5

Newton's Law of Motion

BRIEF REVIEW

Force A pull or push which generates or tends to generate motion in a body at rest, stops or tends to stop a body in motion, increases or decreases the magnitude of velocity of the moving body, changes or tends to change the shape of the body.

Newton's First Law of Motion A body at rest will remain at rest and a body in uniform motion will remain in the state of uniform motion unless it is compelled by some **external force** to change its state.

Inertia The inherent property of the body with which it cannot change its state of rest or of uniform motion unless acted upon by an external force, is called inertia. Hence, Newton's first law of motion may also be called law of inertia.

Note that the term external force was used. It means there would be **internal force** also.

Internal Force If the force applying agent is inside the system, force is internal. Internal force cannot provide motion. For example, if you are sitting in a car and you push the car, car does not move. If you come out of the car and apply the same force, car moves. When you were inside the car, the force applying agent was inside the car, hence, the force was internal and car did not move. When the force applying agent (you) had moved outside, the car moved.

The straight line along which force acts is called **Line of action of the force.**

If a body is to accelerate or decelerate then unbalanced force is needed.

A system of bodies on which no external force acts is called a **closed system.** For example, two bodies moving towards each other due to their mutual electrostatic or gravitational force.

When many forces act on a body at the same point, they are called concurrent forces. The system of concurrent forces may be:

(a) Collinear, that is acting along the same straightline.

(b) Coplanar, that is in the same plane.

(c) Generally directed, but not in the same plane.

Mass In newtonian mechanics mass is considered to be a measure of inertia of a body and is considered independent of its velocity. It is a scalar quantity. Unit $\rightarrow$ kg (SI system).

Momentum The total quantity of motion contained in a body is called momentum. It is a vector quantity. Unit kg ms^{-1} (SI) $\vec{p} = m\vec{v}$.

If two different masses have same momentum, then the lighter one has more kinetic energy (also more velocity).

Newton's Second Law of Motion The time rate of change of momentum is directly proportional to force (external) applied on it and the change in momentum occurs in the direction of force

$$\vec{F} \propto \frac{dp}{dt}, \text{ or } \vec{F} = \frac{d\vec{p}}{dt} = \frac{md\vec{v}}{dt} = m\vec{a}$$

Newton considered mass to be constant. Unit of Force is Netwon (N) or kg Wt (kilogram weight) or kg f (kilogram force). 1 kg Wt = 1 kg f = 9.8 N.

If mass is varying and velocity constant $\vec{F} = v\dfrac{dm}{dt}$

$\vec{F} = \dfrac{dmdv}{dt}$ if both mass and velocity vary.

Impulse Product of force and time for which it acts is called impulse.

$F = \dfrac{dp}{dt}$ or $F\,.\,dt = dp$ i.e. impulse = change in momentum

$F_{av}\,.\,t = \Delta p$ is called impulse momentum theorem.

Newton's Third Law of Motion To every action there is an equal and opposite reaction, i.e., $\vec{F}_{AB} = -\vec{F}_{BA}$. Moreover, action and reaction act on different bodies. According to third law forces in nature occur in pairs. Single isolated force is not possible.

Note: In certain cases of electrostatics and in springs Newton's 3rd law fails.

Law of Conservation of Momentum If no external force acts then the total momentum of the system is conserved

$\vec{F} = \dfrac{d\vec{p}}{dt} = 0$ or $\vec{p}$ = constant.

Equilibrium

Translatory Equilibrium When several forces act on a body such that resultant force is zero, i.e., $\sum F = 0$, the body is said to be in translatory equilibrium. $\sum F = 0$ implies $\sum F_x = \sum F_y = \sum F_z = 0$. It means the body is in the state of rest (static equilibrium) or in uniform motion (dynamic equilibrium).

If the force is conservative then $F = \dfrac{du}{dr} = 0$ means potential energy u = maximum, minimum or constant.

Stable Equilibrium If on slight displacement from equilibrium position, body has the tendency to regain its original position. In such cases centre of Mass (COM) rises on slight displacement. Note that PE is minimum $\left(\dfrac{d^2u}{dr^2} = +ve\right)$ in stable equilibrium.

Unstable Equilibrium If on slight displacement from equilibrium position the body moves in the direction of displacement, the equilibrium is known to be unstable. The COM goes down on slight displacement. PE is maximum and $\dfrac{d^2u}{dr^2} = -ve$ for unstable equilibrium.

