Date: 13/10/2021

Q1. What is inertia? What gives the measure of inertia?

Q2. From which Newton's law of motion, the definition of force comes?

Q3. Is Newton's second law ($F = Ma$) always valid. Give an example in support of your answer.

Q4. Action and reaction forces do not balance each other. Why?

Q5. Name the quantity that remains conserved in rocket propulsion.

Q6. How may Newton's make on kg wt?

Q7. Action and reaction are equal and opposite. Why do they not balance each other?

Q8. In the study of rocket propulsion $\vec{F} = m\vec{a}$ cannot be applied. Why?

Q9. Is force needed to keep a body moving with uniform velocity?

Q10. A body of mass 10 kg is moving with a velocity of 100 cm s^{-1}. Find the magnitude of force required to stop it in 10 seconds. How much distance will it move through before coming to rest?

Q11. A motor car of mass 200 kg is moving with a velocity of 72 km/hr. By the application of brakes it is brought to rest in a distance of 100 metre. Find the average force resisting the motion.

Q12. Two masses are in the ratio 1 : 5. What is the ratio of their inertia?

Q13. Give the magnitude and direction of the net force acting on a drop of rain falling down with a constant speed.

Q14. Give the magnitude and direction of the net force acting on a kite skilfully held stationary in the sky.

Q15. The motion of a particle of mass m is described by $y = ut + \frac{1}{2}gt^2$. Find the force acting on the particle.

Q16. An astronaut accidentally gets separated out of his small spaceship accelerating in inter stellar space at a constant rate of 100 m s^{-2}. What is the acceleration of the astronaut the instant after he is outside the spaceship? (Assume that there are no nearby stars to exert gravitational force on him.)

Q17. A bullet of mass 0.04 kg moving with a speed of 90 m s^{-1} enters a heavy wooden block and is stopped after a distance of 60 cm. What is the average resistive force exerted by the block on the bullet?

Q18. Give the magnitude and direction of the net force acting on a cork of mass 10 g floating on water.

Q19. Give the magnitude and direction of the net force acting on a high-speed electron in space far from all material objects, and free of electric and magnetic fields.

Q20. Give the magnitude and direction of the net force acting on a car moving with a constant velocity of 30 km/h on a rough road.

Q21. The assertion made by the Newton's first law of motion that every body continues in its state uniform motion in the absence of external force appears to be contradicted in everyday experience. Why?

Q22. Why a horse cannot pull a cart and run in the empty space?

Q23. The forces F_1, F_2 and F_3 are acting on a particle of mass *m*, such that F_2 and F_3 are mutually perpendicular and under their effect, the particle remains stationary. What will be the acceleration of the particle, if the force F_1 is removed?

Q24. A disc of mass *m* is placed on a table. A stiff spring is attached to it and is vertical. To the other end of the spring is attached a disc of negligible mass. What minimum force should be applied to the upper disc to press the spring such that the lower disc is lifted off the table when the external force is suddenly removed?

Q25. A force of 128 gf acts on a mass of 490 g for 10 s. What velocity will it give to the mass?

Q26. An elevator weighing 5,000 kgf is moving upward and tension in the supporting cable is 50,000 N. Find the upward acceleration. How far does it rise in a time of 10 seconds starting from rest?

Q27. A body having a mass of 100 gm falls freely under the action of gravity. What is the force that acts on it? Calculate the momentum it possesses after 10 seconds.

Q28. A 20 gram bullet moving at 300 metre per second stops after penetrating 3 cm of bone. Calculate the average force it exerts.

Q29. A constant force acting on a body of mass 3.0 kg changes its speed from 2.0 $m\,s^{-1}$ to 3.5 $m\,s^{-1}$ in 25 s. The direction of the motion of the body remains unchanged. What is the magnitude and direction of the force?

Q30. A constant retarding force of 50 N is applied to a body of mass 20 kg moving initially with a speed of 15 ms^{-1}. How long does the body take to stop?

Q31. A motor car running at the rate of 7 m/sec can be stopped by its brakes in 10 meters prove that the total resistance to the car's motion, when the brakes are on, is one-quarter of the weight of the car.

Q32. On turning a corner, a car driver rushing at 72 km/hr, finds a child 50 m ahead. He immediately applies brakes and just saves the child. Calculate the retarding force and the time required to stop the car. The total weight of the car and passengers is 250 kg.

Q33. A body of mass 5 kg is acted upon by two perpendicular forces 8 N and 6 N. Give the magnitude and direction of the acceleration of the body.

Q34. A passenger of mass 72.2 kg is riding in an elevator which is standing on a platform scale. What does the scale read when the elevator cab is (a) descending with constant velocity (b) ascending with acceleration 3.20 $m\,s^{-2}$?

Q35. A bob of mass 0.1 kg hung from the ceiling of a room by a string 2 m long is set into oscillation. The speed of the bob at its mean position is 1 $m\,s^{-1}$. What is the trajectory of the bob if the string is cut when the bob is (a) at one of its extreme position. (b) at one of its mean position.

Q36. A force of 9 newton pulls block of mass 4 kg through a rope of mass 0.5 kg. The block is resting on a smooth surface. What is the force of reaction exerted by the block on the rope?

Q37. A spring balance is attached to the ceiling of a stationary lift. A man suspends a block from the hook of the spring balance and the balance reads 98 N. what will be the reading of the spring balance, if the lifts starts moving downward with an acceleration of 2 $m\,s^{-2}$?

Q38. A hydrogen gas filled balloon having a mass of 25 g is released up in the air. As the balloon ascends, the gas starts leaking from it with a uniform velocity of 12 $cm\,s^{-1}$ and as a result, the balloon shrinks completely in 5 s. Find average forces acting on the balloon.

Q39. A force acts for 10 s on a body of mass 10 kg after which the force ceases and the body covers 50 m in the next 5 s. Find the magnitude of the force.

Q40. The motion of a body of mass M is described by the equation

$S = ut + \frac{1}{2}at^2$ Find the force acting on the body.

Q41. A bullet of mass 0.04 kg moving with a speed of 90 $m\,s^{-1}$ enters a heavy wooden block and is stopped after a distance of 60 cm. What is the average resistive force exerted by the block on the bullet?

Q42. A rocket with a lift-off mass 20,000 kg is blasted upwards with an initial acceleration of 5.0 $m\,s^{-2}$. Calculate the initial thrust (force) of the blast.

Q43. If, in Exercise 5.21, the speed of the stone is increased beyond the maximum permissible value, and the string breaks suddenly, which of the following correctly describes the trajectory of the stone after the string breaks:

(a) the stone moves radially outwards,

(b) the stone flies off tangentially from the instant the string breaks,

(c) the stone flies off at an angle with the tangent whose magnitude depends on the speed of the particle?

Q44. For ordinary terrestrial experiments, which of the observers below are inertial and which are non-inertial:

(a) a child revolving in a giant wheel.

(b) a driver in a sports car moving with a constant high speed of 200 $km\,h^{-1}$ on a straight road.

(c) the pilot of an aeroplane which is taking off.

(d) a cyclist negotiating a sharp turn.

(e) the guard of a train which is slowing down to stop at a station.

Q45. The driver of a three-wheeler moving with a speed of 36 km/h sees a child standing in the middle of the road and brings his vehicle to rest in 4.0 s just in time What is the average retarding force on the vehicle? The mass of the three-wheeler is 400 kg and the mass of the driver is 65 kg.

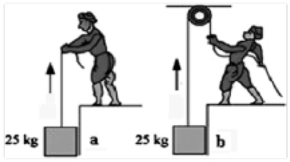
Q46. A truck starts from rest and accelerates uniformly at 2.0 $m\,s^{-2}$. At t = 10s, a stone is dropped by a person standing on the top of the truck (6 m high from the ground). What are the velocity, and acceleration of the stone at t = 11 s? (Neglect air resistance.)

Q47. A pebble of mass 0.05 kg is thrown vertically upwards. Give the direction and magnitude of the net force on the pebble, during its upward motion, during its downward motion, at the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at an angle of 45° with the horizontal direction? Ignore air resistance.

Q48. A body of mass 5 kg is acted upon by two perpendicular forces 16 N and 12 N. Find the magnitude and direction of the acceleration

Q49. For three moving objects the distance are found to be directly proportional to the times t, t^2 and t^3. What is the nature of the net force on each object?

Q50. A block of mass 25 kg is raised by a 50 kg man in two different ways as shown in figure. What is the action on the floor by the man in the two cases? If the floor yields to a normal force of 700 N, which mode floor yielding?



Q51. State Newton's Second law of motion. Prove that second law is the real law of motion.

Q52. (a) A force of 9 newton pulls block of mass 4 kg through a rope of mass 0.5 kg. The block is resting on a smooth surface. What is the force of reaction exerted by the block on the rope?

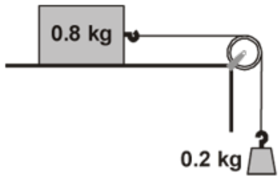
(b) A heavy load of mass 600kg is placed on the weighing machine lying in a lift. What will be reading of the weighing machine, when the lift is (a) at rest (b) moving upwards with an acceleration of 2.2 ms^{-2}, (c) moving downwards with an acceleration of 2.8 ms^{-2} and (d) falling freely due to the rupture of the cable?

Q53. State Newton first law. Discuss how the principle of conservation of momentum is used in the launching of rockets. Deduce an expression for, (a) velocity at any instant and (b) acceleration of the rocket and force experienced.

Q54. What is Inertia? A car starts from rest and accelerates uniformly with 2 ms^{-2}. At t = 10 s, a stone is dropped out of the window (1 m high) of the car. What are the (a) velocity and (b) acceleration of the stone at t = 10.1 s? (Neglect air resistance). Take, g = 9.8 ms^{-2}.

Q55. (a) A bullet of mass 0.04 kg moving with a speed of 90 $m\,s^{-1}$ enters a heavy wooden block and is stopped after a distance of 60 cm. What is the average resistive force exerted by the block on the bullet?

(b) A block of mass 0.8 kg is dragged along a level surface at constant velocity by a hanging block of mass 0.2 kg as shown in the figure
Calculate the tension in the string and the acceleration of the system.



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S1. The inherent property of the bodies that they do not change state unless acted upon by an external force is called ***inertia***.

Mass of the body gives the measure of its inertia.

S2. First law of motion, every body continues in its state of rest of uniform motion in a straight line, unless it is compelled by some external force to change that state.

S3. It is valid in an inertial frame of reference. In a non-inertial frame of reference (such as a car moving along a circular path), Newton's second law does not hold apparently.

S4. When one body exerts force on another body, it gets an equal and opposite reaction. The action and reaction forces do not cancel each other, as they do not act on the same body.

S5. Momentum, since no external force acts.

S6. 1 kg wt. = 9.8 N.

S7. They always act on the two bodies in contact and not on the same body.

S8. Mass varies at every moment.

S9. No.

S10. Here $m = 10$ kg, $t = 10$ sec, $v = 0$ $u = 100$ cms^{-1} = 1 ms^{-1}

∴ Acceleration $a = \dfrac{v-u}{t} = \dfrac{0-1}{10} = -0.1\,\text{m s}^{-2}$

∴ Retarding force $-F = m \times a = 10 \times 0.1 = 1$ N

$$S = \frac{v^2-u^2}{2a} = \frac{0-1\times 1}{-2\times 0.1} = 5\,\text{m}$$

S11. Here $m = 200$ kg, $S = 100$ m, $v = 0$, $u = 72$ km/hr = 20 ms^{-1}

We know $v^2 = u^2 + 2aS$

$$a = \frac{v^2-u^2}{2S} = \frac{0^2-20^2}{2\times 100} = 2\,\text{ms}^{-2}$$

$= 2$ ms^{-2}

$F = m \times a = 200 \times 2 = 400$ N

S12. Mass is a measure of inertia.

Hence the inertia is 1 : 5.

S13. Zero net force.

The rain drop is falling with a constant speed. Hence, it acceleration is zero. As per Newton's second law of motion, the net force acting on the rain drop is zero.

S14. Zero net force.

The kite is stationary in the sky, i.e., it is not moving at all. Hence, as per Newton's first law of motion, no net force is acting on the kite.

S15. We know, $y = ut + \frac{1}{2}gt^2$

Now, $v = \frac{dy}{dt} = u + gt$

acceleration, $a = \frac{dv}{dt} = g$

Then the force is $F = ma = mg$.

S16. Since there are no nearby stars to exert gravitational force on him and the small spaceship exerts negligible gravitational attraction on him, the net force acting on the astronaut, once he is out of the spaceship, is zero. By the first law of motion the acceleration of the astronaut is zero.

S17. The retardation '*a*' of the bullet (assumed constant) is given by

$$a = \frac{-u^2}{2s} = \frac{-90 \times 90}{2 \times 0.6}\ \text{m s}^{-2} = -6750\ \text{m s}^{-2}$$

The retarding force, by the second law of motion, is

$$= 0.04\ \text{kg} \times 6750\ \text{m s}^{-2} = 270\ \text{N}$$

The actual resistive force, and therefore, retardation of the bullet may not be uniform. The answer therefore, only indicates the average resistive force.

S18. Zero net force.

The weight of the cork is acting downward. It is balanced by the buoyant force exerted by the water in the upward direction. Hence, no net force is acting on the floating cork.

S19. Zero net force.

The high speed electron is free from the influence of all fields. Hence, no net force is acting on the electron.

S20. Zero net force.

The car is moving on a rough road with a constant velocity. Hence, its acceleration is zero. As per Newton's second law of motion, no net force is acting on the car.

S21. When we roll a ball on the floor, it ultimately stops because of the force of friction of the ground. Thus, the state of uniform motion of the object changes due to the external force (friction). On the earth, every change uniform motion of a body can be connected with some external force acts, the state of motion described by the Newton's first law can't be obtained and experienced.

S22. To pull the cart, a horse pushes the ground in backward direction with its feet. the reaction from the ground makes the cart to move forward. In an empty space, the horse can not push in backward direction and get a forward reaction. That is why, a horse cannot pull a cart and run in the empty space.

S23. The particle is stationary under the action of forces F_1, F_2 and F_3. It implies that the force F_1 is equal and opposite to the resultant of the forces F_2 and F_3. Therefore, if force F_1 is removed, the particle will move under the action of force $-F_1$. Hence, the acceleration of the particle,

$$a = -\frac{\mathbf{F_1}}{\mathbf{m}}.$$

S24. The minimum force should be *mg*. When a force *mg* is applied vertically downwards on the upper disc, the lower disc will be pressed against the floor with a force mg. The floor will exert an upward reaction *mg*. When the external force is suddenly removed, this reaction will just lift the lower disc.

S25. Given: $F = 128\,\text{gf} = 128 \times 980\,\text{dyne}; \quad M = 490\,\text{g}$

Now, $a = \frac{F}{M} = \frac{128 \times 980}{490} = 256\,\text{cm s}^{-2} = 2.56\,\text{ms}^{-2}$

Also, $v = u + at$

Here, $u = 0$ and $t = 10\,\text{s}$

$\therefore$ $v = 0 + 2.56 \times 10 = \mathbf{25.6\ ms^{-1}}$.

S26. Given: Weight of the elevator, $Mg = 5{,}000\,\text{kgf}$ and tension in the supporting cable, $T = 50{,}000\,\text{N}$

Let *a* be the upward acceleration of the elevator. Then,

T = Apparent weight of the elevator = $M(g + a)$

or $50{,}000 = 5{,}000\,(9.8 + a)$

or $a = \mathbf{0.2\ ms^{-2}}$.

Let *S* be the distance moved by the elevator in 10 s. Then,

$$S = 0 \times 10 + \frac{1}{2} \times 0.2 \times 10^2 = \mathbf{10\ m}.$$

S27. (a) As the body is falling under the action of gravity g = 9.8 m/sec^2 and mass = 100 gm = 0.1 kg

$\therefore$ Force = m $\times$ a = 0.1 $\times$ 9.8 = **0.98 N**

(b) As the body falls from rest, hence the initial velocity u = 0

Let *v* be the velocity acquired by the body after 10 sec, then

$v = u + gt = 0 + 9.8 \times 10 = 98\,\text{ms}^{-1}$

Momentum $p = mv = 0.1 \times 98 = \mathbf{9.8\ kg - m/sec}$.

S28. Here u = 300 m/sec, m = 20 gm = 0.02 kg

As the bullet stops after penetrating 3 cm of the bone

$\therefore$ Final velocity $v = 0$; Distance S = 3 cm = 0.03 m

We know $v^2 = u^2 + 2aS$

Acceleration $a = \dfrac{v^2 - u^2}{2S} = \dfrac{0^2 - 300^2}{2 \times 0.03} = -15 \times 10^5 \text{ ms}^{-2}$

Minus sign indicates retardation.

$\therefore$ Retarding force $F = 0.02 \times 15 \times 10^5 = 3 \times 10^4$ N

S29. Mass of the body, $m = 3$ kg

Initial speed of the body, $u = 2$ m/s

Final speed of the body, $v = 3.5$ m/s

Time, $t = 25$ s

Using the first equation of motion, the acceleration (a) produced in the body can be calculated as:

$$v = u + at$$

$$\therefore \quad a = \frac{v - u}{t}$$

$$= \frac{3.5 - 2}{25} = \frac{1.5}{25} = 0.06 \text{ m/s}^2$$

As per Newton's second law of motion, force is given as:

$$F = ma$$

$$= 3 \times 0.06 = 0.18 \text{ N}$$

Since the application of force does not change the direction of the body, the net force acting on the body is in the direction of its motion.

S30. Retarding force, $F = -50$ N

Mass of the body, $m = 20$ kg

Initial velocity of the body, u

Final velocity of the body, $v = 0$

Using Newton's second law of motion, the acceleration (a) produced in the body can calculated as:

$$F = ma$$

$$-50 = 20 \times a$$

$$\therefore \quad a = \frac{-50}{20} = -2.5 \text{ m/s}^2$$

Using the first equation of motion, the time (t) taken by the body to come to rest can be calculated as:

$$v = u + at$$

$$\therefore \quad t = \frac{-u}{a} = \frac{-15}{-2.5} = 6\,s$$

S31. Here u = 7 m/sec, S = 10 m

$$\therefore \quad \text{Acceleration} \quad a = \frac{v^2 - u^2}{2S} = \frac{-7 \times 7}{2 \times 10} = -2.45\,\text{ms}^{-2}$$

or Retardation = + 2.45 ms^{-2}

$$\therefore \quad \text{Retarding force} \quad F = m \times 2.45\ \text{N}$$

$$W = mg = m \times 9.8\ \text{N}$$

$$\therefore \quad \frac{F}{W} = \frac{m \times 2.45}{m \times 9.8} = \frac{1}{4}$$

$$\text{or} \quad F = \frac{W}{4}$$

Hence the retarding force is one-fourth of the weight of the car.

S32. Here u = 72 km/hour = 20 m/sec ; Distance travelled before stopping S = 50 m

$$\therefore \quad \text{Acceleration,} \quad a = \frac{v^2 - u^2}{2 \times S} = \frac{0^2 - 20}{2 \times 50} = -4\,\text{ms}^{-2}$$

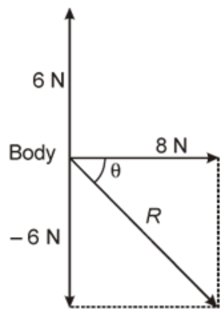
Minus sign means retardation.

$$\therefore \quad \text{Retarding force} \quad F = m \times a = 250 \times 4 = 1000\text{N}.$$

$$\text{Time to stop the car} \quad t = \frac{v - u}{a} = \frac{-20}{-4} = 5\,\text{sec}.$$

S33. Mass of the body, m = 5 kg

The given situation can be represented as follows:



The resultant of two forces is given as: $F = \sqrt{8^2 + 6^2} = \sqrt{100} = 10\,\text{N}$

θ is the angle made by R with the force of 8 N

$$\therefore \quad \theta = \tan^{-1}\left(\frac{-6}{8}\right) = -36.87^\circ$$

The negative sign indicates that θ is in the clockwise direction with respect to the force of magnitude 8 N.

As per Newton's second law of motion, the acceleration (a) of the body is given as

$$F = ma$$

$$\therefore \qquad a = \frac{F}{m} = \frac{10}{5} = 2\,\text{m/s}^2$$

S34. Given, $m = 72.2$ kg

(a) In this case, acceleration = 0

Apparent weight, R = True weight mg

or $R = 72.2 \times 9.8$ N = 707.56 N

(b) In case, the upward acceleration a is 3.20 ms^{-2}.

$$R = mg + ma = m(g + a)$$
$$= 72.2\ (9.8 + 3.2)\ \text{N}$$
$$= 72.2 \times 13\text{N} = 938.6\ \text{N}$$

S35. (a) Vertically downward

At the extreme position, the velocity of the bob becomes zero. If the string is cut at this moment, then the bob will fall vertically on the ground.

(b) Parabolic path

At the mean position, the velocity of the bob is 1 m/s. The direction of this velocity is tangential to the arc formed by the oscillating bob. If the bob is cut at the mean position, then it will trace a projectile path having the horizontal component of velocity only. Hence, it will follow a parabolic path.

S36. Force, $F = 9$ N

Mass of block = 4 kg; Mass of rope = 0.5 kg

Total mass pulled by the given force, m = 4.5 kg

Acceleration, $a = \dfrac{9N}{4.5\,\text{kg}} = 2\,\text{m s}^{-2}$

Force of reaction exerted by block on rope

= Mass of block × Acceleration

= 4 kg × 2 m s^{-2} = 8 N

S37. When the lift is stationary:

The reaction is equal to weight of the block *i.e.*

$$R = Mg = 98\ \text{N}$$

$$M = \frac{98}{g} = \frac{98}{9.8} = 10\ \text{kg}$$

When the lift is moving:

Let R' be reaction, when the lift is moving with acceleration a = 2 ms^{-2} in downward direction. Then,

$$R' = M(g - a) = 10 \times (9.8 - 2) = \mathbf{78\,N}.$$

S38. Given, Mass of the balloon, $M = 25\,g$

Velocity of the escaping gas, $v = 12$ cm s^{-1}

According to Newton's second law of motion,

$$F = v\frac{dM}{dt}$$

Here, velocity of the balloon is constant but its mass is varying with time.

$$\therefore \quad F = v\frac{d}{dt}(M)$$

As 25 g of the gas leaks in 5s,

$$\frac{dM}{dt} = \frac{25}{5} = 5g\ s^{-1}$$

Hence, $F = 12 \times 5 =$ **60 dyne**.

S39. Here, initial velocity of the body, $u = 0$,

Mass (M) =10 kg and time (t) = 10 sec

After the force ceases, the body covers 50 m in 5 s. Therefore, final velocity of the body,

$$v = \frac{\text{distance}}{\text{time}} = \frac{50}{5} = 10\ m\,s^{-1}$$

Now, $v = u + at$

$\therefore$ $10 = 0 + a \times 10$

or $a = 1\ m\,s^{-2}$

Therefore, force applied on the body,

$$F = Ma = 10 \times 1 = \mathbf{10\,N}.$$

S40. Given: $S = ut + \frac{1}{2}at^2$

The velocity of the body is given by

$$v = \frac{dS}{dt} = \frac{d}{dt}\left(ut + \frac{1}{2}at^2\right) = u \times 1 + \frac{1}{2}a \times 2t$$

or $v = u + at$

Now, the acceleration of the body is given by

$$a = \frac{dv}{dt} = \frac{d}{dt}(u + at) = 0 + a \times 1 = a$$

Therefore, force acting on the body,

$$F = M \times a = \boldsymbol{Ma}.$$

S41. Given $u = 90\ \text{m s}^{-1}$, $v = 0$, $S = 60\ \text{cm} = 0.6\ \text{m}$, $a = ?$

We know that $v^2 - u^2 = 2as$

or $0^2 - 90^2 = 2 \times a \times 0.6$

$$a = \frac{-90 \times 90}{2 \times 0.6}\text{m s}^{-2} = -6750\ \text{m s}^{-2}$$

Retardation $= 6750\ \text{m s}^{-2}$

$\therefore$ Retarding force $= 0.04\ \text{kg} \times 6750\ \text{m s}^{-2} = 270\ \text{N}$

S42. Mass of the rocket, $m = 20{,}000\ \text{kg}$

Initial acceleration, $a = 5\ \text{m/s}^2$

Acceleration due to gravity, $g = 10\ \text{m/s}^2$

Using Newton's second law of motion, the net force (thrust) acting on the rocket is given by the relation:

$$F - mg = ma$$

$$F = m(g + a)$$

$$= 20000 \times (10 + 5)$$

$$= 20000 \times 15 = 3 \times 10^5\ \text{N}.$$

S43. Answer: (b)

When the string breaks, the stone will move in the direction of the velocity at that instant. According to the first law of motion, the direction of velocity vector is tangential to the path of the stone at that instant. Hence, the stone will fly off tangentially from the instant the string breaks.

