_s\, mg$

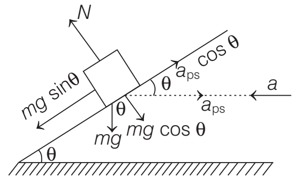
or $\quad M = \mu_s\, m$

Given, $\mu_s = 0.2, \; m = 2$ kg

$\therefore \quad M = 0.2 \times 2$

$= 0.4$ kg

6 Let an acceleration to the wedge is given towards left, then the block (being in non-inertial frame) has a pseudo acceleration to the right because of which the block is not slipping



$\therefore \quad mg\sin\theta = a_{\text{pseudo}}\cos\theta$

$\Rightarrow \quad a_{\text{pseudo}} = \frac{mg\sin\theta}{\cos\theta}$

Hence, total force exerted by the wedge on the block is

$N = N_1 + N_2$

$= mg\cos\theta + a_{\text{pseudo}}\sin\theta$

$= mg\cos\theta + \frac{mg\sin\theta}{\cos\theta} \times \sin\theta$

$= \frac{mg\cos^2\theta + mg\sin^2\theta}{\cos\theta} = \frac{mg}{\cos\theta}$

7 Retardation due to friction $= -\mu g$

Initial velocity $= v$

Now using $v = u + at$

Final velocity is zero,

$\Rightarrow 0 = v - \mu gt \Rightarrow$ time, $t = \frac{v}{\mu g}$

8 Force, $F = \mu R = Mg$

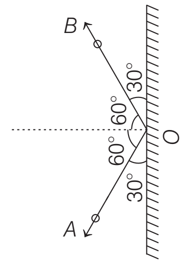
$\therefore$ Weight of block $= \mu R = 0.2 \times 10 = 2$ N

9 $\frac{M}{L}lg = \mu\frac{M}{L}(L - l)\,g \Rightarrow l = (L - l)\mu$

$\frac{l}{L} = \frac{\mu}{1 + \mu}$

$= \frac{0.25}{1.25} = \left(\frac{1}{5} \times 100\right)\% = 20\%$

10 Change in momentum



$\Delta p = OB\sin 30° - (-\,OA\sin 30°)$

$= mv\sin 30° - (-\,mv\sin 30°)$

$= 2\,mv\sin 30°$

Its time rate will appear in the form of average force acting on the wall.

$\therefore \quad F \times t = 2\,mv\sin 30°$

or $\quad F = \frac{2mv\sin 30°}{t}$

Given, $m = 0.5$ kg, $v = 12\ \text{ms}^{-1}$,

and $t = 0.25$ s

$\theta = 30°$

Hence, $F = \dfrac{2 \times 0.5 \times 12 \sin 30°}{0.25} = 24$ N

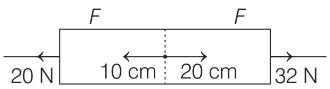
11 By writing the equilibrium equations in horizontal and vertical direction (assuming same angle θ between $(0 \le \theta \le 90°)$ x and y. We can find that rod x is under extension (tension), while rod y is under compression.

12 If man slides down with same acceleration, then its apparent weight decreases. For critical condition rope can bear only $\frac{2}{3}$ of his weight. If a is minimum acceleration.

Breaking strength $= m(g - a) = \frac{2}{3}mg$

$\Rightarrow \quad a = g - \frac{2g}{3} = \frac{g}{3}$

13



Net force on the rod, $f = 32 - 20 = 12$ N

Acceleration, $a = \frac{F}{m} = \frac{12}{3} = 4\ \text{ms}^{-2}$

Equation of motion of 10 cm apart is

$\Rightarrow \left[m' = \frac{1}{3} \times m = \frac{1}{3} \times 3 = 1\text{kg} \right]$

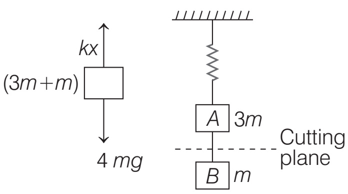
$F - 20 = m'a = 1 \times 4$

$F = 4 + 20 = 24$ N

Similarly, equation of motion of 20 cm apart is $32 - F = m'a = 2 \times 4$

$F = 32 - 8 = 24$ N

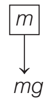
14 Initially system, is in equilibrium with a total weight of $4mg$ over spring.