S44. (a) A giant revolving wheel has accelerated (radially) motion. Therefore, a child revolving in a giant wheel is non-inertial.

(b) The sports car is moving with a constant speed on a straight road. Therefore, the driver in a sports car moving with a constant high speed ($200\ \text{km h}^{-1}$) on a straight road is inertial.

(c) As the aeroplane takes off, it has accelerated motion. Therefore, the pilot of an aeroplane, which is taking off is non-inertial.

(d) While negotiating a sharp turn, there is change in the direction of motion of the cyclist and hence the motion is accelerated. Therefore, a cyclist negotiating a sharp turn is non-inertial.

(e) When a train is slowing down to stop at a station, its motion is retarding. Therefore, the guard of a train which is slowing down to stop at a station acts as non-inertial observer.

S45. Initial speed of the three-wheeler u and final speed of the three-wheeler v,

Time, $t = 4$ s

Mass of the three-wheeler, $m = 400$ kg

Mass of the driver, $m' = 65$ kg

Total mass of the system, $M = 400 + 65 = 465$ kg

Using the first law of motion, the acceleration (a) of the three-wheeler can be calculated as:

$$v = u + at$$

$$\therefore \quad a = \frac{v-u}{t} = \frac{0-10}{4} = -2.5\ \text{m/s}^2$$

The negative sign indicates that the velocity of the three-wheeler is decreasing with time.

Using Newton's second law of motion, the net force acting on the three-wheeler can be calculated as:

$$F = Ma$$

$$= 465 \times (-2.5) = -1162.5\ \text{N}$$

The negative sign indicates that the force is acting against the direction of motion of the three-wheeler.

S46. Initial velocity of the truck, $u = 0$

Acceleration, $a = 2$ m/s^2

Time, $t = 10$ s

As per the first equation of motion, final velocity is given as:

$$v = u + at$$

$t = 10$ s, final velocity is given as:

$$= 0 + 2 \times 10 = 20\ \text{m/s}$$

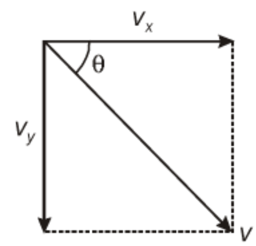
The final velocity of the truck and hence, of the stone is 20 m/s.

At $t = 11$ s, the horizontal component (v_x) of velocity, in the absence of air resistance, remains unchanged, *i.e.*,

$$v_x = 20\ \text{m/s}$$

The vertical component (v_y) of velocity of the stone is given by the first equation of motion as:

$$v_y = u + a_y \Delta t$$



Where, $\Delta t = 11 - 10 = 1$ s

and $a_y = g = 10$ m/s^2

$\therefore \quad v_y = 0 + 10 \times 1 = 10$ m/s

The resultant velocity (v) of the stone is given as:

$$v = \sqrt{v_x^2 + v_y^2}$$

$$= \sqrt{20^2 + 10^2} = \sqrt{400 + 100}$$

$$= \sqrt{500} = 22.36 \text{ m/s}$$

Let θ be the angle made by the resultant velocity with the horizontal component of velocity, v_x

$$\therefore \qquad \tan\theta = \left(\frac{v_y}{v_x}\right)$$

$$\theta = \tan^{-1}\left(\frac{10}{20}\right)$$

$$= \tan^{-1}(0.5)$$

$$= 26.57°$$

When the stone is dropped from the truck, the horizontal force acting on it becomes zero. However, the stone continues to move under the influence of gravity. Hence, the acceleration of the stone is 10 m/s^2 and it acts vertically downward.

S47. Acceleration due to gravity, irrespective of the direction of motion of an object, always acts downward. The gravitation three cases. Its magnitude is given by Newton's second law of motion as:

$$F = ma$$

Where, F = Net force

m = Mass of the pebble = 0.05 kg

a = g = 10 m/s^2

$\therefore \qquad F = 0.05 \times 10 = 0.5$ N.

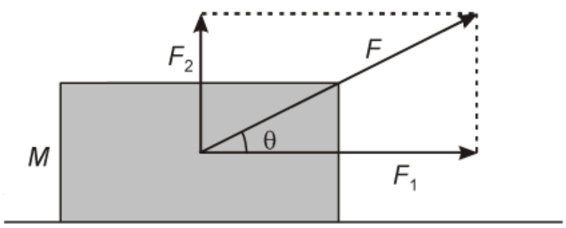
The net force on the pebble in all three cases is 0.5 N and this force acts in the downward direction.

If the pebble is thrown at an angle of 45° with the horizontal, it will have both the horizontal and vertical components of velocity. At the highest point, only the vertical component of velocity becomes zero. However, the pebble will have the horizontal component of velocity throughout its motion. This component of velocity produces no effect on the net force acting on the pebble.

S48. The two perpendicular force F_1 = 16 N and F_2 = 12 N act on the body as shown in the figure below

The magnitude of the resultant force is given by

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{16^2 + 12^2} = 20 \text{ N.}$$



Therefore, magnitude of the acceleration produced,

$$a = \frac{F}{M} = \frac{20}{5} = \mathbf{4\ ms^{-2}}.$$

The acceleration will be produced along the direction of resultant force F. If the resultant force F makes an angle θ with the direction of force F_1, then

$$\cos\theta = \frac{F_1}{F} = \frac{16}{20} = 0.8$$

or $\theta =$ **36.87°** (with 8 N force).

S49. **Case I:** When $x \propto t, \quad x = kt$

As $F = ma$

$$= \frac{mv}{t} = m\frac{(x/t)}{t} = \frac{mx}{t^2}$$

When

$\Rightarrow$ $$F = \frac{m(kt)}{t^2} = \frac{km}{t}$$

i.e., $$F \propto \frac{1}{t}$$

$\therefore$ Net force on the object is inversely proportional to t.

Case II: Similarly, when $x \propto t^2$

$\therefore$ Net force on the object is independent to t.

Case III: Similarly, when $x \propto t^3$

$F \propto t$

So, net force F on the object is directly proportional to the time.

S50. Given, Mass of the block, $m = 25$ kg

Mass of the man, $M = 50$ kg

Acceleration due to gravity, $g = 10$ m/s^2

Force applied on the block, $F = 25 \times 10 = 250$ N

Weight of the man, $W = 50 \times 10 = 500$ N

Case I: When the man lifts the block directly. In this case, the man applies a force in the upward direction. This increases his apparent weight.

$\therefore$ Action on the floor by the man = 250 + 500 = 750 N

Case II: When the man lifts the block using a pulley. In this case, the man applies a force in the downward direction. This decreases his apparent weight.

$\therefore$ Action on the floor by the man = 500 – 250 = 250 N

If the floor can yield to a normal force of 700 N, then the man should adopt the second method to easily lift the block by applying lesser force.

S51. (a) ***Newton's Second law:*** The total unbalanced external force acting on a mass is the product of its mass (m) and acceleration (a), *i.e.*, $F = ma$.

I Law and II Law: According to II law, force experienced is the product of mass and acceleration. When there is no force, the mass does not accelerate and retains the same status. So the view of I law, *i.e.*, when there is no force the body maintains the status of motion.

III Law and II Law: Consider two masses m_1 and m_2 exerting force on each other (internal forces). If their change in momentum are dp_1 and dp_2 then,

$$dp_1 + dp_2 = 0.$$

Since no external force acts on the system of two masses.

$$\therefore \qquad \frac{dp_1}{dt} = -\frac{dp_2}{dt} \qquad i.e., \quad F_1 = -F_2$$

i.e., force experienced by m_1 due to m_2 and by m_2 due to m_1 are equal and opposite, confirming action and reaction.

Since both laws can be derived from second law, so it is real law of motion.

S52. (a) Force, $F = 9$ newton

Mass of block = 4 kg; Mass of rope = 0.5 kg

Total mass pulled by the given force, $m = 4.5$ kg

Acceleration, $a = \dfrac{9N}{4.5\text{ kg}} = 2\text{ m s}^{-2}$

Force of reaction exerted by block on rope

= Mass of block $\times$ Acceleration

= 4 kg $\times$ 2 m s^{-2} = 8 newton.

(b) When a mass M moves with an acceleration a, its apparent weight is given by

$$R = M(g \pm a)$$

The positive sign is taken when the lift moves upwards and the negative sign, when the lift moves downwards.

(i) Given: $M = 600$ kg; $g = 9.8\text{ ms}^{-2}$; $a = 0$

$\therefore \quad R = M(g \pm a) = 600 \times (9.8 \pm 0) =$ **5,880 N**

(ii) Given: $M = 600$ kg; $g = 9.8\text{ ms}^{-2}$; $a = 2.2\text{ ms}^{-2}$

$\therefore \quad R = M(g + a) = 600 \times (9.8 + 2.2) =$ **7,200 N**

(iii) Given: $M = 600$ kg; $g = 9.8\text{ ms}^{-2}$; $a = 2.8\text{ ms}^{-2}$

$\therefore \qquad R = M(g - a) = 600 \times (9.8 - 2.8) = \mathbf{4,200\ N}$

(iv) Given: $M = 600$ kg; $a = g = 9.8$ ms^{-2}

$\therefore \qquad R = M(g - a) = 600 \times (9.8 - 9.8) = \mathbf{0}$.

S53. Newton's first law of motion states that every body continues in its state of rest or of uniform motion in a straight line, unless it is compelled with some external force to change that state.

Consider a rocket with initial mass M_i burning dM amount of fuel in a time dt, to be released with a constant velocity u in the form of fumes. If the mass at any instant of the rocket is M then applying the conservation of momentum, we have

(change in momentum of burnt fuel) = – (Change in momentum of rocket and its contents.)

$\therefore$ $udM = -Mdv$, where du refers to change in velocity of rocket.

(a)
$$udM = -Mdv$$

$$\therefore \qquad dv = -u\frac{dM}{M} \qquad \text{... (i)}$$

Integrating Eq. (i),

$$\int_0^v dv = u\int_{M_i}^{M} \frac{dM}{M}$$

$$v = -u|\log_e M|_{M_i}^{M}$$

$$= -u(\log_e M - \log_e M_i)$$

$$\therefore \qquad v = u\left[\log_e \frac{M_i}{M}\right]$$

(b)
$$udM = -Mdv, \qquad \text{... (ii)}$$

Eq. (ii) defferentiate w.r.t. to 't'

$$\frac{dv}{dt} = -\frac{u\,dM/dt}{M}$$

$$\Rightarrow \qquad a = -\frac{u\,dM/dt}{M}$$

Now, multiply both side M, we get

Therefore, the force or thrust experienced

$$Ma = -u\frac{dM}{dt}$$

$$F = -u\frac{dM}{dt}.$$

S54. It is that property by virtue of which a body in a state of uniform motion tends to maintain its uniform motion.

Given: Initial velocity of the car, $u = 0$; Acceleration, $a = 2\,\text{ms}^{-2}$; time, $t = 10\,\text{s}$.

Now, velocity of the car after 10 s,

$$v = u + at = 0 + 2\times 10 = 20\ \text{ms}^{-1}$$

When the stone is dropped out of the car at $t = 10$ s, the stone will no longer possess the acceleration (2 ms^{-2} along the horizontal) of the car.

Therefore, after 10 s, the stone possesses the following two motions:

(a) Uniform motion with velocity 20 ms^{-1} along the horizontal and

(b) accelerated motion under gravity.

Therefore, at $t = 10.1$ s, the velocity of the stone along the horizontal, $v_x = 20\ \text{ms}^{-1}$.

The velocity of stone along vertical at $t = 10.1$ s *i.e.*, 0.1 s after being dropped out of the car,

$$v_y = 0 + 9.8 \times 0.1 = 0.98\ \text{ms}^{-1}$$

The resultant velocity of the stone at $t = 0.1$ s,

$$v' = \sqrt{v_x^2 + v_y^2} = \sqrt{(20)^2 + (0.98)^2}$$

$$= \sqrt{400 + 0.96} = \mathbf{20.02\ ms^{-1}}.$$

If θ is the angle, the stone makes with the horizontal, then

$$\tan\theta = \frac{v_y}{v_x} = \frac{0.98}{20} = 0.049$$

or $\theta = \mathbf{3.12°}$.

The acceleration of the stone at $t = 10.1$ s,

$$a' = g = 9.8\ \text{ms}^{-2}.$$

S55. (a) Given $u = 90\ \text{m s}^{-1}$, $v = 0$, $S = 60\ \text{cm} = 0.6\ \text{m}$, $a = ?$

We know that $v^2 = u^2 - 2as$

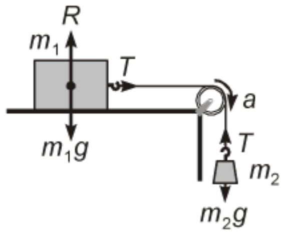
or $-90^2 = 2 \times a \times 0.6$

$$a = \frac{-90\times 90}{2\times 0.6}\text{m s}^{-2} = -6750\ \text{m s}^{-2}$$

Retardation $= -a = 6750\ \text{m s}^{-2}$

$\therefore$ Retarding force $= 0.04\ \text{kg} \times 6750\ \text{m s}^{-2} = 270\ \text{N}$

(b) The forces on the two blocks and tension in the string act in the direction as shown in the figure below



Suppose that the system of two blocks moves with an acceleration a. Along the horizontal, the block of mass m_1 is acted upon by the force due to tension in the string.

$\therefore$ $$m_1 a = T \quad \text{... (i)}$$

Since the block of mass m_2 moves with an acceleration a_2 in downward direction,

$$m_2 a = m_2 g - T \quad \text{... (ii)}$$

Adding the Eq. (i) and (ii), we get

$$a = \frac{m_2 g}{m_1 + m_2} = \frac{0.2 \times 9.8}{0.8 + 0.2} = 1.96 \text{ ms}^{-2}$$

From the equation (i), we get

$$T = 0.8 \times 1.96 = \mathbf{1.568\ N}.$$

Date: 13/10/2021

Q1. What is Impulse? Write its dimension.

Q2. What is an impulsive force?

Q3. Can a body remain in state of rest, when external forces are acting on it? Explain your answer.

Q4. Passengers in a bus fall back as it accelerates. Why?

Q5. Sudden motion on a blanket, removes dust. How?

Q6. The casting of a rocket in flight burns up due to friction. At whose expense is the heat energy required for burning obtained? The rocket or the atmosphere or both.

Q7. A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12 m s^{-1}. If the mass of the ball is 0.15 kg, determine the impulse imparted to the ball. (Assume linear motion of the ball.)

Q8. A cricket ball of mass 500 g is moving with speed of 36 km h^{-1}. It is reflected back with the same speed. What is the impulse applied on it?

Q9. A force of 16 N acts on a ball of mass 80 gm for one micro-second. Calculate the acceleration and impulse.

Q10. A body is accelerating with '*a*' m/s^2 while its mass is increasing at the rate of '*m*' What will be the force experienced by it?

Q11. (a) A soda water bottle is falling freely. Will the bubbles of gas rise in the water of the bottle?

(b) A bird is sitting on the floor of a wire cage and the cage is in the hands of a boy. The bird starts flying in the cage. Will the boy experience any change in the weight of the cage?

Q12. A force of 10 N acts on a body for 3 microsecond (μs). Calculate the impulse. If mass of the body is 5 g, calculate the change of velocity.

Q13. A body of mass 0.25 kg moving with velocity 12 ms^{-1} is stopped by applying a force of 0.6 N. Calculate the time taken to stop the body. Also calculate the impulse of this force.

Q14. A bullet moving with a velocity of 100 ms^{-1} pierces a block of wood and moves out with a velocity of 10 ms^{-1}. If the thickness of the block reduces to one half of the previous value, what will be the emerging velocity of the bullet?

Q15. A bullet of mass 60 g moving with a velocity of 500 ms^{-1} is brought to rest in 0.01 s. Find the impulse and the average force of blow.

Q16. A batsman hits a ball of mass 0.25 kg that was thrown towards him with a velocity of 10 ms^{-1} back towards the bowler with a speed of 20 ms^{-1}. If the time of collision is 0.05 s, compute the impulse and the average force exerted on the ball by the batsman.

Q17. A rubber ball of mass 0.05 kg falls from a height of 1 meter and rebounds to a height of 0.5 *m*. Find the impulse and the average force between the ball and the ground if the time during which they are in contact was 0.1 sec.

Q18. A stream of water flowing horizontally with a speed of 15 ms^{-1} cross-sectional area 10^{-2} m^2, and hits a vertical wall nearby. What is the force exerted on the wall by the impact of water, assuming it does not rebound?

Q19. A batsman deflects a ball by an angle of 45° without changing its initial speed which is equal to 54 km/h. What is the impulse imparted to the ball? (Mass of the ball is 0.15 kg.)

Q20. Two billiard balls each of mass 0.05 kg moving in opposite directions with speed 6 m s^{-1} collide and rebound with the same speed. What is the impulse imparted to each ball due to the other?

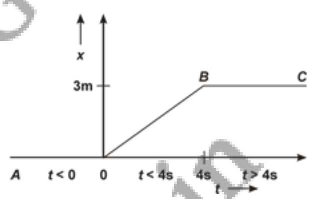
Q21. (a) Discuss graphical method for the measurement of impulse in the following case:

(i) When constant force acts on the body.

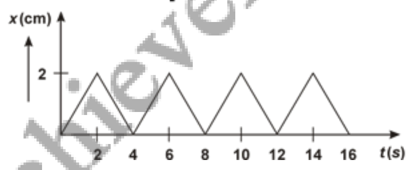
(ii) When a variable force acts on the body.

(b) Define impulsive force. A cricket ball of mass 150 gm moving with speed of 12 m/s is hit by a bat so that the ball is turned back with a velocity of 20 m/s. Calculate the impulse received by the ball.

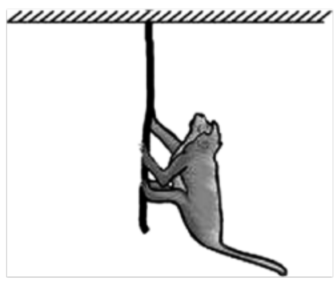
Q22. Figure shows the position-time graph of a particle of mass 4 kg. Find the impulse at $t = 0$ and $t = 4$ s. The motion may be considered one dimensional.



Q23. Figure shows the position-time graph of a body of mass 0.04 kg. Suggest a suitable physical context for this motion. What is the time between two consecutive impulses received by the body? What is the magnitude of each impulse?



Q24. A monkey of mass 40 kg climbs on a rope (as shown in the given figure) which can stand a maximum tension of 600 N. In which of the following cases will the rope break: (a) the monkey climbs up with an acceleration of 6 m s^{-2} (b) climbs down with an acceleration of 4 m s^{-2} (c) climbs up with a uniform speed of 5 m s^{-1} (d) falls down the rope nearly freely under gravity? (Ignore the mass of the rope).



Q25. A body of mass 0.40 kg moving initially with a constant speed of 10 ms^{-1} subject to a constant force of 8.0 N directed towards the south for 30 s. Take the instant the force is applied to be $t = 0$, the position of the body at that time to be predict its position at $t = -5$ s, 25 s, 100 s.

Q26. What is Impulse? A machine gun has a mass of 20 kg. It fires 35 g bullets at the rate of 400 bullets per second with a speed of 400 ms^{-1}. What force must be applied to the gun to keep it in position?

Q27. What is Impulse? A hammer of mass 1 kg moving with a speed of 6 ms^{-1} strikes a wall and comes to rest in 0.1 s. Calculate: (a) the impulse of force, (b) the retardation of the hammer, and (c) the retardation force that stops the hammer.

Q28. (a) A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12 m s^{-1}. If the mass of the ball is 0.15 kg, determine the impulse imparted to the ball. (Assume linear motion of the ball.)

(b) Weights of 50 g and 40 g are connected by a string passing over a smooth pulley. If the system travels 2.18 m in the first 2 seconds, find the value of *g*.

Q29. What is Impulse? A ball moving with a momentum of 15 kg ms^{-1} strikes against the wall at an angle of 30° and is reflected with the same momentum at the same angle. Calculate impulse.

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S1. Impulse received during an impact is defined as the product of the average force and the time for which the force acts.

It is denoted by J

$$\vec{J} = \vec{F}\,\Delta t$$

Its dimension formula of impulse is [MLT^{-1}].

S2. A force which acts for a small time and also varies with time is called an ***impulsive force***.

S3. 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.

S4. Due to inertia of rest.

S5. Due to inertia of rest.

S6. From the kinetic energy of rocket.

S7. Initial velocity of bowler = $12\hat{i}\ m s^{-1}$

Final velocity of bowler = $-12\hat{i}\ m s^{-1}$

Change in velocity,

$$\Delta\vec{v} = (-12\,\hat{i}) - 12\,\hat{i} = -24\,\hat{i}\ ms^{-1}$$

Change in momentum,

$$\Delta P = -0.15 \times 24\,\hat{i}\ N\,s = -3.6\,\hat{i}\ N\,s$$

Magnitude of change in momentum is 3.6 N s.

The direction is from batsman to bowler.

S8. **Given:** $M = 500\text{ g} = 0.5\text{ kg}$; $u = 36\text{ km h}^{-1} = 10\text{ ms}^{-1}$; $v = -10\text{ ms}^{-1}$.

Now, Impulse = $Mu - Mv = M(u - v)$

$= 0.5\,[10 - (-10) =$ **10 kg ms^{-1}**.

S9. Here $F = 16$ N ; Mass m = 80 gm = 0.08 kg

If a is the acceleration produced, then

$$a = \frac{F}{m} = \frac{16}{0.08} = 200\,\text{ms}^{-2}$$

Time for which forces act = 1 micro-sec = 10^{-6} sec

$\therefore$ Impulse $Ft = 16 \times 10^{-6}$ N-sec.

S10. Force required to keep the acceleration is $F = ma$. Due to variation in mass the momentum changes. So the extra force needed is, $F = \frac{dm}{dt}.\vec{v}$, where $\vec{v}$ is the instantaneous velocity. The net force required is,

$$F = m\vec{a} + \frac{dm}{dt}\vec{v}.$$

S11. (a) Bubbles will not rise in water. This is because water in freely falling bottle is in the state of weightlessness. No relational upward force acts on the bubbles.

(b) In a wire cage, air inside is in free contact with atmospheric air. Therefore, when the bird starts flying inside the cage the weight of bird is no more experienced. Hence the cage will appear lighter than before.

S12. Given: $F = 10\,\text{N}$; $t = 3\,\mu\text{s} = 3 \times 10^{-6}\,\text{s}$; $M = 5\,\text{g} = 5 \times 10^{-3}\,\text{kg}$

Now, Impulse act on a body = $F \times t = 10 \times 3 \times 10^{-6} = \mathbf{3 \times 10^{-5}\,Ns}$

Also, Impulse = Change in momentum

$$= Mv_2 - Mv_1 = M(v_2 - v_1)$$

$$(v_2 - v_1) = \frac{\text{impulse}}{M} = \frac{3 \times 10^{-5}}{5 \times 10^{-3}} = \mathbf{6 \times 10^{-3}\,ms^{-1}}.$$

S13. Given: Mass of the body, $M = 0.25$ kg;

Retarding force, $F = -0.6$ N [Retarding force]

Now, $a = \frac{F}{M} = \frac{-0.6}{0.25} = -2.4\,\text{ms}^{-2}$ [Retardation]

Also, $u = 12\,\text{ms}^{-1}$; v = 0

Now, $v = u + at$

$\therefore$ $0 = 12 + (-2.4)\,t$

or $t = \frac{12}{2.4} = 5$ s

Also, Impulse = $F \times t = -0.6 \times 5 = \mathbf{-3.0\,Ns}$.

S14. Let S be the length of the block of wood.

Here $u = 100\,\text{ms}^{-1}$; $v = 10\,\text{ms}^{-1}$

Now, $v^2 - u^2 = 2aS$

or $10^2 - 100^2 = 2aS$

or $aS = -4{,}950$ ... (i)

Suppose that the bullet emerges with the velocity v', when the length of the block is reduced to one half. Then,

$$v'^2 - 100^2 = 2a\left(\frac{S}{2}\right)$$

or $aS = v'^2 - 100^2$ ... (ii)

From the Eq. (i) and (ii), we have

$$v'^2 - 100^2 = -4{,}950$$

or $v'^2 = 100^2 - 4{,}950$

or $v' = \mathbf{71.1\ ms^{-1}}$.

S15. Given: $M = 60\text{ g} = 60 \times 10^{-3}\text{ kg}$; $u = 500\text{ ms}^{-1}$; $v = 0$ and $t = 0.01\text{ s}$.

Now, Impulse $= (I) = Mv - Mu = M(v - u)$

$= 60 \times 10^{-3}(0 - 500) = \mathbf{-30\ Ns}$

If F is average force of blow, then

$$I = Ft$$

or $F = \frac{I}{t} = \frac{-30}{0.01} = -3{,}000\text{ N} = \mathbf{-3\ kN}$.

S16. As the ball was thrown towards the batsman with a velocity of $u = 10\text{ ms}^{-1}$. It was thrown back with a velocity v of 20 ms^{-1},

hence change in velocity $= (10 - (-20) = 30\text{ ms}^{-1})$

Now $m = 0.25\text{ kg}$, $t = 0.05\text{ s}$

$\therefore$ Impulse $Ft = m\{u - (-v)\} = 0.25 \times 30 = 7.5\text{ N-s}$

If F is the average force exerted on the ball, then

$$F = \frac{7.5}{0.05} = 150\text{ N}$$

S17. Mass of ball $m = 0.05\text{ kg}$

Let v be the velocity of the ball which it acquires in falling through a height $h = 1$ m. Also $u = 0\text{ ms}^{-1}$ and $g = 9.8\text{ ms}^{-2}$.

Substituting these values in $v^2 - u^2 = 2gh$, we get

$$v^2 = 2 \times 9.8 \times 1$$

or $v = \sqrt{19.6} = 4.43\text{ ms}^{-1}$

Let u' be the velocity with which the ball rebounds, then $h = 0.5$ m, $v' = 0$ and $g = -9.8\text{ ms}^{-2}$

$$u' = \sqrt{+2 \times 9.8 \times 0.5} = 3.13 \text{ ms}^{-1}$$

Ft = change in momentum

$= mv - (-mu') = m(v + u')$

$= 0.05 (4.43 + 3.13) = 0.378$ N-s

The ball remains in constant with the ground for 0.1 sec

$\therefore$ Average force $= \dfrac{0.378}{0.1} = 3.78 \text{ N}$

S18. Speed of the water stream, $v = 15$ m/s

Cross-sectional area of the tube, $A = 10^{-2} \text{ m}^2$

Volume of water coming out from the pipe per second,

$$V = Av = 15 \times 10^{-2} \text{ m}^3/\text{s}$$

Density of water, $\rho = 10^3 \text{ kg/m}^3$

Mass of water flowing out through the pipe per second = $\rho \times V = 15 \times 10^{-2} \times 10^3 = 150$ kg/s

The water strikes the wall and does not rebound. Therefore, the force exerted by the water on the wall is given by Newton's second law of motion as:

F = Rate of change of momentum with time.

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

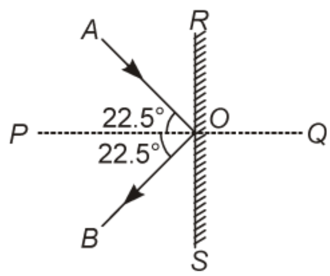
$= \mathbf{150 \times 15 = 2250\ N}$.

S19. The given situation can be represented as shown in the following figure.

OB = Path followed by the ball after deflection

$\angle AOB$ = Angle between the incident and deflected paths of the ball = 45°

$\angle AOP = \angle BOP = 22.5° = \theta$



Initial and final velocities of the ball = v

Horizontal component of the initial velocity = $v \cos \theta$ along RO

Vertical component of the initial velocity = $v \sin \theta$ along PO

Horizontal component of the final velocity = $v \cos \theta$ along OS

Vertical component of the final velocity = $v \sin \theta$ along OP

The horizontal components of velocities suffer no change. The vertical components of velocities are in the opposite directions

$\therefore$ Impulse imparted to the ball = Change in the linear momentum of the ball

$= mv \cos \theta \, (-mv \cos \theta)$

$= 2\, mv \cos \theta$

Mass of the ball, $m = 0.15\,kg$

Velocity of the ball, $v = 54$ km/h = 15 m/s

$\therefore$ Impulse = $2 \times 0.15 \times 15 \cos 22.5° = 4.16$ kg m/s.

S20. Given, Mass of each ball = 0.05 kg

Initial velocity of each ball = 6 m/s

Magnitude of the initial momentum of each ball, $p_i = 0.3$ kg m/s

After collision, the balls change their directions of motion without changing the magnitudes of their velocity.

Final momentum of each ball, $p_f = -0.3$ kg m/s

Impulse imparted to each ball = Change in the momentum of the system

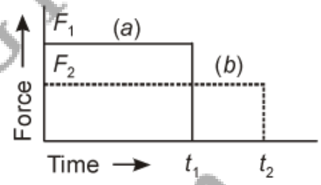
$= p_f - p_i$

$= -0.3 - 0.3 = -0.6$ kg m/s

The negative sign indicates that the impulses imparted to the balls are opposite in direction of motion.

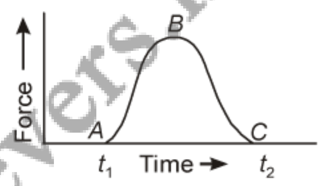
S21. (a) (i) F_1 for curve (*a*) is greater than F_2 for curve (*b*).

The time t_2 for which F_2 acts is greater for curve (*b*) than time t_1 in case of curve (*a*).



$$F_1 \times t_1 = F_2 \times t_2$$

(ii) Impulse of variable force



$$= \int_{t_1}^{t_2} \vec{F} dt = \text{area of } BCA$$

(b) A force which acts for a small time and also varies with time is called an ***impulsive force***.

Momentum before the hit = $150 \times 12 \times 10^{-3}$

$= 1.8$ kg ms^{-1}

Momentum after the hit = $150 \times 10^{-3} \times -20$

$= -3$ kg ms^{-1}

$\therefore$ Impulse = change in momentum

$= 1.8 - (-3)$

$= 4.8$ kg ms^{-1}.

S22. **Impulse at $t = 0$:** Before $t = 0$, the particle is at rest and after $t = 0$, it moves with a constant velocity of 0.75 ms^{-1} *i.e.*,

$$u = 0 \quad \text{and} \quad v = 0.75 \text{ ms}^{-1}$$

Also, mass of the particle, $M = 4$ kg

Therefore, Impulse = total change in momentum

$$= Mv - Mu$$

$$= M(v - u) = 4(0.75 - 0) = \mathbf{3\ kg\ ms^{-1}}.$$

Impulse at $t = 4$s: Before $t = 4$s, the particle is moving with constant velocity of 0.75 ms^{-1} and after $t = 4$ s, it is at rest *i.e.*,

$$u = 0.75\ ms^{-1} \quad \text{and} \quad v = 0$$

Therefore, Impulse $= M(v - u) = 4(0 - 0.75) = -\mathbf{3\ kg\ ms^{-1}}$.

S23. Since x changes at every 2 sec interval, the time between the consecutive impulses is 2 sec.

$$\text{Velocity before impulse} = \frac{(2-0)\times 10^{-2}}{(2-0)} = 10^{-2}\ ms^{-1}$$

$$\text{Velocity after impact} = \frac{(0-2)\times 10^{-2}}{(4-2)} = -10^{-2}\ ms^{-1}$$

Magnitude of change in momentum

$$|\Delta p| = 2\times p = 2\times 10^{-2}\times 0.04$$

$$= 0.08\times 10^{-2}\ kg\ ms^{-1}.$$

S24. (a) Mass of the monkey, $m = 40$ kg

Acceleration due to gravity, $g = 10\ m/s^2$

Maximum tension that the rope can bear, $T_{max} = 600$ N

Acceleration of the monkey, $a = 6\ m/s^2$ upward

Using Newton's second law of motion, we can write the equation of motion as:

$$T - mg = ma$$

$$\therefore \quad T = m(g + a)$$

$$= 40(10 + 6)$$

$$= 640\ N$$

Since $T > T_{max}$, the rope will break in this case.

(b) Acceleration of the monkey, $a = 4\ m/s^2$ downward

Using Newton's second law of motion, we can write the equation of motion as:

$$mg - T = ma$$

$$\therefore \quad T = m(g - a)$$

$$= 40(10 - 4)$$

$$= 240\ N$$

Since $T < T_{max}$, the rope will not break in this case.

(c) The monkey is climbing with a uniform speed of 5 m/s. Therefore, its acceleration is zero, *i.e.*, $a = 0$.

Using Newton's second law of motion, we can write the equation of motion as:

$$T - mg = ma$$

$$T - mg = 0$$

$$\therefore \quad T = mg$$

$$= 40 \times 10 = 400 \text{ N}$$

Since $T < T_{max}$, the rope will not break in this case.

(d) When the monkey falls freely under gravity, its acceleration will become equal to the acceleration due to gravity, *i.e.*,

Using Newton's second law of motion, we can write the equation of motion as:

$$mg - T = mg$$

$$\therefore \quad T = 0$$

Since $T < T_{max}$, the rope will not break in this case.

S25. Mass of the body, $m = 0.40$ kg

Initial speed of the body, $u = 10$ m/s due north

Force acting on the body, $F = -8.0$ N

Acceleration produced in the body,

$$a = \frac{F}{m} = \frac{-8.0}{0.40} = -20 \text{ m/s}^2$$

At $t = -5$ s

Acceleration, $a' = 0$ and $u = 10$ m/s

$$s = ut + \frac{1}{2}a' t^2$$

$$= 10 \times (-5) = -50 \text{ m}$$

At $t = 25$ s

Acceleration, $a'' = -20 \text{ m/s}^2$ and $u = 10$ m/s

$$s = ut' + \frac{1}{2}a'' t^2$$

$$= 10 \times 25 + \frac{1}{2} \times (-20) \times (25)^2$$

$$= 250 - 6250 = -6000 \text{ m}$$

For $0 \le t \le 30$ s

For $a = -20 \text{ m/s}^2$

$u = 10$ m/s

$$s_1 = ut + \frac{1}{2}a'' t^2$$

$$= 10 \times 30 + \frac{1}{2} \times (-20) \times (30)^2$$

$$= 300 - 9000$$

$$= -8700 \text{ m}$$

For $30 < t \le 100$ s

As per the first equation of motion, for

$$v = u + at$$

$$= 10 + (-20) \times 30 = -590 \text{ m/s}$$

Velocity of the body after 30 s = – 590 m/s

For motion between 30 s to 100 s, i.e., in 70 s:

$$s_2 = vt$$

$$= -590 \times 70 = -41300 \text{ m}$$

$$s'' = s_1 + s_2 = -8700 - 41300 = -50000 \text{ m}$$

∴ Total distance.

S26. Impulse received during an impact is defined as the product of the average force and the time for which the force acts.

It is denoted J

$$\vec{J} = \vec{F}\,\Delta t$$

Let the mass of the machine gun, $M = 20$ kg

mass of the bullet $m = 35 \text{ g} = 0.035$ kg

Velocity of bullet $v = 400 \text{ ms}^{-1}$

Velocity of recoil of the gun $V = ?$

By the law of conservation of momentum,

$$MV + mv = 0$$

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

$$= -\frac{0.035 \times 400}{20} = -0.7 \text{ms}^{-1}$$

–ve sign shows that the gun recoils.

∴ force required to hold the gun in position

$$F = Ma$$

$$= M\left(\frac{V-u}{t}\right)$$

$$= \frac{20 \times (0.7 - 0)}{1/400} = 5600\,\text{N}.$$

S27. Impulse received during an impact is defined as the product of the average force and the time for which the force acts.

It is denoted J

$$\vec{J} = \vec{F}\,\Delta t$$

Mass of the hummer $m = 1$ kg

Initial velocity, $u = 6$ ms^{-1},

(a) Impulse $= Ft = m(v - u)$

$= 1(0 - 6) = -6$ Ns

(b) Retardation of the hammer

$$= \frac{F}{m} = \frac{60}{1} = 60\,\text{ms}^{-2}.$$

(c) Retarding force that stops the hammer,

$$F = \frac{\text{impulse}}{\text{time}} = \frac{6}{0.1} = 60\,\text{N}.$$

S28. (a) Initial velocity of bowler = $12\hat{i}\ ms^{-1}$

Final velocity of bowler = $-12\hat{i}\ ms^{-1}$

Change in velocity,

$$\Delta\vec{v} = (-12\,\hat{i}) - 12\,\hat{i} = -24\,\hat{i}\ ms^{-1}$$

Change in momentum

$$\Delta\vec{p} = -0.15 \times 24\,\hat{i}\ N\,s = -3.6\,\hat{i}\ N\,s$$

Magnitude of change in momentum is 3.6 N s.

The direction is from batsman to bowler.

(b) Distance travelled by the system,

$$S = 2.18\text{ m},\quad t_1 = 2\text{s}$$

$$m_1 = \frac{50}{1000} = 0.05\text{ kg},$$

$$m_2 = \frac{40}{1000} = 0.04\text{ kg},$$

Initial velocity, $u = 0$

Using, $S = ut + \frac{1}{2}at^2$

$\Rightarrow$ $2.18 = \frac{1}{2} \times a \times 4$

or $a = 1.09 \text{ ms}^{-2}$

Also, $a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)g$

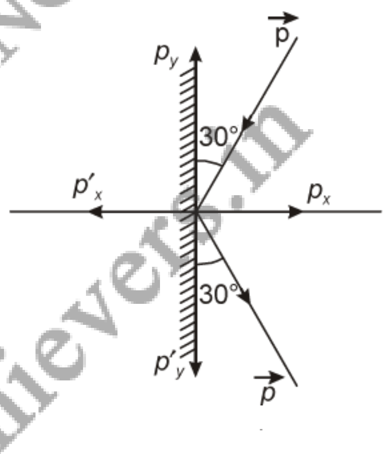
$$1.09 = \left(\frac{0.05 - 0.04}{0.05 + 0.04}\right) \times g$$

or $g = \frac{1.09 \times 0.09}{0.01} = 9.81 \text{ ms}^{-2}$.

S29. Impulse received during an impact is defined as the product of the average force and the time for which the force acts.

It is denoted J

$$\vec{J} = \vec{F}\,\Delta t$$



Initial momentum $\vec{p}$ = 15 kg m/s

Resolving it into two components

$p_y = p \cos 30°$, $p_x = p \sin 30°$

Final momentum $\overrightarrow{P'}$ = 15 kg m/s

$$\overrightarrow{p'} = \vec{p}$$

Resolving $\vec{p}$ into two components

$$p_y' = p' \cos 30°, \; p_x' = p' \sin 30°$$

The two x-components are in opposite direction so they cancel out.

$\therefore$ Impulse = change in momentum

$= p_y + p_y'$

$= 2 \times p \cos 30°$

$= 30 \times \frac{\sqrt{3}}{2} = 15\sqrt{3}$ kg m/s

Date: 13/10/2021

Q1. **State principle of conservation of momentum.**

Q2. **A stone breaks the window glass into pieces, while a bullet pierces through the same. Why?**

Q3. **A cricket player, while catching the ball, pulls his hand back. Why?**

Q4. **Why do we use shock absorbers in automobiles?**

Q5. **Why do aeroplanes having wings fly at low altitudes?**

Q6. **A retarding force is applied to stop a motor car. If the speed of the motor car is doubled, how much more distance will it cover before stopping under the same retarding force?**

Q7. **A rocket burns 0.2 kg of fuel per second and ejects it as a gas with a velocity of 10 km/sec. Calculate the force exerted by the ejected gas on the rocket. How will you retard it in free space?**

Q8. **A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12 $m\,s^{-1}$. If the mass of the ball is 0.15 kg, determine the impulse imparted to the ball. (Assume linear motion of the ball)**

Q9. **State impulse-momentum theorem.**

Q10. **A nucleus is at rest in the laboratory frame of reference. Show that if it disintegrates into two smaller nuclei the products must move in opposite directions.**

Q11. **A rope passes over a pulley, which is sufficiently high. Two monkeys of equal weights climb the rope from opposite ends, one of them climbing quickly than the other, relative to the rope. Which of the monkeys will reach the top first? Assume that pulley is weightless, while the rope is weightless as well as inextensible.**

Q12. **A body is in limiting equilibrium on a rough inclined plane inclined at an angle of 30° with the horizontal. Calculate acceleration with which the body will slide down, when inclination of the plane is changed to 45° Given: ($g = 9.8\ ms^{-2}$).**

Q13. **A cart of mass 500 kg is standing at rest on the rails. A man weighing 70 kg and running parallel to rail track with a velocity of 10 ms^{-1} jumps on to the cart approaching it. Find the velocity with which the cart will start moving.**

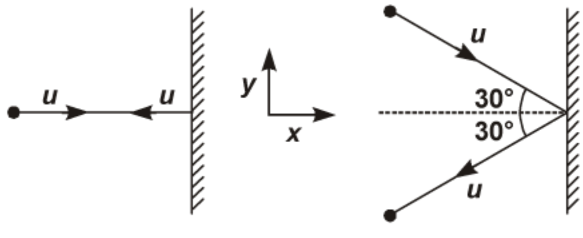
Q14. **A hunter has a machine gun that can fire 50 g bullets with a velocity of 150 ms^{-1}. A 60 kg tiger springs at him with a velocity of 20 ms^{-1}. How many bullets must the hunter fire into the tiger in order to stop him in his track?**

Q15. **Two masses of 0.01 kg and 0.04 kg are moving with equal kinetic energies. What is the ratio of the magnitude of their momentum?**

Q16. **A body of mass 1 kg initially at rest explodes and breaks into three fragments of masses in the ratio 1 : 1 : 3. The two pieces with equal masses fly off perpendicular to each other with a speed of 30 ms^{-1} each. What is the velocity of the heavier fragment?**

Q17. A neutron having a mass 1.67×10^{-27} kg and moving at 10^8 ms^{-1} collides with a deuteron at rest and sticks to it. If the mass of deuteron is 3.34×10^{-27} kg find the speed of the combination.

Q18. Two identical billiard balls strike a rigid wall with the same speed but at different angles, and get reflected without any change in speed, as shown in figure. What is (i) the direction of the force on the wall due to each ball? (ii) the ratio of the magnitudes of impulses imparted to the balls by the wall?



Q19. State the law of conservation of momentum. Establish the same for a '*n*' body system.

Q20. A mass less rope is passed over a frictionless pulley. A monkey holds on to one end of the rope and a mirror having the same weight as the monkey, is attached to the other end of the rope at the monkey's level. Can the monkey get away from his image seen in the mirror (a) by climbing up the rope (b) by climbing down the rope (c) by releasing the rope?

Q21. State impulse-momentum theorem. A shell of mass 10 kg moving with a velocity of 20 ms^{-1} explodes into two portions of 6 kg and 4 kg respectively. If the former is just brought to rest after the explosion find the velocity of the latter.

Q22. (a) A hunter has a machine gun that can fire 50 g bullets with a velocity of 900 ms^{-1}. A 40 kg trigger springs at him with a velocity of 10 ms^{-1}. How many bullets must the hunter fire into the tiger in order to stop him in his track?

(b) A man of mass 62 kg is standing on a stationary boat of mass 238 kg. The man is carrying a sphere of mass 0.5 kg in his hands. If the man throws the sphere horizontally with velocity of 12 ms^{-1}, find the velocity with which the boat will move.

Q23. (a) A gun weighing 10 kg fires a bullet of 30 g with a velocity of 330 m s^{-1}. With what velocity does the gun recoil? What is the combined momentum of the gun and bullet before firing and after firing?

(b) A shell of mass 0.020 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m s^{-1}, what is the recoil speed of the gun?

Q24. Sate Law of conservation of momentum? A bomb is thrown in a horizontal direction with a velocity of 50 m s^{-1}. It explodes into two parts of mass 6 kg and 3 kg. The heavier fragment continues to move in the horizontal direction with a velocity of 80 m s^{-1}. calculate the velocity of the lighter fragment.

Q25. (a) Derive the law of conservation of momentum from Newton's second laws of motion?

(b) A machine gun has a mass of 20 kg. It fires 35 g bullets at the rate of 4 bullets per second, with a speed of 400 ms^{-1}, What force must be applied to the gun to keep it in position?

Date: 13/10/2021

S1. It states that if no external force acts on a system, the momentum of the system remains constant.

S2. The velocity of bullet being large, the bullet remains in contact with window glass for a shorter time than the stone of lesser velocity.

S3. To reduce the force experienced, by increasing the time of contact.

S4. To reduce the effect of any force by increasing the time of experience.

S5. The wings of aeroplane push the air backwards and the reaction of the air pushes the plane forward. At low altitudes, air is dense and as such the reaction of the air on plane is large.

S6. Retarding force is same. For the same car, the mass is same. So the deceleration is same. We know that $v = 0$, $u \neq 0$.

Using $v^2 - u^2 = 2as$ we have $s = \dfrac{u^2}{2a}$.

S7. Mass of fuel burnt $m = 0.2$ kg

velocity of ejected gases $v = 10 \times 10^3 \text{ ms}^{-1} = 10^4 \text{ ms}^{-1}$

Momentum of ejected gases $= 0.2 \times 10^4 = 2000 \text{ N-ms}^{-1}$

These gases exert a thrust on the rocket in the forward direction.

$$Ft = \text{Change of momentum}$$

or $$F \times 1 = 2000$$

$\therefore$ $$F = 2000 \text{ N}$$

If the gases are ejected in the direction of motion of the rocket it gets retarded.

S8. We know, $J = \Delta P$ [J = Impulse]

Change in momentum $= 0.15 \times 12 - (-0.15 \times 12)$

$= 3.6$ N s,

Impulse $= 3.6$ N s,

in the direction from the batsman to the bowler.

This is an example where the force on the ball by the batsman and the time of contact of the ball and the bat are difficult to know, but the impulse is readily calculated.

S9. Impulse received during an impact is equal to the product of average force during the impact and the time for which the impact last and also equal to the total change in momentum produced during the impact.

$$I = F_{avg} = P_2 - P_1$$

S10. Let m, m_1, and m_2 be the respective masses of the parent nucleus and the two daughter nuclei. The parent nucleus is at rest. Initial momentum of the system (parent nucleus) = 0

Let v_1 and v_2 be the respective velocities of the daughter nuclei having masses m_1 and m_2.

Total linear momentum of the system after disintegration = $m_1v_1 + m_2v_2$

According to the law of conservation of momentum:

Total initial momentum = Total final momentum

$$0 = m_1v_1 + m_2v_2$$

$$v_1 = \frac{-m_2v_2}{m_1}$$

Here, the negative sign indicates that the fragments of the parent nucleus move in directions opposite to each other.

S11. Both will reach the top at the same time. It is because, length of the two segments of the rope on the two sides of the pulley will always remain equal.