$\therefore \quad kx = 4mg$

When string is cut at the location as shown above.

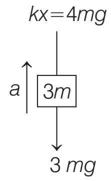
Free body diagram for m is



So, force on mass $m = mg$

$\therefore$ Acceleration of mass, $m = g$

For mass $3m$; free body diagram is



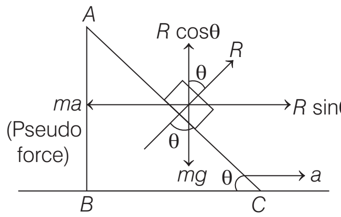
If a = acceleration of block of mass $3m$, then $F_{\text{net}} = 4mg - 3mg$

$\Rightarrow \quad 3m \cdot a_A = mg$ or $a_A = \frac{g}{3}$

So, accelerations for blocks A and B are

$a_A = \frac{g}{3}$ and $a_B = g$

15. According to the question, the FBD of the given condition will be



Since, the wedge is accelerating towards right with a, thus a pseudo force acts in the left direction in order to keep the block stationary. As, the system is in equilibrium.

$\therefore \quad \Sigma F_x = 0$ or $\Sigma F_y = 0$

$\Rightarrow \quad R \sin\theta = ma$

or $\quad mg \sin\theta = ma \quad$ ...(i)

Similarly, $\quad R\cos\theta = mg$

or $\quad mg\cos\theta = mg \quad$ ...(ii)

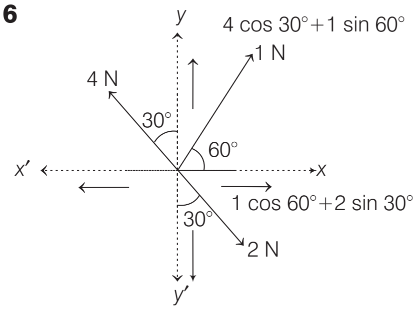
Dividing Eq. (i) by Eq (ii), we get

$\frac{mg \sin\theta}{mg \cos\theta} = \frac{ma}{mg} \Rightarrow \tan\theta = \frac{a}{g}$

or $\quad a = g \tan\theta$

$\therefore$ The relation between a and g for the block to remain stationary on the wedge is $a = g \tan\theta$.

16



Breaking all the forces in X and Y-axis.

Total force along $(+x)$ axis

$= (1\cos 60° + 2\sin 30°)$

along $(-X)$ axis $= (4\sin 30°)$

along $(+Y)$ axis $= (4\cos 30° + 1\sin 60°)$

along $(-Y)$ axis $= (2\cos 30°)$

$\Rightarrow$ Net force along X-axis

$= -(1\cos 60° + 2\sin 30°) + 4\sin 30°$

$\Rightarrow \quad -\left(\frac{1}{2} + 2 \times \frac{1}{2}\right) + 4 \times \frac{1}{2}$

$\Rightarrow \quad \frac{-3}{2} + 2 = +\frac{1}{2}$

Net force along Y-axis

$= 4\cos 30° + 1\sin 60° - 2\cos 30°$

$= 4 \times \frac{\sqrt{3}}{2} + \frac{\sqrt{3}}{2} - 2 \times \frac{\sqrt{3}}{2}$

$= \frac{5\sqrt{3}}{2} - \frac{2\sqrt{3}}{2}$

$= \frac{3\sqrt{3}}{2}$

To have, resultant only in Y-axis we must have $\frac{1}{2}$ N force towards $+X$-axis, so that it can compensate the net force of $-X$ axis.