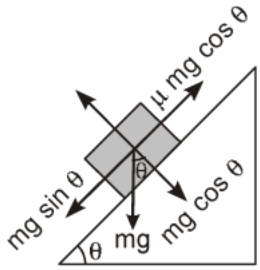
S12. Since body is in limiting equilibrium, when inclination is 30°, it corresponds to angle of repose. Therefore,

$$\mu = \tan 30° = 0.5774$$

When inclination is 45°:

Now, $ma = mg\sin\theta - \mu\, mg\cos\theta$

$$a = g(\sin\theta - \mu\cos\theta)$$
$$= 9.8\,(\sin 45° - 0.5774 \times \cos 45°)$$
$$= 9.8\,(0.7071 - 0.5774 \times 0.7071)$$
$$= 9.8\,(0.7071 - 0.4083)$$
$$= \mathbf{2.93\ ms^{-2}}.$$



S13. Given: Mass of the cart, $M_1 = 500$ kg;

Initial velocity of the cart, $v_1 = 0$;

Mass of the man, $M_2 = 70$ kg;

Velocity of the man, $v_2 = 10\ \text{ms}^{-1}$.

Let v be the velocity with which the cart and the man move, when the man jumps on to the cart.

Now, according to principle of conservation of momentum,

$$(M_1 + M_2)\, v = M_1 v_1 + M_2 v_2$$

$\therefore$ $$(500 + 70) \times v = 500 \times 0 + 70 \times 10$$

or $$570\, v = 700$$

or $$v = \mathbf{1.23\ ms^{-1}}.$$

S14. Given: Mass of a bullet, $m = 50\ \text{g} = 0.05\ \text{kg}$

Velocity of the bullet, $v = 150\ \text{ms}^{-1}$

Mass of the tiger, $M = 60\ \text{kg}$

Velocity of the tiger, $V = -10\ \text{ms}^{-1}$ [opposite direction]

Let n be the number of bullets fired per second at the tiger in order to stop it in its track.

According to principle of conservation of momentum,

$$n(mv) + MV = 0$$

or $$n = \frac{MV}{mv} = -\frac{60 \times (10)}{0.05 \times 150} = \mathbf{80}.$$

S15. Kinetic energy

$$E = \frac{1}{2} mv^2$$

or $$2mE = m^2v^2 = p^2 \qquad (\therefore \quad p = mv)$$

$\therefore$ $$p = \sqrt{2mE}$$

If two masses m_1 and m_2 have equal *K. E.*, then

$\therefore$ $$\frac{p_1}{p_2} = \sqrt{\frac{2m_1E}{2m_2E}} = \sqrt{\frac{m_1}{m_2}}$$

Now $m_1 = 0.01$ kg, and $m_2 = 0.04$ kg

$\therefore$ $$\frac{p_1}{p_2} = \sqrt{\frac{0.01}{0.04}} = \frac{1}{2}$$

Hence momentum are in the ratio 1 : 2.

S16. On explosion the body explodes into three pieces of masses m_1, m_2 and m_3 in the ratio 1 : 1 : 3.

$$m_1 = 0.2\ \text{kg},\ m_2 = 0.2\ \text{kg and } m_3 = 0.6\ \text{kg}$$

The two pieces B and C of equal masses m_1 and m_2 fly with the same velocity in directions perpendicular to each other. The components of momentum of these two masses along OD are equal *i.e.*

$$m_1v_1 \cos 45° = m_2v_2 \cos 45°$$

$\therefore$ Momentum along $OD = 2m_1v_1 \cos 45°$

If v is the velocity of the mass m_3 along OA, then

$$m_3v = 2m_1v_1 \cos 45°$$

$$v = \frac{2 \times 0.2 \times 30 \times 1}{0.6 \times \sqrt{2}}$$

$$= 10\sqrt{2} = 14.142\ \text{ms}^{-1}$$

S17. Let m_1 and v_1 be the mass and velocity of neutron, then

$$m_1 = 1.67 \times 10^{-27}\ \text{kg and } v_1 = 10^8\ \text{ms}^{-1}$$

Mass of deuteron $= 3.34 \times 10^{-27}$ kg

Combined mass $m_2 = (3.34 + 1.67)\ 10^{-27}\ \text{kg} = 5.01 \times 10^{-27}$ kg

If v_2 is the velocity of the combination, then

$$m_2v_2 = m_1v_1$$

or

$$v_2 = \frac{m_1v_1}{m_2} = \frac{1.67 \times 10^{-27} \times 10^8}{5.01 \times 10^{-27}}$$

$$= 0.333 \times 10^8\ \text{ms}^{-1}$$

S18. An instinctive answer to (i) might be that the force on the wall in case (a) is normal to the wall, while that in case (b) is inclined at 30° to the normal. This answer is wrong. The force on the wall is normal to the wall in both cases.

How to find the force on the wall? The trick is to consider the force (or impulse) on the ball due to the wall using the second law, and then use the third law to answer (i). Let u be the speed of each ball before and after collision with the wall, and m the mass of each ball. Choose the x and y-axes as shown in the figure, and consider the change in momentum of the ball in each case:

Case (a): $(p_x)_{\text{initial}} = mu$ $(p_y)_{\text{initial}} = 0$

$(p_x)_{\text{initial}} = -mu$ $(p_y)_{\text{initial}} = 0$

Impulse is the change in momentum vector.

Therefore, x-component of impulse $= -2\ m\ u$

y-component of impulse $= 0$

Impulse and force are in the same direction. Clearly, from above, the force on the ball due to the wall is normal to the wall, along the negative x-direction. Using Newton.s third law of motion, the force on the wall due to the ball is normal to the wall along the positive x-direction. The magnitude of force cannot be ascertained since the small time taken for the collision has not been specified in the problem.

Case (b): $(p_x)_{\text{initial}} = mu \cos 30°$, $(p_y)_{\text{initial}} = -mu \sin 30°$

$(p_x)_{\text{initial}} = -mu \cos 30°$, $(p_y)_{\text{initial}} = -mu \sin 30°$

Note, while p_x changes sign after collision, p_y does not. Therefore,

Therefore, x-component of impulse = $-2\, m\, u \cos 30°$

y-component of impulse = 0

The direction of impulse (and force) is the same as in (a) and is normal to the wall along the negative x-direction. As before, using Newton's third law, the force on the wall due to the ball is normal to the wall along the positive x-direction.

The ratio of the magnitudes of the impulses imparted to the balls in (a) and (b) is

$$2mu/(2\,mu\cos 30°) = \frac{2}{\sqrt{3}} \approx 1.2$$

S19. When no external force acts on a system the momentum will remain conserved. Consider a system of n bodies of masses $m_1, m_2, m_3, \ldots, m_n$. If $p_1, p_2, p_3, \ldots, p_n$ are the momentum associated then the rate of change of momentum with system.

$$\frac{dp}{dt} = \frac{dp_1}{dt} + \frac{dp_2}{dt} + \frac{dp_3}{dt} + \ldots + \frac{dp_n}{dt}$$

$$= \frac{d}{dt}(p_1 + p_2 + p_3 + \ldots p_n)$$

If no external force acts,

$$\frac{dp}{dt} = 0, \quad \therefore \; p = \text{constant}$$

i.e., $\mathbf{p_1 + p_2 + \ldots + p_n = \text{constant}}$.

S20. (a) When the monkey climbs up, the length of the segment of the rope (between monkey and the pulley) decreases in length. Immediately, the segment of the rope holding the mirror will also decrease, so that it always becomes equal to the segment of the rope held by the monkey. Therefore, the mirror will remain in front of the monkey and he will always see his image in the mirror.

(b) In this case, the segment of the rope holding the mirror will increase but as explained above, the monkey will always see his image in the mirror.

(c) The monkey releases the rope, both the monkey and the mirror will fall freely under gravity. As such, both will fall through the same distance in a given interval of time and hence the monkey will always be seeing his image in the mirror.

S21. Impulse received during an impact is equal to the product of average force during the impact and the time for which the impact last and also equal to the total change in momentum produced during the impact.

$$I = F_{avg} = P_2 - P_1.$$

Given: Mass of the shell, M = 10 kg and velocity of the shell, $u = 20\,ms^{-1}$.

Let M_1 and M_2 be the masses of the two portions of the shell and v_1 and v_2 be their respective velocities. Then,

$$M_1 = 6\,kg; \quad M_2 = 4\,kg \quad \text{and} \quad v_1 = 0$$

According to the principle of conservation of momentum,

$$Mu = M_1 v_1 + M_2 v_2$$

$\therefore$ $$10 \times 20 = 6 \times 0 + 4 \times v_2$$

or $$v_2 = \mathbf{50\ ms^{-1}}.$$

S22. (a) Mass of bullet, m = 50 g = 0.05 kg

Velocity of bullet, v = 40 kg

Velocity of tiger, $V = 10\ ms^{-1}$

Let n be the number of bullets required to be pumped into the tiger to stop him in his track.

If the bullets and the tiger are supposed to constitute one isolated system, then the magnitude of the momentum of n bullets should be equal to the magnitude of momentum of the tiger.

$\therefore$ $$n \times m\,v = \text{MV} \quad \text{or} \quad n = \frac{MV}{mv}$$

$\therefore$ $$n = \frac{40 \times 10}{0.05 \times 900} = 8.89 \approx 9$$

(b) Man, boat and sphere form an isolated system *i.e.*, a system on which no external force acts. According to the law of conservation of momentum, the momentum of an isolated system remains constant.

Before throwing the sphere, the common velocity of man, boat and sphere is zero. Initital momentum of system is zero.

Let $\vec{V}$ be the common velocity of man and boat. Using law of conservation of momentum, we get

$$0.5 \times 12 + (238 + 62)\,V = 0 \text{ or, } V = -\frac{0.5 \times 12}{238 + 62}\,ms^{-1}$$

or $$V = -\frac{6}{300}\,ms^{-1} = -\frac{1}{50}\,ms^{-1} = -0.02\,ms^{-1}.$$

The negative sign shows that the common velocity of the man and boat will be in a direction opposite to the direction of velocity of the sphere. Magnitude of the velocity of man and boat is 0.02 ms^{-1} *i.e.*, 2 $cm\,s^{-1}$.

S23. (a) Given, Mass of gun, M = 10 kg; Mass of bullet, m = 30 g = 0.03 kg; Velocity of bullet; $v = 330\,m\,s^{-1}$; Velocity of recoil, V = ?

In magnitude, momentum of gun = momentum of bullet

$$\therefore \qquad MV = mv \qquad \text{or} \qquad V = \frac{mv}{M}$$

$$\therefore \qquad V = \frac{0.03 \times 330}{10}\,ms^{-1} = 0.99\,m\,s^{-1}$$

(b) Given, Mass of the gun, M = 100 kg; Mass of the shell, m = 0.020 kg; Muzzle speed of the shell, v = 80 m/s; Recoil speed of the, gun = V

Both the gun and the shell are at rest initially.

$$p_i = 0.3 \text{ kg m/s}$$

$$p_f = -0.3 \text{ kg m/s}$$

Initial momentum of the system = 0

Final momentum of the system = $mv - MV$

Here, the negative sign appears because the directions of the shell and the gun are opposite to each other.

According to the law of conservation of momentum:

Final momentum = Initial momentum

$$mv - MV = 0$$

$$\therefore \qquad V = \frac{mv}{M}$$

$$= \frac{0.020 \times 80}{100} = 0.016 \text{ m/s}.$$

S24. The total vector sum of the momentum of bodies, in an isolated system, along any straight line remains conserved and is unchanged due to the mutual action and reaction between the bodies in the system.

Given, Mass of bomb, $M = (6 + 3)$ kg = 9 kg

Velocity of bomb, $V = 50\,ms^{-1}$ (in horizontal direction)

Mass of heavier fragment m_1 = 6 kg

Velocity of heavier fragment, $v_1 = 80 \text{ ms}^{-1}$ (in horizontal direction)

Mass of lighter fragment, $m_2 = 3$ kg

Velocity of lighter fragment, $v_2 = ?$

According to law of conservation of momentum,

Total momentum of fragments = Momentum of bomb

$$m_1v_1 + m_2v_2 = MV$$

$$\therefore \quad 6 \times 80 + 3 \times v_2 = 9 \times 50 \quad \text{or} \quad 3v_2 = -30$$

$$v_2 = -10 \text{ m s}^{-1}$$

The negative sign shows that the lighter fragment moves in a direction opposite to that of the heavier fragment.

S25. (a) According to Newton's second law of motion, the time rate of change of momentum is equal to the applied force.

If the system is isolated, then $\vec{F} = 0$

In that case, $\frac{d}{dt}(\vec{p}) = 0$

$$\therefore \quad \vec{p} = \text{constant}$$

In the absence of external forces, the total momentum of the system is conserved.

(b) Mass of gun, $M = 20$ kg

Mass of bullet, $m = 35 \text{ g} = 0.035$ kg

Velocity of bullet, $v = 400 \text{ m s}^{-1}$

If V be the velocity of recoil, then

$$V = \frac{mv}{M} = \frac{0.035 \times 400}{20} \text{m s}^{-1} = 0.7 \text{ m s}^{-1}$$

Time taken to fire one bullet, $t = \frac{1}{4}$ second

If F be the average force required to hold the gun in position, then

$$F \times t = MV \quad [\because \text{ Initial momentum of gun is zero.}]$$

$$\therefore \quad F = \frac{MV}{t} = \frac{20 \times 0.7}{1/4} \text{N} = 56 \text{ N}$$

Aliter: Number of bullets fired per second, $n = 4$

Momentum given to the bullets per second = nmv

Same momentum per second is gained by the gun. This gives the force acting on the gun and also the force applied to keep the gun in position.

So, $$F = nmv = 4 \times 0.035 \times 400 \text{ N} = 56 \text{ N}$$

Date: 13/10/2021

Q1. Two boys on ice skates hold a rope between them. One boy is much heavier than the other. Discuss their motion when one of the boys pulls on the rope.

Q2. A body is dropped from the ceiling of a transparent cabin falling freely towards the earth. Describe the motion of the body as observed by an observer (a) sitting in the cabin (b) standing on earth.

Q3. It is easier to maintain the motion of a body than to start it. Why?

Q4. A lift has a mass of 6000 kg. The upward tension of the supporting cable is 3×10^5 N. Calculate the upward acceleration.

Q5. Why is it necessary to keep the rate of fuel consumption in a rocket constant?

Q6. Why does a gun recoil? Derive the recoil velocity of a gun.

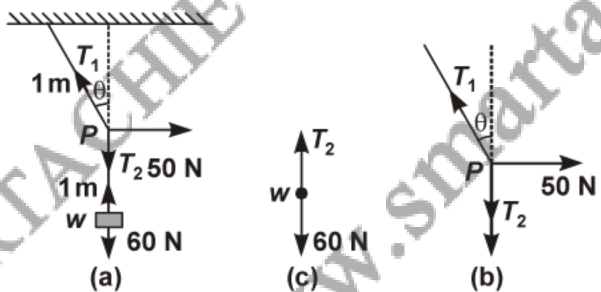
Q7. A monkey is ascending a branch with constant acceleration. If the breaking strength is 160% of the monkey's weight what is the maximum acceleration permitted for the monkey?

Q8. Find the minimum force required to pull a body up a rough inclined plane (θ, μ).

Q9. What is the principle behind the launch of rockets?

Q10. A monkey is descending from the branch of a tree with constant acceleration. If the breaking strength is 75% of the weight of the monkey, what is the minimum acceleration with which monkey can slide down without breaking the branch?

Q11. As shown in the figure, a mass of 6 kg is suspended by a rope of length 2 m from the ceiling. A force of 50 N in the horizontal direction is applied at the midpoint *P* of the rope, as shown. What is the angle the rope makes with the vertical in equilibrium? (Take g = 10 m s^{-2}). Neglect the mass of the rope.



Q12. A man of mass 70 kg stands on a weighing scale in a lift which is moving

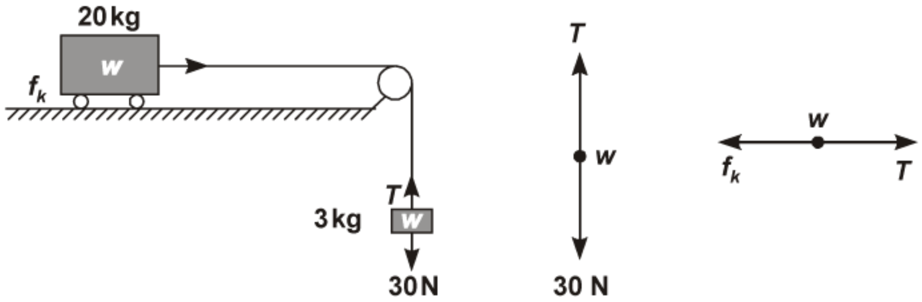
(a) upwards with a uniform speed of 10 m s^{-1}

(b) downwards with a uniform acceleration of 5 m s^{-2}

(c) upwards with a uniform acceleration of 5 m s^{-2}. What would be the readings on the scale in each case?

(d) What would be the reading if the lift mechanism failed and it hurtled down freely under gravity?

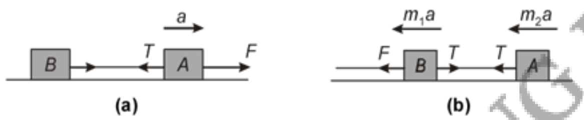
Q13. What is the acceleration of the block and trolley system shown in a figure (a), if the coefficient of kinetic friction between the trolley and the surface is 0.04? What is the tension in the string? (Take $g = 10\ \text{m s}^{-2}$). Neglect the mass of the string.



(a) (b) (c)

Q14. Two masses 8 kg and 12 kg are connected at the two ends of a light inextensible string that goes over a frictionless pulley. Find the acceleration of the masses, and the tension in the string when the masses are released.

Q15. Two bodies of masses 10 kg and 20 kg respectively kept on a smooth, horizontal surface are tied to the ends of a light string. A horizontal force $F = 600$ N is applied to as shown in figure (a) and (b) along the direction of string. What is the tension in the string in each case?



Q16. A string of length L and mass M is lying on a horizontal table. A force F is applied at one of its end. What is the tension in string at a distance x from the end at which force is applied?

Q17. Find the apparent weight of a person weighing 49 kg on earth when he is sitting in a lift which (a) rising with an acceleration of $1.2\ \text{ms}^{-2}$, (b) going down with the same acceleration, (c) falling freely under the action of gravity and (d) going up or down with uniform velocity. Given $g = 9.8\ \text{ms}^{-2}$.

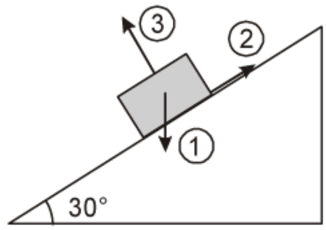
Q18. A helicopter of mass 1000 kg rises with a vertical acceleration of $15\ \text{m s}^{-2}$. The crew and the passengers weigh 300 kg. Give the magnitude and direction of the force on the floor by the crew and passengers, action of the rotor of the helicopter on the surrounding air, force on the helicopter due to the surrounding air.

Q19. State Newton's third law? Consider the bodies of mass m_1 and m_2 in contact placed on a frictionless table as shown. When force F is applied on mass m_1, calculate the acceleration produced, and the force of contact between the bodies. What will be the force of contact when the force F is applied on mass m_2?

Q20. State Newton's second law? A block of wood of mass 3 kg is resting on the surface of a rough inclined surface, inclined at an angle θ as shown in the figure:

(a) Name the forces (1, 2, 3).

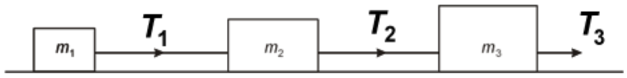
(b) If the coefficient of static friction is 0.2, calculate the value of all the three forces (may use $g = 10\ \text{m/s}^2$)



Q21. State Newton's First law of motion. Two masses 7 kg and 12 kg are connected at the two ends of a light inextensible string that passes over a frictionless pulley. Find the acceleration of the masses and the tension in the string, when the masses are released.

Q22. (a) A force acts for 10 second on a body of mass 10 g. After it cases to act, the body describes 50 cm in the next 5 second. Find the magnitude of the force.

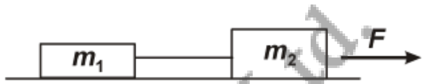
(b) Three blocks are connected as shown on a horizontal frictional table, and pulled to the right with a force of T_3 = 60 N.



If m_1 = 10 kg, m_2 = 20 kg and m_3 = 30 kg. prove that $\frac{T_1}{T_2} = \frac{1}{3}$

Q23. (a) A motor car of mass 20 quintal moving with a velocity of 60 km h^{-1}, by the application of brakes, is brought to rest in a distance of 3 km. Find the average force of resistance in newton.

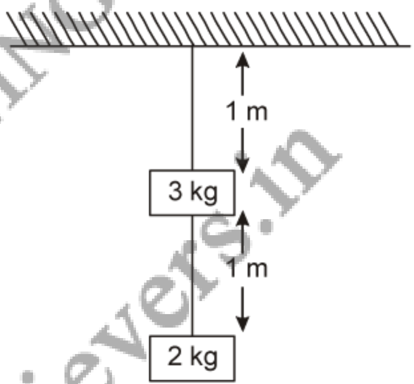
(b) Consider the case of two bodies of mass m_1 and m_2 connected by a string and placed on a smooth horizontal surface as shown.



Calculate the acceleration of the system, and tension in the string when the force F is applied on m_2.

Q24. (a) A cricket ball, weighing 0.25 kg, hits a bat with a velocity of 6 m s^{-1}. The ball is hit back to the bowler, leaving the bat with a velocity of 8 m s^{-1}. What is the change momentum of ball, assuming the ball is in contact with the bat for 1/10 second?

(b) Two blocks 3 kg and 2 kg are suspended from a rigid support by two inextensible wires, each of length 1 m and having linear mass density 0.2 kg/m (as shown in the figure). Find the tension at the mid-point of each wire as the arrangement gets an upward acceleration of 2 m/s^2.



Date: 13/10/2021

S1. The initial momentum of the boys holding the rope is zero. When one of the two pulls the other they move towards each other. To conserve momentum in the absence of external force the heavier of the two boys will move slower than the other.

S2. (a) Appears stationary in the lift.

(b) Appears to fall freely ($a = g$ m/s^2)

S3. We have to overcome static friction, which is more than kinetic friction.

S4. If T is the tension of the string and m the mass of lift, then as the lift is moving up

$$T - mg = ma$$

Here $T = 3 \times 10^5$ N, m = 6000 kg = 6×10^3 kg ; $g = 9.8$ ms^{-2}

$\therefore$ $3 \times 10^5 - 6 \times 10^3 \times 9.8 = 6 \times 10^3$ a

$$a = 50 - 9.8 = 40.2 \text{ ms}^{-2}$$

S5. If the rate of fuel consumption is not kept the same, the energy produced every moment will be different and may lead to problem of controlling large energy or accelerating the rocket.

S6. Since no external force acts on gun, the momentum has to be conserved. So the gun recoils. If m_g and m_b are the mass of gun and bullet with velocity of bullet being v_b and velocity of gun v_g, according momentum of conservation

$$m_g v_g + m_b v_b = 0$$

$$\therefore \quad v_g = -\frac{m_b v_b}{m_g}$$

– *ve* sign means that the gun moves opposite to the direction of the bullet.

S7.

Breaking strength = $\frac{160}{100} mg$, where m is the mass of the monkey.

While ascending the apparent weight

$$W = m(g + a),$$

For safety, $m(g + a) \le \frac{160}{100} mg,$

$\therefore$ $$a \le \left(\frac{160}{100} - 1\right)g,$$

$$a \le 0.6 \text{ m/s}^2.$$

S8. As the mass has to be pulled up, the component of force of gravity and the force of friction act downward. Therefore, the minimum force required is, ($mg \sin\theta + \mu\, mg \cos\theta$).

S9. The principle behind the launch of rocket is the law of conservation of momentum. The change in momentum with the burnt fuel provides momentum to the rocket.

S10. For descending monkey

$$T = mg - ma = m(g - a)$$

as $$T = 75\% \text{ of } mg$$

i.e., $$T = \frac{3}{4}mg$$

$$\frac{3}{4}mg = m(g - a)$$

$$a = \frac{g}{4}.$$

S11. Figures (b) and (c) are known as free-body diagrams. Figure (b) is the free-body diagram of W and figure (c) is the free-body diagram of point P.

Consider the equilibrium of the weight W.

Clearly, $$T_2 = 6 \times 10 = 60 \text{ N}.$$

Consider the equilibrium of the point P under the action of three forces – the tensions T_1 and T_2, and the horizontal force 50 N. The horizontal and vertical components of the resultant force must vanish separately:

$$T_1 \cos\theta = T_2 = 60 \text{ N}$$
$$T_1 \sin\theta = 50 \text{ N}$$

which gives that

$$\tan\theta = \frac{5}{6} \quad \text{or} \quad \tan^{-1}\left(\frac{5}{6}\right) = 40°$$

Note the answer does not depend on the length of the rope (assumed massless) nor on the point at which the horizontal force is applied.

S12. (a) Mass of the man, $\boldsymbol{m = 70}$ **kg**

Acceleration, $a = 0$

Using Newton's second law of motion, we can write the equation of motion as:

$$R - mg = ma$$

Where, *ma* is the net force acting on the man.

As the lift is moving at a uniform speed, acceleration $a = 0$.

$$\therefore \quad R = mg$$

$$= 70 \times 10 = 700\text{ N}$$

$\therefore$ Reading on the weighing scale = $\frac{700}{g} = \frac{700}{10} = 70\text{ kg}$

(b) Mass of the man, $m = 70\text{ kg}$

Acceleration, $a = 5\text{ m/s}^2$ downward

Using Newton's second law of motion, we can write the equation of motion as:

$$R + m\text{g} = ma$$

$$R = m(\text{g} - a)$$

$$= 70\,(10 - 5) = 70 \times 5$$

$$= 350\text{ N}$$

$\therefore$ Reading on the weighing scale = $\frac{350}{g} = \frac{350}{10} = 35\text{ kg}$

(c) Mass of the man, $m = 70\text{ kg}$

Acceleration, $a = 5\text{ m/s}^2$ upward

Using Newton's second law of motion, we can write the equation of motion as:

$$R - m\text{g} = ma$$

$$R = m\,(g + a)$$

$$= 70\,(10 + 5) = 70 \times 15$$

$$= 1050\text{ N}$$

$\therefore$ Reading on the weighing scale = $\frac{1050}{g} = \frac{1050}{10} = 105\text{ kg}$

(d) When the lift moves freely under gravity, acceleration $a = g$.

Using Newton's second law of motion, we can write the equation of motion as:

$$R + m\text{g} = ma$$

$$R = m(g - a)$$

$$= m\,(g - g) = 0$$

$\therefore$ Reading on the weighing scale = $\frac{0}{g} = 0\text{ kg}$

The man will be in a state of weightlessnes.

S13. As the string is inextensible, and the pully is smooth, the 3 kg block and the 20 kg trolley both have same magnitude of acceleration. Applying second law to motion of the block (figure (b)),

$$30 - T = 3a$$

Apply the second law to motion of the trolley (figure (c)),

$$T - f_k = 20a$$

Now, $f_k = \mu_k N$, [Here, N is the normal reaction]

Here, $\mu_k = 0.04$,

$$N = 20 \times 10 = 200\,\text{N}.$$

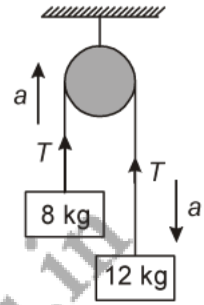
Thus the equation for the motion of the trolley is

$$T - 0.04 \times 200 = 20a \quad \text{Or} \quad T - 8 = 20a.$$

These equations give $a = \dfrac{22}{23}\ \text{m s}^{-2} = 0.96\ \text{m s}^{-2}$

and $T = 27.1$ N.

S14. The given system of two masses and a pulley can be represented as shown in the following figure:



Smaller mass, $m_1 = 8$ kg

Larger mass, $m_2 = 12$ kg

Tension in the string = T

Mass m_2, owing to its weight, moves downward with acceleration upward.

Applying Newton's second law of motion to the system of each mass:

For mass m_1:

The equation of motion can be written as:

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

For mass m_2:

The equation of motion can be written as:

$$m_2 g - T = m_2 a \quad \text{... (ii)}$$

Adding equations (i) and (ii), we get:

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

$$\therefore \quad a = \left(\frac{m_2 - m_1}{m_1 + m_2}\right)g \quad \text{... (iii)}$$

$$= \left(\frac{12 - 8}{12 + 8}\right) \times 9.8$$

$$= \frac{9.8}{5} = 1.96 \sim 2\ \text{m/s}^2$$

Therefore, the acceleration of the masses is 2 m/s^2.

Substituting the value of 'a' in equation (ii), we get:

$$m_2g - T = m_2\left(\frac{m_2 - m_1}{m_1 + m_2}\right)g$$

$$T = \left(m_2 - \frac{m_2^2 - m_1m_2}{m_1 + m_2}\right)g$$

$$= \left(\frac{2m_1m_2}{m_1 + m_2}\right)g$$

$$= \left(\frac{2\times 12\times 8}{12+8}\right)\times 10 = 96 \text{ N}$$

Therefore, the tension in the string is 96 N.

S15. Given, Horizontal force, $F = 600$ N

Mass of body A, $m_1 = 10$ kg

Mass of body B, $m_2 = 20$ kg

Total mass of the system, $m = m_1 + m_2 = 30$ kg

Using Newton's second law of motion, the acceleration (a) produced in the system can be calculated as:

$$F = ma$$

$$\therefore \quad a = \frac{F}{m} = \frac{600}{30} = 20 \text{ m/s}^2$$

When force F is applied on body A:

The equation of motion can be written as:

$$F - T = m_1a$$

$$\therefore \quad T = F - m_1a$$

$$= 600 - 10\times 20 = \mathbf{400\ N}$$

When force F is applied on body B:

The equation of motion can be written as:

$$F - T = m_2a$$

$$T = F - m_2a$$

$$\therefore \quad T = 600 - 20\times 20 = \mathbf{200\ N}$$

S16. If ρ is the mass per unit length of the string, mass of entire string $m = L\rho$.

Acceleration produced in the string,

$$a = \frac{F}{m} = \frac{F}{L\rho}$$

Force acting on the length $(L - x)$ of the string = mass of $(L - x)$ length of string $\times$ acceleration (a)

$$= (L - x)\frac{\rho \times F}{L\rho}$$

$$= \frac{F(L - x)}{L}.$$

S17. Given $g = 9.8\ \text{ms}^{-2}$, $a = 1.2\ \text{ms}^{-2}$; $M = 49$ kg

(a) When the lift is moving up with acceleration $1.2\ \text{ms}^{-2}$

Apparent weight $R = M(a + g) = 49\ (1.2 + 9.8)$

$$= 49 \times 11\ \text{N} = \frac{49 \times 11}{9.8} = 55\ \text{kg f}$$

(b) When the lift is going down with acceleration $1.2\ \text{m s}^{-2}$

Apparent weight $R = M(g - a) = 49\ (9.8 - 1.2)$

$$= 49 \times 8.6\ \text{N} = \frac{49 \times 8.6}{9.8} = 43\ \text{kg f}$$

(c) When the lift is falling freely $a = g$

$\therefore$ Apparent weight $R = M(g - g) = 0$

(d) When the lift moves up or down with uniform velocity, then $a = 0$

$$R - Mg = 0 \quad \text{or} \quad R = Mg = 49\ \text{kg}.$$

S18. Mass of the helicopter, $m_h = 1000$ kg

Mass of the crew and passengers, $m_p = 300$ kg

Total mass of the system, $m = 1300$ kg

Acceleration of the helicopter, $a = 15\ \text{m/s}^2$

Using Newton's second law of motion, the reaction force R, on the system by the floor can be calculated as:

$$R - m_p g = ma$$

$$= m_p(g + a)$$

$$= 300\ (10 + 15) = 300 \times 25$$

$$= 7500\ \text{N}$$

Since the helicopter is accelerating vertically upward, the reaction force will also be directed upward. Therefore, as per Newton's third law of motion, the force on the floor by the crew and passengers is 7500 N, directed downward.

Using Newton's second law of motion, the reaction force R', experienced by the helicopter can be calculated as:

$$
\begin{aligned}
R' - mg &= ma \\
&= m(g + a) \\
&= 1300\,(10 + 15) = 1300 \times 25 \\
&= 32500 \text{ N}
\end{aligned}
$$

The reaction force experienced by the helicopter from the surrounding air is acting upward. Hence, as per Newton's third law of motion, the action of the rotor on the surrounding air will be 32500 N, directed downward.

The force on the helicopter due to the surrounding air is 32500 N, directed upward.

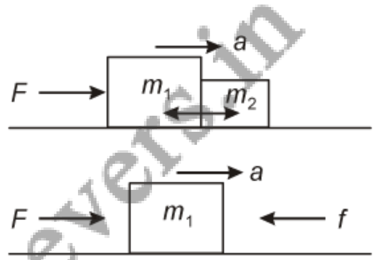
S19. **Newton's Third Law:** To every action, there is always an equal (in magnitude) and opposite (in direction) reaction.

Case I: Let F be applied on m_1 and f is the force of contact between the two bodies.

$\therefore$ $$F - f = m_1 a \quad \text{... (i)}$$

Also, $$f = m_2 a \quad \text{... (ii)}$$

Adding (i) and (ii), we have

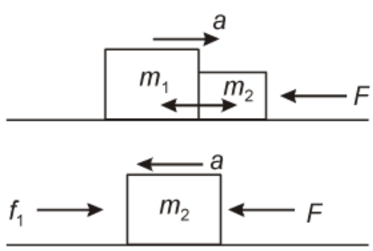


$$F = (m_1 + m_2)a$$

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

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

Case II: Similarly, in the 2nd case



$$F - f_1 = m_2 a \text{ and } f_1 = m_1 a$$

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

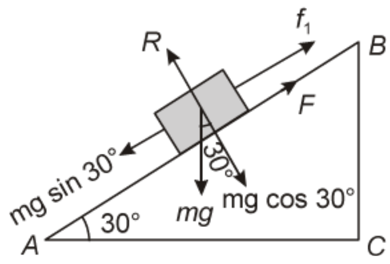
$$f_1 = \frac{m_1 F}{(m_1 + m_2)}$$

S20. **Newton's Second Law:** The time rate of change of momentum of a body is directly proportional to the impressed force and takes place in the direction of the force.

(a) Force 1 = weight = mg

Force 2 = force of limiting friction

Force 3 = Normal Reaction R



(b) $\mu = 0.2$, m = 3 kg, $\theta = 30°$

Force 1 = Weight = mg

$= 3 \times 10 = 30$ N

Force 2 = f_1 = mg sin $\theta - F$

$\because$ $mg \sin\theta = 3 \times 10 \times \sin 30°$

$= 15$ N

And force of friction $F = \mu R$

$= \mu\, mg \cos\theta$

$= 0.2 \times 3 \times 10 \cos 30°$

$= 3\sqrt{3}$ N

then force $2 = f_1 = 15 - 3\sqrt{3} \approx 9.8$ N

Force 3 = Normal reaction R

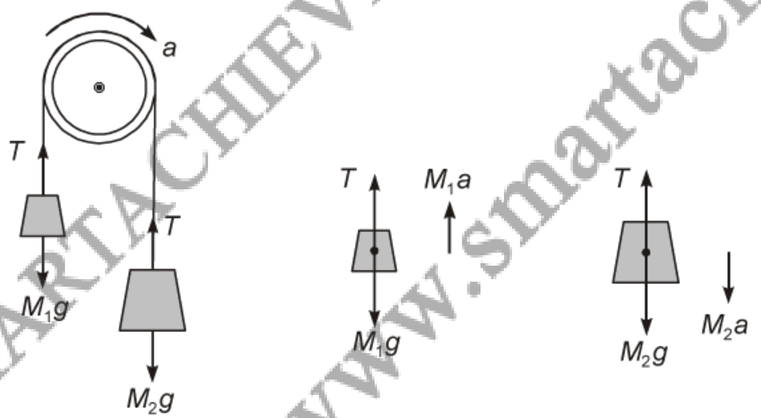
$R = mg \cos\theta$

$= 3 \times 10 \cos 30°$

$= 15\sqrt{3}$ N

S21. Newton's First Law: Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it.

Given: $M_1 = 7$ kg and $M_2 = 12$ kg



The tension (T) in the string acts as shown in the figure (a). Suppose that the system moves with an acceleration a as shown in the figure.

For mass M_1 : Figure (b) is free-body diagram for the mass M_1. It follows that

$$M_1 a = T - M_1 g \quad \text{... (i)}$$

For mass M_2: Figure (b) is free-body diagram for the mass M_2. It follows that

$$M_2 a = M_2 g - T \quad \text{... (ii)}$$

Adding the Eq. (i) and (ii), we get

$$(M_1 + M_2) a = (M_2 - M_1) g$$

or
$$a = \frac{(M_2 - M_1) g}{M_1 + M_2} \quad \text{... (iii)}$$

Substituting for M_1, M_2 and g, we have

$$a = \frac{(12 - 7) \times 9.8}{(12 + 7)} = \mathbf{2.58\ ms^{-2}}$$

From the Eq. (i), we get

$$T = M_1 a + M_1 g = 7 \times 2.58 + 7 \times 9.8 = \mathbf{86.66\ N}.$$

S22. (a) When the force cases to act, the motion would be uniform motion.

$$v = \frac{50\text{ cm}}{5\text{ s}} = 10\text{cm s}^{-1}, \quad u = 0, \quad t = 10\text{s}$$

$$10 = 10 + 10a\ ;\ a = 1\text{ cm s}^{-2};$$

$$F = 10 \times 1\text{ dyne} = 10\text{ dyne}$$

(b) From the forces acting along the horizontal (Shown below)

$$T_1 = m_1 a \quad \text{... (i)}$$

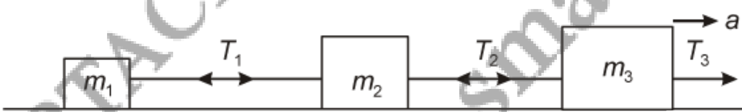
$$T_2 - T_1 = m_2 a \quad \text{... (ii)}$$

$$T_3 - T_2 = m_3 a \quad \text{... (iii)}$$

Adding equation (i), (ii) and (iii), we get

$$T_3 = (m_1 + m_2 + m_3) a$$

$$a = \frac{T_3}{m_1 + m_2 + m_3}$$



Putting various values, we get

$$a = \frac{60}{10 + 20 + 30}$$

$$= \frac{60}{60} = 1\text{ms}^{-2}$$

$\therefore$
$$T_1 = m_1 a = 10\text{N}$$

and
$$T_2 - T_1 = (20 \times 1)\text{ N}$$

or $T_2 = (10 + 20)$ N

$= 30$ N

Thus the required ratio $\frac{T_1}{T_2} = \frac{10}{30} = \frac{1}{3}$.

S23. (a) $m = 20 \times 100$ kg,

$$u = 60 \times \frac{5}{18}\,\text{ms}^{-1} = \frac{50}{3}\,\text{m s}^{-1},$$

$v = 0$, $S = 3000$ m

Now, $$0^2 - \frac{50}{3} \times \frac{50}{3} = 2 \times a \times 3000;$$

$$a = -\frac{2500}{9 \times 2 \times 3000}\,\text{m s}^{-2}$$

$$F = 20 \times 100\left(\frac{2500}{9 \times 2 \times 3000}\right)\text{N}$$

$= 92.6$ N

(b) When force is applied on m_2, the system moves forward with acceleration a and tension T is produced in the thread.

The forces acting on the two bodies are shown separately in second figure :

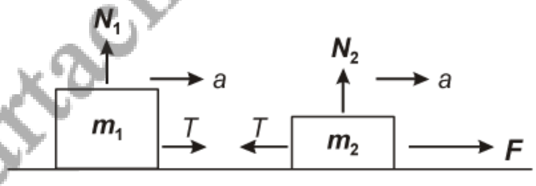
$N_1 = m_1 g$ and $N_2 = m_2 g$, where N_1 and N_2 are normal reactions on m_1 and m_2 respectively.

$T = m_1 a$ ... (i)

$F - T = m_2 a$ ... (ii)

Adding (i) and (ii), we have

$F = (m_1 + m_2)a$



or $a = \frac{F}{(m_1 + m_2)}$ ... (iii)

Again, $T = F - m_2 a$

$$= F - m_2 \times \frac{F}{(m_1 + m_2)}$$

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

$$T = \frac{m_1 F}{(m_1 + m_2)} \quad \text{... (iv)}$$

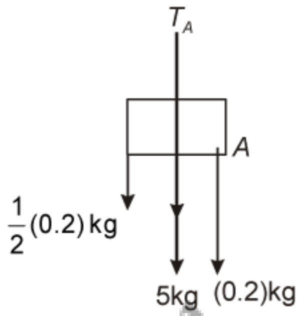
Thus, the acceleration (a) and tension (T) are given by expressions (iii) and (iv) respectively.

S24. (a) Change in momentum = $\frac{1}{4}[-6-8] = -3.5\,\text{Ns}$

$$F = \frac{3.5 \times 10}{1}\,\text{N} = 35\,\text{N}$$

(b) Since the strings carry mass there will be varying tension at different points. At the middle of the string attached to the roof, the forces are as shown.

The tension T_A when the array is at rest is,



$$T_A = \frac{1}{2}(0.2) + 5 + (0.2)$$

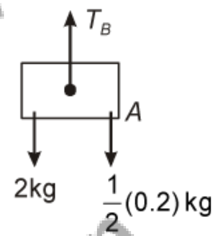
$$T_A = \frac{1}{2}(0.2) + 5 + (0.2)$$

$$T_A = 5.3\text{ kg}$$

The tension T_B when the array stays at rest is,

$$T_B = 2\text{ kg} + 0.1\text{ kg} = 2.1\text{ kg}$$

At the middle of the lower string the forces are when the arrangement is accelerated,



$$T_A = 5.3\,(g + a)$$

$$= 62.54\text{ N}$$

$$T_B = (2.1)\,(g + a) = 24.78\text{ N}$$

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Q1. What are the factors on which the coefficient of friction between two surface depend?

Q2. Why do we call friction a self adjusting force?

Q3. What happens to coefficient of friction, when weight of body is doubled?

Q4. What is the angle between frictional force and instantaneous velocity of the body moving on a rough road?

Q5. Why do we say friction is independent of area of contact?

Q6. Why do we use ball-bearings?

Q7. What is the acceleration associated with a mass '*m*' moving up an inclined plane (θ) with friction coefficient μ?

Q8. What happens to the fluid friction, as speed of the object moving through it is increased?

Q9. Why are wheels made circular?

Q10. Why are tyres made of rubber and not iron?

Q11. What happens to limiting friction, when a wooden block is moved with increasing speed on a horizontal surface?

Q12. Why is friction a non-conservative force?

Q13. What is the unit of coefficient of limiting friction?

Q14. Define limiting friction.

Q15. A cubical block rests on a plane of $\mu = 1/\sqrt{3}$. Determine the angle through which the plane be inclined to the horizontal so that the block just slides down.

Q16. A block of mass 25 kg is lying on a rough horizontal surface. When a force of 122.5 N is applied horizontally, the block just begins to move. Find the coefficient of friction between the surface and the block.

Q17. A force of 98 N is just able to move a body weighing 45 kg on rough horizontal surface, Calculate the coefficient of friction and the angle of friction.

Q18. A constant retarding force of 50 N is applied to a body of mass 20 kg moving initially with a speed of 15 ms^{-1}. How long does the body take to stop?

Q19. If the coefficient of friction is 0.6, calculate the angle of friction.

Q20. Determine the maximum acceleration of the train in which a box lying on its floor will remain stationary, given that the co-efficient of static friction between the box and the train's floor is 0.15.

Q21. Smoother the surface, lesser is friction. Comment.

Q22. Polishing a surface beyond a certain limit may increase friction. Why?

Q23. Sand is thrown on tracks covered with snow in hilly areas. Why?

Q24. Automobile tyres have generally irregular projections over their surfaces. Why?

Q25. Explain, how friction helps in walking.

Q26. Why is it difficult to move a cycle along a road with its brakes on?

Q27. Why are lubricants used in machines?

Q28. Why is it difficult to walk on sand?

Q29. Define limiting friction. If limiting friction is equal to normal reaction, find the angle of friction.

Q30. A mass *m* is at rest on a rough surface. Draw the variation of the force of friction experienced with the force applied on it.

Q31. Define force of friction. How does the use of ball bearing reduce friction?

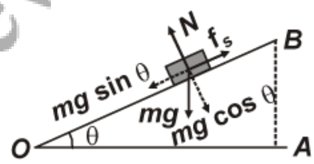
Q32. A mass of 100 kg is resting on a rough inclined plane of angle 30°. If the coefficient of frictions is $1/\sqrt{3}$, find the greatest and the least forces that acting parallel to the plane in both cases, just maintain the mass in equilibrium.

Q33. A ball rolled on ice with a velocity of 14 ms^{-1} comes to rest after travelling 40 m. Find the coefficient of friction. Given g = 9.8 ms^{-2}.

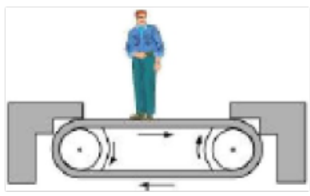
Q34. A horizontal force of 1.2 kgf is applied to a 1.5 kg block, which rests on a horizontal surface. If the coefficient of friction is 0.3, find the acceleration produced. Given: g = 9.8 ms^{-2}.

Q35. A body moving on the ground with a velocity of 15 ms^{-1} comes to rest after covering a distance of 25 m. If the acceleration due to gravity is 10 ms^{-2}, find the coefficient of friction between the ground and the body.

Q36. In the figure, a mass of 4 kg rests on a horizontal plane. The plane is gradually inclined until at an angle θ = 15° with the horizontal, the mass just begins to slide. What is the coefficient of static friction between the block and the surface?



Q37. Figure shows a man standing stationary with respect to a horizontal conveyor belt that is accelerating with 1 m s^{-2}. What is the net force on the man? If the coefficient of static friction between the man's shoes and the belt is 0.2, up to what acceleration of the belt can the man continue to be stationary relative to the belt? (Mass of the man = 65 kg.)



Q38. A body placed on a rough inclined plane just begins to slide, when the slope of the plane is 1 in 4. Calculate the coefficient of friction.

Q39. (a) The coefficient of friction between a horizontal surface and a moving body is μ. With what speed must a body of mass *m* be projected parallel to the surface to travel a distance *S* before stopping?

(b) A block of mass 0.1kg is held against a wall by applying a horizontal force of 5 N on the block. If coefficient of friction between the wall and block is 0.5, what is the magnitude of frictional force acting on the block? Given g = 9.8 ms^{-2}.

Q40. Define the term 'coefficient of limiting friction' between two surfaces. A body of mass 10 kg is placed on an inclined surface of angle 30°. If the coefficient of limiting friction is $\frac{1}{\sqrt{3}}$ find the force required to just push the body up the inclined surface. the force is being applied parallel to the inclined surface.

Q41. Prove that the coefficient of static friction is "tangent" of the angle of repose.

Q42. Distinguish between static friction, limiting friction and kinetic friction. How do they vary with the applied force, explain by diagram.

Q43. A horizontal force of 12 kgf pushes a block weighing 5 kgf against a vertical wall. The coefficient of static friction between the wall and the block is 0.5 and the coefficient of kinetic friction is 0.4.

(a) Will the block slide down against the wall? Assume that the block was not moving initially.

(b) Will the answer change, if the block was initially sliding?

Q44. A bullet of mass 0.01 kg is fired horizontally into a 4 kg wooden block at rest on a horizontal surface. The coefficient of the kinetic friction between the block and the surface is 0.25. The bullet gets embedded in the block and the combination moves 20 m before coming to rest. With what speed did the bullet strike the block?

Q45. A train of mass 150 metric ton is drawn up an incline of 1 in 100 at the rate of 36 km h^{-1}. If resistance due to friction is 12 newton per ton, calculate the power of the engine.

Q46. Calculate the force required to move a train of 2,000 quintals up on incline of 1 m 50 with an acceleration of 2 ms^{-2}, the force of friction being 0.5 N per quintal.

Q47. The rear side of a truck is open and a box of 40 kg mass is placed 5 m away from the open end as shown in figure. 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).

Q48. (a) Show that kinetic friction is less than the static friction.

(b) Establish that static friction is self-adjustable force.

(c) Write the basic laws of limiting friction.

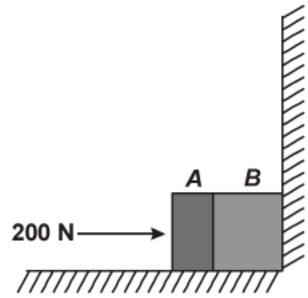
Q49. A block of mass 15 kg is placed on a long trolley. The coefficient of static friction between the block and the trolley is 0.18. The trolley accelerates from rest with 0.5 ms^{-2} for 20s and then moves with uniform velocity. Discuss the motion of the block as viewed by (a) a stationary observer on the ground, (b) an observer moving with the trolley.

Q50. An aircraft executes a horizontal loop at a speed of 720 km/h with its wings banked at 15°. What is the radius of the loop?

Q51. A body starts rolling down an inclined plane, the top half of which is perfectly smooth and the lower half is rough. Find the ratio of force of friction and the weight of the body, if the body is brought to rest just when it reaches the bottom. Given that inclination of plane with the horizontal is 30°.

Q52. Two bodies *A* and *B* of masses 5 kg and 10 kg in contact with each other rest on a table against a rigid wall.

The coefficient of friction between the bodies and the table is 0.15. A force of 200 N is applied horizontally to the partition (a) the action-reaction forces between is removed? Does the answer to (b) change, when the bodies are in motion? Ignore the difference between μ_s and μ_k.



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S1. The coefficient of friction between two surfaces depends upon the nature of the two surface and their state of roughness.

S2. When applied force is zero, friction is zero. As the applied force is increased, friction also increases and becomes equal to the applied force. It happens so, till the body does not start moving. That is why, friction is called a self adjusting force.

S3. Remains constant **because it depends on the nature of the surface**.

S4. The angle between the frictional force and instantaneous velocity is 180°.

S5. Any change in area, leads to only variation in the pressure experienced, but the force to be balanced remains the same.

S6. To reduce friction under rolling.

S7. Forces acting are $mg \sin\theta$ and $\mu mg \cos\theta$, both in the downward direction, as the mass moves up so, acceleration associated with mass m,

$$a = g(\sin\theta + \mu\cos\theta)$$

S8. The fluid friction increases, as the speed of the object moving through it, is increased.

S9. The rolling friction is less than the sliding friction. The wheels are made circular so as to convert the sliding friction into the rolling friction.

S10. It is because, the coefficient of friction between rubber and concrete (material of the road) is less than that between iron and the road.

S11. The limiting friction decreases as the wooden block is moved with increasing speed on the horizontal surface.

S12. It is because, work done against friction along a closed path is non-zero **as it depend on the path followed**.

S13. It has no unit.

S14. The maximum value of the force of friction which comes into play before a body just begins to slide over the surface of another body is called limiting value of static friction.

S15. Suppose that the block starts sliding down, when the plane is inclined at an angle θ with the horizontal. Then,

$$\tan\theta = \mu; \quad \text{or} \quad \tan\theta = \frac{1}{\sqrt{3}}$$

$$\theta = 30°.$$

S16. Given: $F = 122.5\,\text{N}$; $R = Mg = 25 \times 9.8\,\text{N}$

Now, $\mu = \frac{F}{R} = \frac{122.5}{25 \times 9.8} = \mathbf{0.5}$. $\qquad \mu = \tan\theta = \frac{F}{R}$

S17. Given: $F = 98\,\text{N}$; $R = Mg = 45\,\text{kgf} = 45 \times 9.8\,\text{N}$

Now, $\mu = \frac{F}{R} = \frac{98}{45 \times 9.8} = \mathbf{0.22}$.

If α is the angle of friction, then

$$\tan\alpha = \mu = 0.22$$

$$\alpha = \mathbf{12°\text{–}24'}.$$

S18. Given $F = -50\,\text{N}$, m = 20 kg $u = 15\,\text{ms}^{-1}$, $v = 0$, $t = ?$

$$F = ma \quad \text{or} \quad a = \frac{F}{m} = \frac{-50}{20} = -2.5\,\text{ms}^{-2}$$

$$v = u + at \quad \text{or} \quad 0 = 15 - 2.5\,t,\ t = \frac{15}{2.5} = 6\,s.$$

S19. Here, $\mu = 0.6$

If α is the angle of friction, then

$$\tan\alpha = \mu \quad \text{or} \quad \tan\alpha = 0.6$$

or $\alpha = \mathbf{31°}$.

S20. Since the acceleration of the box is due to the static friction,

$$ma = f_s \le \mu_s N = \mu_s m g$$

i.e., $a \le \mu_s g$

$\therefore$ $a_{\text{max}} = \mu_s g = 0.15 \times 10\,\text{m s}^{-2}$

$= 1.5\,\text{m s}^{-2}$.

S21. When the surfaces are made smoother, the size of the irregularities in the surfaces decreases. As a result, the area of actual contact decreases. As the number of atoms in contact will also decrease due to the force of also decrease the force of molecular attraction and hence the force of friction decreases.

S22. When the surfaces are polished beyond a certain limit, the area at each point of contact becomes very small. However, the actual area of contact between the two surfaces increases appreciably. It is because, the number of points of contact becomes very large on making the surfaces highly polished. Since number of atoms (or molecules) of the two surfaces in contact is proportional to their area in contact, the force of friction increases due to the greater force of molecular attraction between the two surfaces.

S23. When the tracks in hilly areas get covered with snow, the force of friction between the tyres of a vehicle and the snow covered track reduces appreciably. Due to this, the driving is no longer safe. In order to produce sufficient force of friction for safe driving, sand is thrown on the snow covered tracks.

S24. It is done in order to increase friction between the tyres and the road for better road grip. In case, the irregular projections on the tyres wear out, the vehicle may skid on applying brakes. It is because, force of friction between the road and a bald tyre is much less than that between the road and the tyres having irregular projections.

S25. When we walk, we push the ground in backward direction. Our foot will get equal and opposite reaction from the ground only, if the foot does not slip *i.e.*, there is adequate friction between the foot and the ground. The forward horizontal component of the reaction helps us to move forward.

S26. Between the tyres of the cycle and the road, friction is of rolling type in nature. But when the cycle is moved with brakes on, the wheels cannot revolve, but can only skid. Due to this, the sliding friction comes into play. As the sliding friction is greater than rolling friction, it becomes difficult to move the cycle with brakes on.

S27. When a machine is lubricated, thin layers of the lubricant cover the two surfaces moving in contact with each other. The sliding motion now takes place between the two layers of the lubricant rather than the two solid surfaces *i.e.*, the sliding friction is converted into fluid friction. Since fluid friction is much less than the sliding friction, the wear and tear of the machine is much reduced due to decrease in the friction.

S28. When we walk on sand, our feet get depressed in the sand. Due to this, the reaction from the sand on our feet is much smaller. Since the forward horizontal component of the reaction helps in moving forward, the walking on the sand becomes difficult due to the small value of the horizontal component of the reaction.

S29. **Limiting friction:** The maximum value of force of friction which comes into play before a body just begins to slide over the surface of another body is called limiting value of static friction.

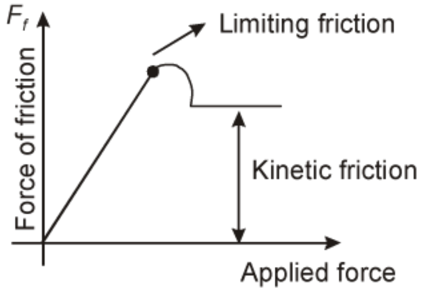
If F and R are limiting friction and normal reaction respectively, then angle of friction α is given by

$$\tan \alpha = \frac{F}{R}$$

Here, $F = R$

$$\therefore \qquad \tan \alpha = \frac{R}{R} = 1 \quad \text{or} \quad \alpha = \mathbf{45°}.$$

S30.



S31. The force parallel to the surface of contact which opposes relative motion between the two surfaces. By using ball bearings, the wheel rolls on balls instead of sliding on axle. So the sliding friction so converted into rolling friction which is much less.

S32. The greatest force along the plane, which can maintain the mass in equilibrium,

$$F_{max} = mg(\sin\theta + \mu\cos\theta)$$

$$= 100 \times 9.8\left(\sin 30° + \frac{1}{\sqrt{3}}\cos 30°\right)$$

$$= 100 \times 9.8\left(\frac{1}{2} + \frac{1}{\sqrt{3}} \cdot \frac{\sqrt{3}}{2}\right)$$

$$= 100 \times 9.8 = 980\text{ N} = \mathbf{100\ kgf}.$$

The least force along the plane, which can maintain the mass in equilibrium,

$$F_{min} = mg(\sin\theta - \mu\cos\theta)$$

$$= 100 \times 9.8\left(\sin 30° - \frac{1}{\sqrt{3}}\cos 30°\right)$$

$$= 100 \times 9.8\left(\frac{1}{2} - \frac{1}{\sqrt{3}} \cdot \frac{\sqrt{3}}{2}\right) = \mathbf{0}.$$

S33. Given: $u = 14\text{ ms}^{-1}$, $v = 0$ and $S = 40\text{ m}$

We know that, $v^2 - u^2 = 2aS$

$\therefore$ $0^2 - 14^2 = 2 \times a \times 40$

or $a = -2.45\text{ ms}^{-2}$

$F = \mu R$

Now, $\mu = \frac{F}{R} = \frac{Ma}{Mg} = \frac{a}{g} = \frac{2.45}{9.8} = \mathbf{0.25}$.

S34. Given: $Mg = 1.5\text{ kgf} = 1.5 \times 9.8\text{ N}$ and $\mu = 0.3$

Force of friction, $F_r = \mu R = \mu Mg = 0.3 \times 1.5 \times 9.8 = 4.41\text{ N}$

Applied force, $F = 1.2\text{ kgf} = 1.2 \times 9.8 = 11.76\text{ N}$

Therefore, net force acting on the block,

$$F - F_r = 11.76 - 4.41 = 7.35 \text{ N}$$

Since mass of the block is 1.5 kg

$$\text{Acceleration produced} = \frac{7.35}{1.5} = \mathbf{4.9\ ms^{-2}}.$$

S35. Given: $u = 15\,\text{ms}^{-1}$; $v = 0$; $S = 25\,\text{m}$

From the relation: $v^2 - u^2 = 2aS$, we have

$$0^2 - 15^2 = 2a \times 25$$

or $$a = \frac{15^2}{2 \times 25} = 4.5 \text{ ms}^{-2}$$

$$F = \mu R$$

Now, $$\mu = \frac{F}{R} = \frac{Ma}{Mg} = \frac{a}{g} = \frac{4.5}{10} = \mathbf{0.45}.$$

S36. The forces acting on a block of mass m at rest on an inclined plane are (i) the weight mg acting vertically downwards (ii) the normal force N of the plane on the block, and (iii) the static frictional force f_s opposing the impending motion. In equilibrium, the resultant of these forces must be zero. Resolving the weight mg along the two directions shown, we have

$$mg \sin\theta = f_s, \qquad mg \cos\theta = N$$

As θ increases, the self-adjusting frictional force f_s increases until at $\theta = \theta_{max}$, f_s achieves its maximum value, $(f_s)_{max} = \mu_s N$.

Therefore, $$\tan\theta_{max} = \mu_s \quad \text{or} \quad \theta_{max} = \tan^{-1}\mu_s$$

When θ becomes just a little more than θ_{max}, there is a small net force on the block and it begins to slide. Note that θ_{max} depends only on μ_s and is independent of the mass of the block.

For $$\theta_{max} = 15°,$$

$$\mu_s = \tan 15° = 0.27$$

S37. Mass of the man, $m = 65$ kg

Acceleration of the belt, $a = 1\ \text{m/s}^2$

Coefficient of static friction, $\mu = 0.2$

The net force F, acting on the man is given by Newton's second law of motion as:

$$f_{net} = ma = 65 \times 1 = 65\,\text{N}$$

The man will continue to be stationary with respect to the conveyor belt until the net force on the man is less than or equal to the frictional force f_s, exerted by the belt, *i.e.*,

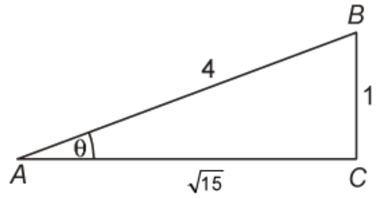
$\therefore$ $a' = 0.2 \times 10 = 2 \text{ m/s}^2$

Therefore, the maximum acceleration of the belt up to which the man can stand stationary is 2 m/s^2.

S38. The figure shows, the slope of the plane equal to 1 in 4 implies that if $BC = 1$ and $AB = 4$. Suppose that the plane is inclined at angle θ with the horizontal AC.

From the relation between the coefficient of friction and the

angle of repose, we have



$$\mu = \tan\theta = \frac{BC}{AC} = \frac{BC}{\sqrt{AB^2 - BC^2}}$$

$$= \frac{1}{\sqrt{4^2 - 1^2}} = \frac{1}{\sqrt{15}} = \mathbf{0.258}.$$

S39. (a) Let u be the speed with which the body should be projected parallel to the horizontal surface

Now, $\mu = \frac{F}{R} = \frac{a}{g}$

or $a = \mu g$ [retardation]

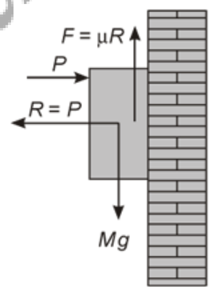
We know, $v^2 - u^2 = 2aS$

Here, $a = -\mu g$; $v = 0$

$\therefore$ $0^2 - u^2 = 2 \times (-\mu g) \times S$

or $u = \sqrt{\mathbf{2\mu gS}}$.

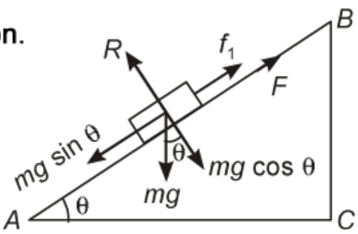
(b) The block is held against wall by applying a horizontal force F. The wall gives normal reaction R to the block. As the block tends to slide down along the wall, force of friction F acts along the wall in the upward direction. It follows that in order to hold the block against the wall, weight of the block must be balanced by the force of friction *i.e.*,



$$F = \mu M g = 0.1 \times 9.8 = \mathbf{0.98\ N}.$$

S40. Coefficient of limiting friction between two surfaces in contact is defined as the ratio of force of limiting friction and normal reaction between them.

Total force required = Force of friction + Force in downward direction.



$m = 10 \text{ kg}$

$\theta = 30°$

$\mu = \frac{1}{\sqrt{3}}$

$R = mg\cos\theta$

Force of friction

$$F = \mu R = \mu\, mg \cos\theta$$
$$= \frac{1}{\sqrt{3}} \times 10 \times 9.8 \times \cos 30^\circ$$
$$= \frac{1}{\sqrt{3}} \times 98 \times \frac{\sqrt{3}}{2} = 49\,\text{N}$$
$$mg \sin\theta = 10 \times 9.8 \times \cos 30^\circ = 49\,\text{N}$$

Force required to push the body inclined on surface = (49 + 49) = 98 N.

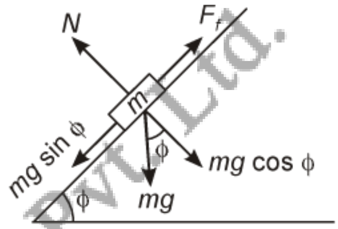
S41. The angle of repose is defined as the maximum inclination of the plane for which the mass kept over it can stay at rest. Let ϕ be the angle of repose. Then,

$$N = mg\cos\phi; \quad F_f = mg\sin\phi$$

Also, $F_f = \mu N$

$\therefore$ $\mu\, mg \cos\phi = mg \sin\phi$,

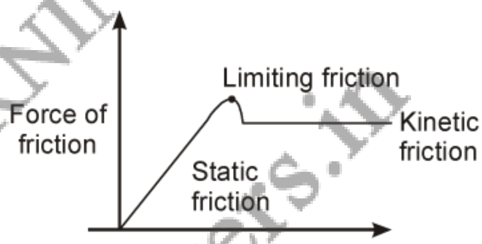
i.e., $\mu = \tan\phi$.



Since the body is at rest, the friction is static friction and the coefficient is for static case.

S42. Static friction exists as long as the body stays at rest. It increases with the force applied. Limiting friction is the maximum value of static friction.

Kinetic friction is the friction when the body is on the move. This will be a constant and depends on the nature of surface only. The variation of frictional force is as shown in figure.



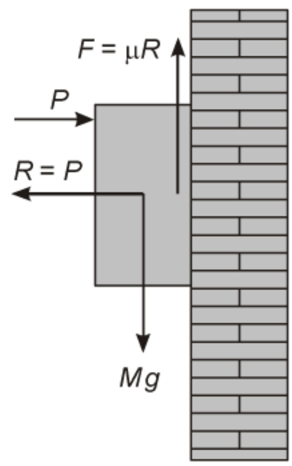
S43. The figure shows a block of weight *Mg* being pushed against the wall by applying a horizontal force *P*. The weight of the block acts vertically downwards, while the normal reaction *R* (= *P*) acts along normal to the wall.

(a) The weight Mg (5 *kgf*) of the block tends to slide the block in downward direction. Since the block is not moving initially, the force of friction μR will act at the interface in upward direction. Here, μ is coefficient of static friction.

Now, normal reaction, $R = P = 12$ kgf

force static friction, $F = \mu R = 0.5 \times 12 = 6$ kgf

As the force of static friction is greater than the weight of the body, the block ***will not slide down***.



(b) In case the block was sliding initially, then

force of kinetic friction, $F_k = \mu_k R = 0.4 \times 12 = 4.8$ kgf

Since the force of kinetic friction is less than the weight of the block, the block ***will continue sliding***.

S44. Given: $\mu = 0.25$; mass of the bullet, $m = 0.01$ kg; mass of the block, $M = 4$ kg

Total mass of the bullet and the block,

$$m + M = 0.01 + 4 = 4.01 \text{ kg}$$

The normal reaction received by the bullet and the block from the horizontal surface,

$$R = (m + M)\,g = 4.01 \times 9.8 \text{ N}$$

Let F be the force of friction between the block and the surface. If μ is the coefficient of limiting friction between the block and the surface, then

$$F = \mu R = 0.25 \times 4.01 \times 9.8 = 9.8245 \text{ N}$$

Suppose that the bullet strikes the block which a velocity v, As the block and the bullet come to rest after covering a distance S = 20 m, it follows that the kinetic energy of the bullet is used up in performing work against the friction between the block and the surface i.e.,

$$\frac{1}{2} mv^2 = FS$$

$$\frac{1}{2} \times 0.01 \times v^2 = 9.8245 \times 20$$

or $$v = \sqrt{\frac{9.8245 \times 20 \times 2}{0.01}} = 198.24 \text{ ms}^{-1}.$$

S45. Given: Mass of train, $M = 150$ metric ton $= 150 \times 10^3$ kg

$$\sin\theta = \frac{1}{100}$$

Resistance due to friction, $F = 150 \times 12 = 1{,}800$ N

Speed of the train, $v = 36 \text{ km h}^{-1} = 10 \text{ ms}^{-1}$

If θ is the inclination of track with the horizontal, then the force required to draw the train up the track,

$$P = Mg \sin\theta + F$$

$$= 150 \times 10^3 \times 9.8 \times \frac{1}{100} + 1{,}800$$

$$= 14{,}700 + 1{,}800 = 16{,}500 \text{ N}$$

Hence, Power of the engine $= P \times v$

$= 16{,}500 \times 10 = 1{,}65{,}000$ W = **165 kW**.

S46. Force required to move the train up on incline,

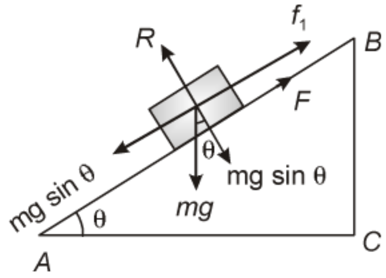
$$P = Mg \sin\theta + F$$

Here, M = 2,000 quintals

$= 2{,}000 \times 100 = 2 \times 10^5$ kg;

$g = 9.8$ ms^{-2}; $\sin\theta = 1/50$

and $F = 2{,}000 \times 0.5 = 1{,}000$ N



$$\therefore \quad P = 2 \times 10^5 \times 9.8 \times \frac{1}{50} + 1000$$

$$= 39{,}200 + 1{,}000 = \mathbf{40{,}200\ N}.$$

S47. Mass of the box, $m = 40$ kg

Coefficient of friction, $\mu = 0.15$

Initial velocity, $u = 0$

Acceleration, $a = 2$ m/s^2

Distance of the box from the end of the truck, $s' = 5$ m

As per Newton's second law of motion, the force on the box caused by the accelerated motion of the truck is given by:

$$F = ma$$

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

As per Newton's third law of motion, a reaction force of 80 N is acting on the box in the backward direction. The backward motion of the box is opposed by the force of friction f, acting between the box and the floor of the truck. This force is given by:

$$f = \mu mg$$

$$= 0.15 \times 40 \times 10 = 60\ \text{N}$$

$\therefore$ Net force acting on the block:

F_{net} = Force due to acceleration of truck – Force of friction

F_{net} = 80 – 60 = 20 N backward

The backward acceleration produced in the box is given by:

$$a_{back} = \frac{F_{net}}{m} = \frac{20}{40} = 0.5\ \text{m/s}^2$$

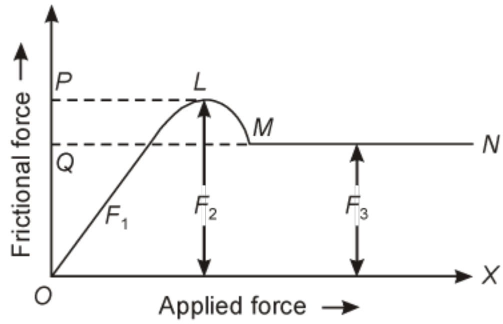
Using the second equation of motion, time t can be calculated as:

S48. (a) Plotting a graph between applied force and frictional force (see figure), we have

OL = static friction = F_1

OP = limiting friction = F_2

MN = kinetic friction = F_3



F_1 goes on increasing with applied force, at L, the static friction is maximum beyond, L the frictional force decreases slightly. As the portion MN of the curve is parallel on OX.

Therefore kinetic friction as once motion actually starts irregularities of one surface are not able to get locked into irregularities of another surface.

(b) Magnitude and direction of the static friction force adjust themselves according to applied force. When we change the applied force, force of static friction changes accordingly in the direction opposite to the applied force.

(c) Laws of limiting friction:

(i) Magnitude of force of limiting friction (F) between any two bodies in contact is directly proportional to normal reaction (R), *i.e.*, $F \propto R$.

(ii) Direction of force of limiting friction is always opposites to the one in which the body starts moving over another.

(iii) As long as normal reaction between two bodies in contact remains same, the force of limiting friction is independent of area of contact.

(iv) Force of limiting friction only depends upon the material and nature of the surfaces in contact.

S49. Mass of the block, $m = 15$ kg

Coefficient of static friction, $\mu = 0.18$

Acceleration of the trolley, a $a = 0.5$ m/s^2

(a) As per Newton's second law of motion, the force (F) on the block caused by the motion of the trolley is given by the relation:

$$F = ma = 15 \times 0.5 = 7.5 \text{ N}$$

This force is acted in the direction of motion of the trolley.

Force of static friction between the block and the trolley:

$$f = \mu m g$$

$$= 0.18 \times 15 \times 10 = 27 \text{ N}$$

The force of static friction between the block and the trolley is greater than the applied external force. Hence, for an observer on the ground, the block will appear to be at rest. When the trolley moves with uniform velocity there will be no applied external Only the force of friction will act on the block in this situation.

(b) An observer, moving with the trolley, has some acceleration. This is the case of non inertial frame of reference. The frictional force, acting on the trolley backward, is opposed by a pseudo force of the same magnitude. However, this force acts in the opposite direction. Thus, the trolley will appear to be at rest for the observer moving with the trolley.

S50. Speed of the aircraft,

$$v = 720 \text{ km/h} = 720 \times \frac{5}{18} = 200 \text{m/s}$$

Acceleration due to gravity, $g = 10$ m/s

Angle of banking, $\theta = 15°$

For radius *r*, of the loop, we have the relation:

$$\tan\theta = \frac{v^2}{rg}$$

$$r = \frac{v^2}{g\tan\theta}$$

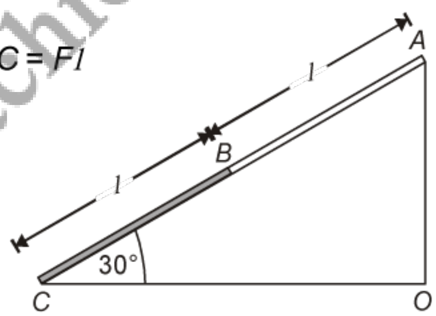
$$= \frac{200 \times 200}{10 \times \tan 15} = \frac{4000}{0.268}$$

$$= 14925.37 \text{ m} = 14.92 \text{ km.}$$

S51. Consider that a body of weight *Mg* is placed at the top of the inclined plane at the point *A*. The length of the inclined plane is $2l$, so that the upper half *AB* is perfectly smooth and the lower half is rough as shown in the figure.

As the body comes to rest at the point *C*, it follows that work done against friction along lower half of the plane = potential energy of the body at the point *A*.
If *F* is limiting friction, then

Work done against friction along the lower half $BC = Fl$



Potential energy of body at the point *A*

$$= Mg(OA) = Mg(2l\sin 30°)$$

$$= Mgl$$

Now, $Fl = Mgl$

or $\frac{F}{Mg} = \mathbf{1}$.

S52. Given, Mass of body *A*, $m_A = 5$ kg; Mass of body *B*, $m_B = 10$ kg; Applied force, $F = 200$ N; Coefficient of friction, $\mu_s = 0.15$

(a) The force of friction is given by the relation:

$f_s = \mu(m_A + m_B)g$ $\quad\quad\quad\quad f_s = \mu R$

$= 0.15\ (5 + 10) \times 10$

$= 1.5 \times 15 = 22.5$ N leftward

Net force acting on the partition = 200 – 22.5 = 177.5 N rightward

As per Newton's third law of motion, the reaction force of the partition will be in th direction opposite to the net applied force.

Hence, the reaction of the partition will be 177.5 N, in the leftward direction. Force of friction on mass *A*:

$$f_A = \mu m_A g = 0.15 \times 5 \times 10 = 7.5 \text{ N leftward}$$

Net force exerted by mass *A* on mass *B* = 200 – 7.5 = 192.5 N rightward.

(b) As per Newton's third law of motion, an equal amount of reaction force will be exerted by mass *B* on mass *A*, *i.e.*, 192.5 N acting leftward. When the wall is removed, the two bodies will move in the direction of the applied force.

Net force acting on the moving system = 177.5 N

The equation of motion for the system of acceleration *a*, can be written as:

$$\text{Net force} = (m_A + m_B)\, a$$

$$\therefore \quad a = \frac{\text{Net force}}{m_A + m_B}$$

$$= \frac{177.5}{5+10} = \frac{177.5}{15} = 11.83 \text{ m/s}^2$$

Net force causing mass *A* to move:

$$F_A = m_A a$$

$$= 5 \times 11.83 = 59.15 \text{ N}$$

Net force exerted by mass A on mass *B* = 192.5 – 59.15 = 133.35 N

Date: 13/10/2021

Q1. A bob of mass 0.1 kg hung from the ceiling of a room by a string 2 m long is set into oscillation. The speed of the bob at its mean position is ms^{-1}. What is the trajectory of the bob if the string is cut when the bob is (a) at one its extreme positions. (b) at its mean position?

Q2. Why does a child in a merry-go-round press the side of his seat radially outwards?

Q3. If a string of a rotating stone breaks, in which direction will the stone move?

Q4. Is the large brake on a bicycle wheel more effective than a small one? Explain.

Q5. What is the weight felt by a person in a lift when it has free fall?

Q6. Is a bus moving along a circular track, an inertial frame of reference?

Q7. If the net force acting on a body be zero, will the body remain necessarily in rest position? Explain your answer.

Q8. Name physical situation, where the mass of a body changes with time.

Q9. A stone is moved along a vertical circle so as to just loop the loop. What is the minimum velocity, the stone should possess at the lowest point?

Q10. What will be the maximum velocity with which a vehicle can negotiate a turn of radius r safely, when the coefficient of friction between the tyres and the road is μ.

Q11. For uniform circular motion, does the direction of the centripetal force depend upon the sense of rotation?

Q12. A particle of mass 0.1 kg is whirled uniformly at the end of a string 2 m long. If the string makes 120 rev/min, calculate the tension in the string.

Q13. A 500 kg car takes a round turn of 50 m with a velocity of 36 km/hr. How much centripetal force is required?

Q14. A body of mass 0.5 kg is whirled with a velocity of 2 ms^{-1} using 0.5 length of string which can withstand a tension of 15 N. Neglecting the force of gravity on the body predict whether or not the string will break. Give reasons.

Q15. A racing car travelling at 30 ms^{-1} along a circular path of radius 500 m, starts picking up speed at the rate of 2 ms^{-2}. What is its total acceleration?

Q16. What is angular acceleration? Derive the relation between linear acceleration and angular acceleration.

Q17. What is the centripetal force? Find its value in circular motion.

Q18. An electric bulb suspended from the roof of a railway train by a flexible wire shifts through an angle $19° - 48'$, when the train goes round the curved path 100 meter in radius. Find the speed of the train (g = 9.8 m/sec^2).

Q19. The roadway bridge over a canal is in the form of an arc of radius 16 m. What is the maximum speed with which a car can move without leaving the ground at the highest point? $g = 9.8\ ms^{-2}$.

Q20. A flywheel requires 3 sec to rotate through 234 radian. If its angular velocity at this instant is 108 rad/sec, find the initial velocity and the uniform acceleration.

Q21. A particle moving in a circle of radius 88 cm has its angular velocity increased by 180 revolutions per minute. Calculate (a) linear acceleration, and (b) the angular acceleration.

Q22. A pulley 44 cm in diameter is rotated at the rate of 480 revolutions per minute. What are its angular and linear velocities?

Q23. A bucket containing water is rotated in vertical circle. Explain, why the water does not fall?

Q24. Why the passengers are thrown outwards, when the bus takes a circular turn?

Q25. Why does a child in a merry-go-round press the side of his seat radially outward?

Q26. A string just supports a hanging ball without breaking. If the ball is set to swinging, the string will break. Why?

Q27. Moon is continuously revolving round the earth without falling towards it. Justify, why it does so?

Q28. Compute the magnitude and direction of total linear acceleration of a particle moving in a circle of radius 0.4 m having an instantaneous angular velocity of 2 rad s^{-1} and angular acceleration 5 rad s^{-2}.

Q29. A cyclist moving at a speed of 17.64 km/hour describes a circle of radius 9.8 metre. What is smallest value of the coefficient of friction between the tyres and the ground, so that the cyclist may be held in balance?

Q30. A bend in a level road has a radius of 100 metre. Find the maximum speed which a car turning this bend may have without skidding if the co-efficient of friction between the tyres and the road is 0.8.

Q31. A cyclist goes round a circular track of 440 m length in 20 second. Find the angle that his cycle makes with the vertical.

Q32. The radius of curvature of a railway line at a place is 0.8 km. A train is running at 20 ms^{-1}. The distance between the two rails is 1.5 m. Find the elevation of the other rail over the inner one, so that the train may be able to run safely. Given, $g = 9.8\ ms^{-2}$.

Q33. A ball of mass 0.1 kg is revolved in a horizontal circular groove of radius 25 cm having vertical side walls. Find the contact force on the ball due to the wall of the groove, if it completes one round of the groove in 0.2 s.

Q34. An object of mass 0.4 kg is whirled in a horizontal circle of radius 2 m. If it performs 60 revolutions min^{-1}, calculate the centripetal force acting on it.

Q35. A child is sitting in a merry-go-round, which can rotate in a horizontal plane about its central axis. The distance of the child's seat from the centre of the joy wheel is 2.5 m and the coefficient of static friction between the child and his seat is 0.3. Find the maximum speed of rotation of the merry-go-round, so that the child can enjoy the ride without skidding from his seat.

Q36. The centripetal force of 45 N is required to revolve a stone of mass 100 g along a circular path of radius 50 cm. Find the constant speed of the stone

Q37. A pulley 22 cm in diameter is rotated at the rate of 420 revolutions per minute. What are its angular and linear velocities?

Q38. A train runs along an unbanked circular track of radius 30 m at a speed of 54 km/h. The mass of the train is 106 kg. What provides the centripetal force required for this purpose – The engine or the rails? What is the angle of banking required to prevent wearing out of the rail?

Q39. A circular racetrack of radius 300 m is banked at an angle of 15°. If the coefficient of friction between the wheels of a race-car and the road is 0.2, what is the (a) optimum speed of the racecar to avoid wear and tear on its tyres, and (b) maximum permissible speed to avoid slipping?

Q40. A cyclist speeding at 18 km/h on a level road takes a sharp circular turn of radius 3 m without reducing the speed. The co-efficient of static friction between the tyres and the road is 0.1. Will the cyclist slip while taking the turn?

Q41. The roadway bridge over a canal is in the form of an arc of a circle of radius 20 m. What is the maximum speed with which a car can cross the bridge without leaving contact with the ground at the highest point? Given, $g = 9.8\ ms^{-2}$.

Q42. A stone of mass 1.3 kg tied to the end of ring in a horizontal plane is whirled round in a circle of diameter 2m with a frequency of 40 rpm. What is the tension in the string? What is the maximum speed with which the one can be whirled around, if the string can withstand a maximum tension of 200 N?

Q43. A body weighing 0.4 kg is whirled in a vertical circle making 2 revolutions per second. If the radius of the circle is 1.2 m, find the tension in the string, when body is (a) at the bottom of the circle, (b) at the top of the circle.

Q44. A train rounds a curved of radius 150 m at a speed of 20 ms^{-1}. Calculate the angle of banking, so that there is no side thrust on the rails. Also find the elevation of the outer rail over the inner rail, if the distance between the rails is 1 m.

Q45. A stone of mass *m* tied to the end of a string revolves in a vertical circle of radius *R*. The net forces at the lowest and highest points of the circle directed vertically downwards are:

[Choose the correct alternative]

	Lowest Point	Highest Point
(a)	$mg - T_1$	$mg + T_2$
(b)	$mg + T_1$	$mg - T_2$
(c)	$mg + T_1 - (mv_1^2)/R$	$mg - T_2 + (mv_1^2)/R$
(d)	$mg - T_1 - (mv_1^2)/R$	$mg + T_2 + (mv_1^2)/R$

T_1 and v_1 denote the tension and speed at the lowest point. T_2 and v_2 denote corresponding values at the highest point.

Q46. You may have seen in a circus a well' (a hollow spherical chamber with holes, so the spectators can watch from outside). Explain clearly why the motorcyclist does not drop down when he is at the uppermost point, with no support from below. What is the minimum speed required at the uppermost position to perform a vertical loop if the radius of the chamber is 25 m?

Q47. Find the angle through which a cyclist bends when he curves a circular path 34.3 metre in circumference in $\sqrt{22}$ second. Given value of $g = 9.8$ m/sec^2.

Q48. The radius of curvature of railway line at a place when the train is moving with a speed of 72 kg/ hour is 1500 meter. If the distance between the rails is 1.54 meter, find the elevation of the outer rail above the inner rail so that there is no side pressure on the rails.

Q49. A ball of mass 0.1 kg is suspended by a string 30 m long. Keeping the string always taut, the ball describes a horizontal circle of radius 15 cm. Find the angular speed.

Q50. One end of a string of length 61.25 cm is attached to a bucket containing water and the bucket is rotated about the other end in a vertical circle. Find the minimum speed with which it can be rotated without spilling the water at the highest point. How many revolutions per minute is it making. $g = 9.8$ m/sec^2.

Q51. A flywheel rotates about a fixed axis and slows down from 300 rev/min to 100 rev/min in 2 minutes.

(a) What is the angular acceleration in rad/min^2?

(b) How many revolutions does the wheel complete during this time?

Q52. A 70 kg man stands in contact against the inner wall of a hollow cylindrical drum of radius 3 m rotating about its vertical axis with 200 rev/min. The coefficient of friction between the wall and his clothing is 0.15. What is the minimum rotational speed of the cylinder to enable the man to remain stuck to the wall (without falling) when the floor is suddenly removed?

Q53. (a) A stone of mass 0.25 kg tied to 1.5 m string is whirled with a speed of 40 rev./min in a horizontal plane. What is the tension in the string? What is the maximum speed with which the stone can be whirled around if the string can withstand a maximum tension of 200 N?

(b) Compute the magnitude and direction of total linear acceleration of a particle moving in a circle of radius 0.4 m having an instantaneous angular velocity of 2 rad s^{-1} and angular acceleration 5 rad s^{-2}.

Q54. A car of mass *M* moves with a constant speed *v* over a (a) horizontal flat surface (b) a convex bridge (c) a concave bridge. What force is exerted by the car on the bridge in each of these cases, as it passes the middle point of the bridge? Take radius of curvature of the bridge in the cases (b) and (c) as *r*.

Q55. Explain:

(a) Why are ball bearings used in machinery?

(b) Why does a horse have to apply more force to start a cart than to keep it moving?

(c) What is the need for banking the tracks?

(d) State two advantages and two disadvantages of friction.

Q56. (a) Derive expression for velocity of a car on a banked circular having coefficient of frictions. Hence write the expression for optimum velocity.

(b) A cyclist moving at a speed of 17.64 km/hour describes a circle of radius 9.8 metre. What is smallest value of the coefficient of friction between the tyres and the ground, so that the cyclist may be held in balance?

Q57. A disc revolves with a speed of $33\frac{1}{3}$ rev/min, and has a radius of 15 cm. Two coins are placed at 4 cm and 14 cm away from the centre of the record. If the co-efficient of friction between the coins and the record is 0.15, which of the coins will revolve with the record?

Date: 13/10/2021

S1. (a) At each extreme position, velocity of the bob is zero. If the string is cut at the extreme position, it is only under the action of '*g*'. Hence the bob will fall vertically downwards.

(b) At the mean position, velocity of the bob is 1 ms^{-1} along the tangent to the arc, which is in the horizontal direction. If the string is cut at mean position, the bob will be a horizontal projectile. Hence it will follow a parabolic path.

S2. Due to the accelerated nature of the frame, a pseudo force acts outward radially.

S3. The stone will move along the tangent at the point of breaking. Since, velocity is tangential.

S4. No, because the frictional force is independent of area of contact.

S5. Zero, since there will be no reaction.

S6. No. It is a non-inertial frame of reference.

S7. In case the body is in uniform motion along a straight line, it will continue do so, if the net force acting on a body be zero.

S8. When the body moves with a speed comparable to the speed of light. For example, the mass of a charged particle increases, when it is a accelerated in a cyclotron.

S9. At the lowest point, the stone should possess a minimum velocity.

$$v = \sqrt{gr}.$$

where *r* is radius of the circular path.

S10. The maximum permissible velocity is given by

$$v = \sqrt{\mu r g}.$$

S11. The direction of the centripetal force does not depend, whether the body is moving in clockwise or anticlockwise direction. It is always directed along the radius and towards the centre of the circle.

S12. Here, $m = 0.1$ kg, radius of circle $r = 2$ m ; No. of rev/sec = 120/60 = 2

The tension in the string = centripetal force *F*

$$\therefore \quad F = mr\omega^2 = 4\pi^2 n^2 mr$$

$$= 4 \times \pi^2 \times 4 \times 0.1 \times 2 = 31.58 \text{ N}$$

S13. Here, $m = 500$ kg, $r = 50$ m; $v = 36$ km/hr = 10 ms^{-1}

$\therefore$ Centripetal force $F = \frac{mv^2}{r} = \frac{500 \times 10 \times 10}{50} = 1000\text{N}.$

S14. Here $m = 0.5$ kg, r = 0.5 m and $v = 2$ ms^{-1}

$\therefore$ Centripetal force acting = $\frac{mv^2}{r} = \frac{0.5 \times 2 \times 2}{0.5} = 4N$

As the string can withstand a tension of 15 N, which is very large as compared to the centripetal force of 4 N, hence the string will not break.

S15. Here $v = 30$ ms^{-1}, $r = 500$ m and $a_T = 2$ ms^2

Radial acceleration $a_R = \frac{v^2}{r} = \frac{30 \times 30}{500} = 1.8\ \text{ms}^{-2}$

$\therefore$ Total acceleration $a = \sqrt{a_T^2 + a_R^2} = \sqrt{2 \times 2 + 1.8 \times 1.8}$

$= 2.69\ \text{ms}^{-2}$

S16. **Angular acceleration:** If the angular velocity of a rotating body is not uniform, it is said to have an angular acceleration. It is defined as the rate of change of angular velocity with time. If the angular velocity increases from ω_1 to ω_2 in a time t, then

$$\text{Angular acceleration } \alpha = \frac{\omega_2 - \omega_1}{t} = \frac{2\pi n_2 - 2\pi n_1}{t}$$

where n_1 and n_2 the number of revolutions made per second by the body in each case. It is expressed in radian per sec^2. If a denotes the linear acceleration, then

$$\alpha = \frac{a}{r} \text{ or } a = \alpha r$$

Angular acceleration is a vector quantity and in vector notation

$$\vec{a} = \vec{\alpha} \times \vec{r}.$$

S17. **Centripetal force:** It is that constant external force which acting continuously at right angle to the direction of motion of a particle causes it to move in a circular path. This force acts always along the radius of the circle towards the center. The acceleration produced is called the centripetal acceleration.

If m is the mass of particle, v the uniform speed and r the radius of the circle, then

Centripetal acceleration $= \frac{v^2}{r} = r\omega^2$ and

Centripetal force $F = \frac{mv^2}{r} = mr\omega^2$

where ω is the angular velocity.

S18. The bulb suspended from the roof will act like a simple pendulum. When the train move on a curved path on a banked track the string by which the bulb is suspended will turn through the same angle as the angle of banking to remain vertical.

$\therefore$ Angle of banking $\theta = 19° - 48'$; Radius of the curved path $r = 100$ m

If v is the velocity of train, then in equilibrium $\tan\theta = \frac{v^2}{rg}$

or $v = \sqrt{rg\tan\theta} = \sqrt{100 \times 9.8 \times 0.36}$

$= 18.78$ m/sec $= 67.62$ km/hour .

S19. In order that the car should not leave the ground at the highest point, the gravitational pull on the car must provide the necessary centripetal force. Hence if m is the mass of car, then

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

or $v = \sqrt{rg}$

Here $r = 16\ m$, $g = 9.8\ ms^{-2}$

$\therefore$ Speed $v = \sqrt{rg} = \sqrt{16 \times 9.8} = 12.52\ ms^{-1}$

S20. Let ω_0 be the initial angular velocity and α be the angular acceleration. Applying the relation

$$\omega = \omega_0 + \alpha t, \quad \text{... (i)}$$

We get, $108 = \omega_0 + 3\alpha$

or $\omega_0 = 108 - 3\alpha$

Applying the relation $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$,

We get, $234 = (108 - 3\alpha)\ 3 + \frac{1}{2}\alpha \times 9 = -9\alpha \times 9 = -9\alpha + 324 + 4.5\,\alpha$

or $\alpha = \frac{90}{4.5} = 20$ rad/sec^2

Substituting the value of α in (i), we get $\omega_0 = 108 - 3 \times 20 = 48$ rad/sec.

S21. Radius of the circle = 88 cm = 0.88 m

Change in velocity of the particle/minute = 180 rev/min = $3 \times 2\pi r\ ms^{-1}$

$\therefore$ Change in velocity of the particle/sec = $3 \times 2\pi \times 0.88 = 16.61\ ms^{-1}$

Rate of change of velocity = acceleration

$\therefore$ (a) Linear acceleration $a = 16.61\ \text{ms}^{-2}$

(b) Angular acceleration $\alpha = \frac{a}{r} = \frac{16.61}{0.88} = 18.36\ \text{rads}^{-2}$.

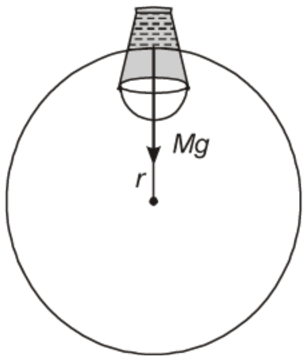
S22. Radius of the pulley $r = 44/2 = 22$ cm = 0.22 m

Number of revolutions/sec, $n = 480/60 = 8$

$\therefore$ Angular velocity $\omega = 2\pi n = 2 \times \frac{22}{7} \times 8 = 50.26$ rad/sec

Linear velocity $v = r\omega = 0.22 \times 50.26 = 11.05$ m/sec

S23. The figure shows a bucket containing water and whirled in a vertical circle.



Let v be the velocity of the bucket at the top of the circular path. For rotating the bucket of water along a vertical circle, it requires a centripetal force Mv^2/r, where M is the mass of water and r, the radius of the circular path. The weight of the water provides the centripetal force and hence the water does not fall. In other words, the weight due to which the water can fall is used up in providing the necessary centripetal force.

S24. When the bus takes a turn, the centripetal acceleration of the bus acts towards the centre of the circular turn and along its radius. Due to inertia, the passengers are thrown outwards. The force experienced by the passengers is called the centrifugal force.

Note: To be more exact, the outward force (fictitious force) acts on the passenger due to the fact that the passenger is situated in a non-inertial frame. The bus taking a circular turn has an accelerated motion and hence it is a no-inertial frame of reference.

S25. When the child presses the side of his seat radically outward in a merry-go-round, the side of the seat presses the child radically inwards in accordance with Newton's third law of motion. This force, which comes as a reaction, provides the child the necessary centripetal force to move along a circular path.

S26. When the ball is at rest, tension in the string (equal to weight of the ball) acts towards the point of suspension.

When the ball is set swinging; in addition to the tension, the required centripetal force also acts towards the point of suspension. When the ball is set to swinging, the force in the string becomes greater than the weight it can support. As a result, the string breaks.

S27. For revolving round the earth, the moon provides itself the necessary centripetal force at the expense of its weight. We know that a body falls under the effect of its weight. Since the weight of the moon gets used in providing it the necessary centripetal force, it revolves round the earth, without falling towards it.

S28. Here r = 0.4 m ω = 2 rad s^{-1} and α = 5 rad s^{-2}

$$a_R = r\omega^2 = 0.4 \times 4 = 1.6 \text{ ms}^{-2}$$

$$a_T = r\,\alpha = 0.4 \times 5 = 2 \text{ ms}^{-2}$$

$\therefore$ Linear acceleration $$a = \sqrt{a_R^2 + a_T^2} = \sqrt{1.6^2 + 2^2} = 2.56 \text{ ms}^{-2}$$

$$\tan\beta = \frac{a_R}{a_T} = \frac{1.6}{2} = 0.8$$

$$\beta = 38^\circ\, 40'$$

S29. Speed of cyclist v = 17.64 km/hour = 4.9 m/sec;

Radius of circle r = 9.8 m

Let μ be the co-efficient of friction and θ the angle through which the cyclist leans for equilibrium, then

Centripetal force = Friction force

$$\frac{mv^2}{r} = \mu\, mg$$

$$\tan\theta = \mu = \frac{v^2}{rg}$$

$$\mu = \frac{4.9 \times 4.9}{9.8 \times 9.8} = 0.25$$

S30. The car will not skid so long as the force of friction supplies the necessary centripetal force.

Centripetal force = Friction force

$$\frac{mv^2}{r} = \mu\, mg$$

or $$v = \sqrt{\mu r g}$$

Here radius of bend r = 100 m ; μ = 0.8 and g = 9.8 m/sec^2

$\therefore$ $$v = \sqrt{0.8 \times 100 \times 9.8} = 28 \text{ m/sec.}$$

S31. Given:

$$v = \frac{440}{20} = 22\ \text{ms}^{-1}$$

Also, $2\pi r = 440$

or $$r = \frac{440}{2\pi} = \frac{440 \times 7}{2 \times 22} = 70\ \text{m}$$

Now, $$\tan\theta = \frac{v^2}{rg} = \frac{22^2}{70 \times 9.8} = 0.7055$$

or $\theta =$ **35.2°**.

S32. Given: $r = 0.8$ km $= 800$ m; $v = 20\ \text{ms}^{-1}$; $g = 9.8\ \text{ms}^{-2}$ and distance between the rails, $l = 1.5$ m.

The distance through which the outer rail has to be raised,

$$h = \frac{v^2}{rg} \times l = \frac{20^2 \times 1.5}{800 \times 9.8} = 0.0765\ \text{m} = \mathbf{7.65\ m}.$$

S33. Given $r = 0.25$ m ; $T = 0.2$ sec

$M = 0.1$ kg

we know $$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.2} = 10\pi$$

$F = Mr\omega^2$

$= 0.1 \times 0.25 \times (10\pi)^2$

$= 24.67.$

We find the centripetal force required to revolve the ball. It will be found that

$F = 24.67$ N

The contact force on the ball due to the wall of the groove

= Normal reaction due to the wall

= **24.67 N**.

S34. Given: $M = 0.4$ kg; $r = 2$ m; $n = 60$ r.p.m. = 1 r.p.s.

Now, $\omega = 2\pi n = 2\pi \times 1 = 2\pi\ \text{rad s}^{-1}$.

The centripetal force is given by

$$F = Mr\omega^2 = 0.4 \times 2 \times (2\pi)^2 = \mathbf{31.58\ N}.$$

S35. Given: $r = 2.5$ m and $\mu = 0.3$.

The child will not skid, so long as the force of friction supplies the necessary centripetal force *i.e.*,

$$Mr\omega^2 = \mu Mg$$

The maximum speed, at which the merry-go-round may rotate, is given by

or $$\omega = \sqrt{\frac{\mu g}{r}} = \sqrt{\frac{0.3 \times 9.8}{2.5}} = \mathbf{1.176\ rad\ s^{-1}}.$$

S36. Given: $F = 45\,N$; $M = 100\,g = 0.1\,kg$; $r = 50\,cm = 0.5\,m$

Now, centripetal force is given by

$$F = \frac{Mv^2}{r}$$

Therefore, constant speed of the stone is given by

$$v = \sqrt{\frac{Fr}{M}} = \sqrt{\frac{45 \times 0.5}{0.1}} = \mathbf{15\ ms^{-1}}.$$

S37. Radius of the pulley $r = 22/2 = 11$ cm = 0.11 m

No. of rev. per sec. = 420/60 = 7

$\therefore$ Angular velocity $\omega = 2\pi n = 2 \times \frac{22}{7} \times 7 = 44$ rad/sec

Linear velocity $v = r\omega = 0.11 \times 44 = 4.84$ m/sec

S38. Radius of the circular track, $r = 30$ m

Speed of the train, $v = 54$ km/h = 15 m/s

Mass of the train, $m = 10^6$ kg

The centripetal force is provided by the lateral thrust of the rail on the wheel. As per Newton's third law of motion, the wheel exerts an equal and opposite force on the rail. This reaction force is responsible for the wear and rear of the rail.

The angle of banking θ, is related to the radius (r) and speed (v) by the relation:

$$\tan\theta = \frac{v^2}{rg}$$

$$= \frac{(15)^2}{30 \times 10} = \frac{225}{300}$$

$$\theta = \tan^{-1}(0.75) - 36.87°$$

Therefore, the angle of banking is about 36.87°.

S39. On a banked road, the horizontal component of the normal force and the frictional force contribute to provide centripetal force to keep the car moving on a circular turn without slipping. At the optimum speed, the normal reaction.s component is enough to provide the needed centripetal force, and the frictional force is not needed. The optimum speed *vo* is given by Eq. (5.22):

$$v_O = (Rg \tan\theta)^{1/2}$$

Here, $R = 300\text{ m}, \quad \theta = 15°, \quad g = 9.8\text{ m s}^{-2}$

we have $v_O = 28.1\text{ m s}^{-1}$.

The maximum permissible speed v_{max} is given by Eq. (5.21):

$$v_{max} = \left(Rg\,\frac{\mu_s + \tan\theta}{1-\mu_s\tan\theta}\right)^{1/2} = 38.1\text{ m s}^{-1}.$$

S40. On an unbanked road, frictional force alone can provide the centripetal force needed to keep the cyclist moving on a circular turn without slipping. If the speed is too large, or if the turn is too sharp (*i.e.*, of too small a radius) or both, the frictional force is not sufficient to provide the necessary centripetal force, and the cyclist slips. The condition for the cyclist not to slip is given by Eq. (5.18):

$$v^2 \le \mu_s R g$$

Now, $R = 3\text{ m}, \quad g = 9.8\text{ m s}^{-2}, \quad \mu_s = 0.1$

That is, $\mu_s R g = 2.94\text{ m}^2\text{s}^{-2}, \quad v = 18\text{ km/h} = 5\text{ m s}^{-1};$

i.e., $v^2 = 25\text{ m}^2\text{ s}^{-2}$.

The condition is not obeyed. The cyclist will slip while taking the circular turn.

S41. At the highest point of the railway bridge, the centripetal force is provided by the weight of the car. If v_{max} is the maximum speed, the car can cross the bridge without Learning the contact.

$$\frac{mv_{max}^2}{r} = mg$$

or $v_{max} = \sqrt{gr}$

Now, $r = 20\text{ m} \quad \text{and} \quad g = 9.8\text{ ms}^{-2}$

$\therefore$ $v_{max} = \sqrt{9.8 \times 20} = \mathbf{14\text{ ms}^{-1}}$.

S42. Given: $M = 0.3\text{ kg}; \quad r = 1\text{ m}$

$$n = 40\text{ rev min}^{-1} = 40\text{ rev} \times (60\text{ s})^{-1} = \frac{2}{3}\text{ r.p.s.}$$

$\therefore$ $\omega = 2\pi n = 2\pi \times \frac{2}{3} = \frac{4\pi}{3} = \textbf{rad s}^{-1}$.

The tension in the string provides the necessary centripetal force. Therefore,

$$T = \frac{Mv^2}{r} = Mr\omega^2$$

$$= 0.3 \times 1 \times \left(\frac{4\pi}{3}\right)^2 = \mathbf{5.264\text{ N}}.$$

Let v_{max} be the maximum speed at which tension would become 200 N. Then,

$$\frac{Mv_{max}^2}{r} = 200$$

or $$v_{max} = \sqrt{\frac{200 \times r}{M}} = \sqrt{\frac{200 \times 1}{0.3}} = \mathbf{25.82\ ms^{-1}}.$$

S43. Given: $M = 0.4$ kg; $r = 1.2$ m; $n = 2$ r.p.s.

Now, angular speed, $\omega = 2\pi n = 2\pi \times 2 = 4\pi$ rad s^{-1}

(a) ***When body is at the bottom of the circle:*** Let T_1 be tension in the string, when the body is at the bottom of the circle. Then

$$T_1 - Mg = \text{Centripetal force} = Mr\omega^2$$

or $$T_1 = M(g + r\omega^2)$$

$$= 0.4\,[9.8 + 1.2 \times (4\pi)^2]$$

$$= 0.4\,(9.8 + 1.2 \times 16 \times 9.87)$$

$$= 0.4\,(9.8 + 189.5) = \mathbf{79.72\ N}.$$

(b) ***When body is at the top of the circle:*** Let T_2 be tension in the string, when the body is at the top of the circle. Then,

$$T_2 + Mg = \text{Centripetal force} = Mr\omega^2$$ [Since both T_2 and mg are working in downward direction]

or $$T_2 = M(r\omega^2 - g)$$

$$= 0.4\,[(1.2 \times (4\pi)^2 - 9.8]$$

$$= o.4\,(189.5 - 9.8) = \mathbf{71.88\ N}.$$

S44. Given: $v = 20\ ms^{-1}$; $r = .150$ m; $l = 1$ m

If θ is angle of banking, then

$$\tan\theta = \frac{v^2}{rg}\,l = \frac{20^2}{150 \times 9.8} = 0.2781$$

$\therefore$ $$\theta = \mathbf{15.54°}$$

Suppose that h is the distance through which the outer rail has to be raised with respect to the inner rail.

$$\sin\theta = \frac{h}{l}$$

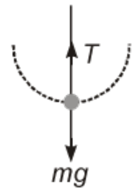
Since θ is small, $$\sin\theta \approx \tan\theta$$

$\therefore$ $$\frac{h}{l} = \frac{v^2}{rg}$$ [$\because$ $\tan\theta \approx v^2/rg$]

or $$h = \frac{v^2}{rg}\,l = \frac{20^2 \times 1}{150 \times 9.8} = \mathbf{0.272\ m}.$$

S45. The free body diagram of the stone at the lowest point is shown in the folllowing figure.

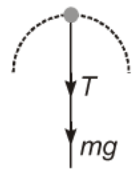
According to Newton's second law of motion, the net force acting on the stone at this point is equal to the centripetal force, *i.e.*,



$$F_{net} = T - mg = \frac{mv_1^2}{R} \qquad \dots \text{(i)}$$

Where, v_1 = Velocity at the lowest point

The free body diagram of the stone at the highest point is shown in the following figure.



Using Newton's second law of motion, we have:

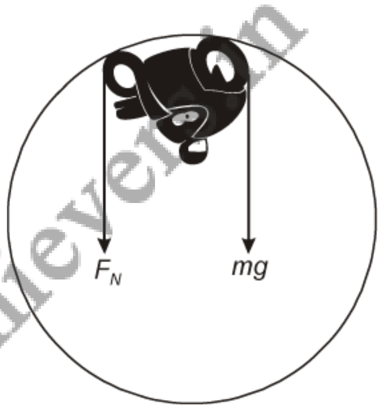
$$T + mg = \frac{mv_2^2}{R} \qquad \dots \text{(ii)}$$

Where, v_2 = Velocity at the highest point

It is clear from equations (i) and (ii) that the net force acting at the lowest and the highest points are respectively $(T - mg)$ and $(T + mg)$.

S46. In a death-well, a motorcyclist does not fall at the top point of a vertical loop because both the force of normal reaction and the weight of the motorcyclist act downward and are balanced by the centripetal force. This situation is shown in the following figure.

The net force acting on the motorcyclist is the sum of the normal force (F_N) and the force due to gravity ($F_g = mg$).



The equation of motion for the centripetal acceleration

$$F_{net} = ma_c$$

$$F_N + F_g = ma_c$$

$$F_N + mg = \frac{mv^2}{r}$$

Normal reaction is provided by the speed of the motorcyclist.

At the minimum speed

$$(n_{min}),\ F_N = 0$$

$$mg = \frac{mv_{min}{}^2}{r}$$

$$\therefore \qquad v_{min} = \sqrt{rg}$$

$$= \sqrt{25 \times 10} = 15.8 \text{ m/s}$$

S47. As the cyclist covers 34.3 metre in $\sqrt{22}$ second

$\therefore$ Speed of the cyclist $\qquad v = \frac{34.3}{\sqrt{22}}$ m/sec

Radius of the circular path $r = \dfrac{34.3}{2\pi}$ metre

If θ is the angle through which the cyclist bends in order to avoid skidding, then

$$\tan\theta = \frac{v^2}{rg} = \frac{34.3\times 34.3}{22}\times\frac{2\pi}{34.3}\times\frac{1}{9.8} = 1.000$$

$$\theta = 45°$$

S48. Radius of track $r = 1500$ m

$v = 72$ km/hour = 20 m/sec

$\therefore$ $$\tan\theta = \frac{v^2}{rg} = \frac{20\times 20}{1500\times 9.8} = \frac{4}{147}$$

If h is the elevation of the outer rail above the inner rail, then

$$\frac{h}{l} = \tan\theta$$

$$h = l\tan\theta = \frac{1.54\times 4}{147}$$

$$= 0.0419 \text{ m} = 4.19 \text{ cm.}$$

S49. Consider a ball of mass m suspended by a string OA. Let ω be the angular velocity with which the ball describes a horizontal circle of radius AC. various forces acting are:

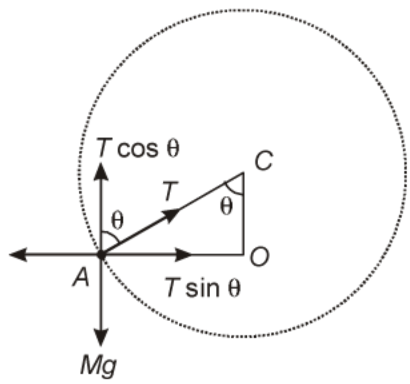
(a) Weight mg of the ball acting vertically downward.

(b) Tension T of the string acting along AO which makes an angle θ with vertical.

The component $T\cos\theta$ balances the weight mg and component $T\sin\theta$ provides the necessary centripetal force for the ball to describe a horizontal circle of radius $AC = r$

$T\cos\theta = mg$ ... (i)

And $T\sin\theta$ provide centripetal force.



and $T\sin\theta = m r\omega^2$ ... (ii)

or $\dfrac{T\sin\theta}{T\cos\theta} = \dfrac{mr\omega^2}{mg}$

or $\tan\theta = \dfrac{r\omega^2}{g}$ ... (iii)

Now $AC = r = 15$ cm $= 0.15$ m

$OA = 30$ cm $= 0.3$ m and $g = 9.8$ ms^{-2}

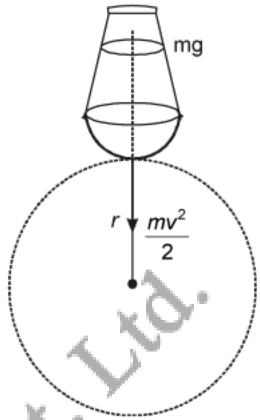
From figure, we find $\sin\theta = 0.15/0.30 = 0.5$

$$\theta = 30°$$

From Eq. (iii), we have $\omega = \sqrt{\frac{g\tan\theta}{r}} = \sqrt{\frac{9.8 \times 0.5774}{0.15}}$

$= 6.145 \text{ rad s}^{-1}$

S50. In order that the water does not spill out at the highest point the downward weight *mg* must provide the necessary centripetal force $\frac{mv^2}{r}$



$\therefore \quad \frac{mv^2}{r} = mg$

or $\quad v = \sqrt{gr}$

Now $\quad r = 61.25 \text{ cm} = 0.6125 \text{ m}$

$\therefore \quad v = \sqrt{0.6125 \times 9.8} = 2.45 \text{ ms}^{-1}$

If *n* is number of revolutions/min, then

$$n = \frac{v}{2\pi r} \times 60 = \frac{2.45 \times 60}{2\pi \times 0.6125} = 38.2$$

S51. Here $\quad \omega_1 = 2\pi n_1 = 2\pi \times 300 = 600\,\pi$ rad/min,

$\omega_2 = 2\pi\, n_2 = 2\pi \times 100 = 200\,\pi$ rad/min

$t = 2$ minutes

(i) $\therefore \quad \alpha = \frac{\omega_2 - \omega_1}{t} = \frac{200\pi - 600\pi}{2}$

$= -200\,\pi \text{ rad/min}^2 = -628.4 \text{ rad/min}^2$

(ii) Applying the relation $\quad \theta = \omega_0 t + \frac{1}{2}\alpha t^2$, we get

$$\theta = 600\,\pi \times 2 + \frac{1}{2}(-200\,\pi \times 4) = 800\pi \text{ rad.}$$

Now 2π rad are traced out in 1 revolution

$\therefore$ Number of complete revolution in 2 min = $\frac{800\pi}{2\pi} = 400$

S52. Mass of the man, $\quad m = 70$ kg

Radius of the drum, $\quad r = 3$ m

Coefficient of friction, $\quad \mu = 0.15$

Frequency of rotation, $\quad \nu = 200$ rev/min

$= \frac{200}{60} = \frac{10}{3}$ rev/s

The necessary centripetal force required for the rotation of the man is provided by the normal force (F_N).

When the floor revolves, the man sticks to the wall of the drum. Hence, the weight of the man (mg) acting downward is balanced by the frictional force ($f = \mu F_N$) acting upward.

Hence, the man will not fall until:

$$mg < f$$

$$mg < \mu F_N - \mu mr\omega^2$$

$$g < \mu r\omega^2$$

$$\omega > \sqrt{\frac{g}{\mu r}}$$

The minimum angular speed is given as:

$$\omega_{min} = \sqrt{\frac{g}{\mu r}}$$

$$= \sqrt{\frac{10}{0.15 \times 3}} = 4.71 \text{ rad s}^{-1}.$$

S53. (a) Mass of the stone, $m = 0.25$ kg

Radius of the circle, $r = 1.5$ m

$$n = \frac{40}{60} = \frac{2}{3} \text{ rps}$$

Number of revolution per second,

Angular velocity, $\omega = \frac{v}{r} = 2\pi n$

The centripetal force for the stone is provided by the tension

Maximum tension in the string,

Therefore, the maximum speed of the stone is 34.64 m/s.

(b) Here $r = 0.4$ m $\omega = 2$ rad s^{-1} and $\alpha = 5$ rad s^{-2}

$$a_R = r\omega^2 = 0.4 \times 4 = 1.6 \text{ ms}^2$$

$$a_T = r\,\alpha = 0.4 \times 5 = 2 \text{ ms}$$

∴ Linear acceleration $a = \sqrt{a_R^2 + a_T^2} = \sqrt{1.6^2 + 2^2} = 2.56 \text{ ms}^2$

$$\tan\beta = \frac{a_R}{a_T} = \frac{1.6}{2} = 0.8$$

$$\beta = \mathbf{42.95°}.$$

S54. *The car is acted upon by two forces*: its weight Mg and the normal reaction R both acting along vertical.

(a) When the car runs over a horizontal bridge, the normal reaction, say R_1 is just equal and opposite to its weight Mg

i.e., $$R_1 = Mg$$

Thus, force on the bridge is ***equal to the weight of the car***.

(b) When the car runs over a convex bridge, it requires a centripetal force vertically down wards. If R_2 is normal reaction, then

$$Mg - R_2 = \frac{Mv^2}{r}$$

or $$R_2 = Mg - \frac{Mv^2}{r}$$

i.e., $$R_2 < Mg.$$

Thus, force on the bridge is ***less than the weight of the car***.

(c) When the car runs over a concave bridge, it requires a centripetal force vertically upwards. If R_3 is normal reaction, then

$$R_3 - Mg = \frac{Mv^2}{r}$$

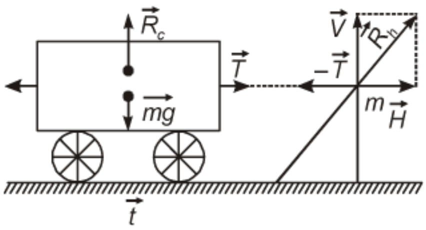
or $$R_3 = Mg + \frac{Mv^2}{r}$$

i.e., $$R_3 > Mg.$$

Thus, force on the bridge is ***greater than the weight of the car***.

S55. (a) Ball bearings are used to reduce friction under rolling as it is easier to roll a body than to slide as $\mu_r < \mu_k$.

(b) Horse presses the ground in slanting direction, the reaction $\vec{R}_h$ of the ground on the horse acts in opposite direction, $\vec{R}_h$ can be resolved into two rectangular component.



(i) $\vec{V}$ = vertical component.

(ii) $\vec{H}$ = horizontal component.

The horse moves forward if $H > T$, in that case

net force acting on horse = $H - T$

If the acceleration of horse is 'a' and 'm' its mass.

$$H - T = ma \qquad \text{... (i)}$$

The cart moves forward if $T > f$, in that case

net force acting on cart = $T - f$

$$T - f = Ma \qquad \dots \text{(ii)}$$

Adding Eq. (i) and (ii), we get

$$a = \frac{H - f}{M + m} \qquad \dots \text{(iii)}$$

'a' is positive if $(H - f)$ is positive

if $H - f > 0$ or if $H > f$ thus the system moves if $H > f$ thus the system moves if $H > f$.

So the horse has to apply more force to start.

(c) **Banking is necessary because:**

(i) Force of friction providing centripetal force is not reliable one.

(ii) It prevents skidding.

(iii) The speed can be more without skidding.

(iv) Wear and tear can be reduced.

(d) **Advantages of friction:**

(i) Had there been no friction it would have been impossible to transmit power with help of belts.

(ii) Friction helps us to tie knots in strings and ropes. The knots will untie readily in the absence of friction.

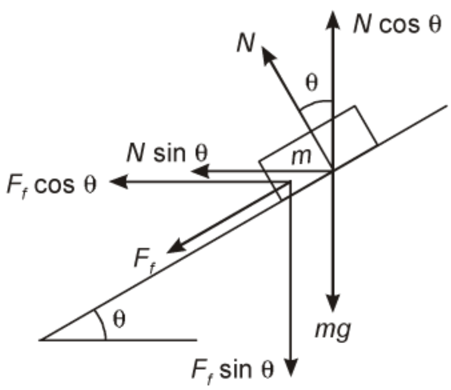
(iii) Brakes make use of friction to stop the vehicles. Special high friction materials are used for the brakes of automobiles.

Disadvantages of friction:

(i) It causes wear and tear of machinery.

(ii) Reduces speed of vehicle.

S56. (a) From the forces acting on the vehicle in a banked curve (θ).



$$N\cos\theta - F_f\sin\theta = mg$$

$$N\sin\theta + F_f\cos\theta = mv^2/r. \qquad F_f = \mu N.$$

Dividing the equations , we have,

$$\frac{v^2}{rg} = \frac{N\sin\theta + \mu N\cos\theta}{N\cos\theta - \mu N\sin\theta}$$

Dividing each term of right side by $N\cos\theta$

$$v^2 = rg\left(\frac{\tan\theta + \mu}{1 - \mu\tan\theta}\right); \qquad v = \sqrt{rg\left(\frac{\mu + \tan\theta}{1 - \mu\tan\theta}\right)}$$

(b) Speed of cyclist v = 17.64 km/hour = 4.9 m/sec ; Radius of circle r = 9.8 m

Let μ be the co-efficient of friction and θ the angle through which the cyclist leans for equilibrium, then

$$\tan\theta = \mu = \frac{v^2}{rg}$$

$$\mu = \frac{4.9 \times 4.9}{9.8 \times 9.8} = 0.25.$$

S57. Coin placed at 4 cm from the centre

Mass of each coin = m

Radius of the disc, r = 15 cm = 0.15 m

Frequency of revolution, $\nu = 33\frac{1}{3}$ = rev/min = $\frac{100}{3 \times 60} = \frac{5}{9}$ rev/s

Coefficient of friction, μ = 0.15

In the given situation, the coin having a force of friction greater than or equal to the centripetal force provided by the rotation of the disc will revolve with the disc. If this is not the case, then the coin will slip from the disc.

Since $f > F_{cent}$, the coin will revolve along with the record.

Coin placed at 4 cm:

Radius of revolution, r'' = 14 cm = 0.14 m

Angular frequency, $\omega = 3.49\ s^{-1}$

Frictional force, f = 1.5 mN

Centripetal force is given as:

$$F_{cent.} = mr''\omega^2$$

$$= m \times 0.14 \times (3.49)^2$$

$$= 1.7\ m\text{N}$$

Since $f < F_{cent}$, the coin will slip from the surface of the record.