Neutral Equilibrium If the body remains at the displaced position after a slight displacement then such an equilibrium is neutral. The COM does not change and PE is constant but not zero.

Fig. 5.1 illustrates all the types of equilibrium: stable, unstable and neutral.

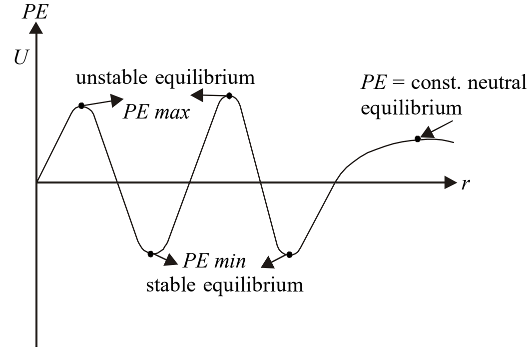


Fig. 5.1 Types of equilibrium explanations

Strings String is considered to be massless unless stated and hence, tension remains constant throughout the string.

String is assumed to be inextensible unless stated and hence, acceleration of any number of masses connected to it is always equal or same. If the pulley is massless and smooth, and string is also massless then tension at each point (or two sides of string) is constant as shown in Fig. 5.2.

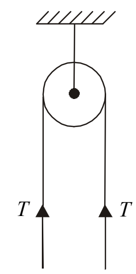


Fig. 5.2 Tension in string for a light and smocth pulley

If the string changes tension changes as illustrated in Fig. 5.3.

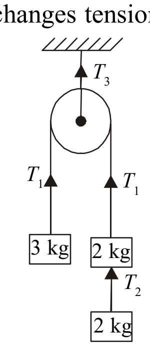


Fig. 5.3 Tension in different strings

T_1, T_2 and T_3 in Fig 5.3 are different as string changes. In Fig 5.3 $T_3 = 2T_1$

$T_2 = 2\,(g - a)$

Fig. 5.4

If forces are equal and opposite on a massless string as shown in Fig 5.4 then tension T is equal to either of the two forces, i.e., $T = F$.

The maximum tension which a string can bear is called its breaking strength. If the string has mass tension is different at each point as illustrated in Fig. 5.5.

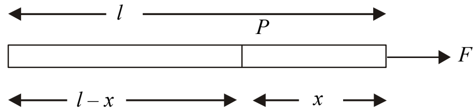


Fig. 5.5 **Illustration of tension in a stringrod having mass**

Mass per unit length $\lambda = \frac{M}{l}$. We have to find tension at P. Mass of $(l - x)$ part is $\frac{M(l-x)}{l}$.

Tension at $P = \frac{F}{M}\left(\frac{M(l-x)}{l}\right) = \frac{F(l-x)}{l}$.

Springs Springs are assumed massless unless stated. Restoring force is same every where, i.e. $F = -k\,x$

Springs can be stretched or compressed. Stretch or compression is taken positive.

Restoring force is linear as is clear from $F = -kx$. k is called spring constant or force constant.

$k \propto \frac{1}{l}$ (k also depends upon radius, length and material used).

In series $\frac{1}{k_{\text{effective}}} = \frac{1}{k_1} + \frac{1}{k_2} + ...$

In parallel $k_{\text{effective}} = k_1 + k_2 + ...$

If masses m_1 and m_2 connected to a spring as shown in Fig. 5.6 are oscillating or both masses move then find reduced mass μ $\frac{1}{\mu} = \frac{1}{m_1} + \frac{1}{m_2}$.

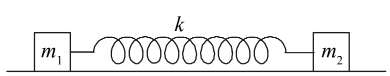


Fig. 5.6

If the spring has mass m_s, then $\frac{m_s}{3}$ is used to produce extension.

Psuedo Forces The hypothetical forces added while dealing with problems associated with non-inertial or accelerated frame of reference, so that Newton's laws may be applied are called psuedo forces or inertial forces. If a frame of reference is moving with an acceleration a_o, then force on a particle of mass m is ma_o. In the force equation a force $-ma_o$ will be added to make the frame of reference inertial.

Friction If we try to slide a body over a surface the motion is resisted by the bonding between the body and the surface. This resistance is represented by a single force called friction. The friction is parallel to the surface and opposite to the direction of intended motion. Remember static friction is a self adjusting force. If a body is at rest and not being pulled, force of friction is zero. If a pulling force is applied and the body does not move, friction still acts and is called static friction. The maximum value of static friction is called limiting friction. See Fig. 5.7. If we apply the force beyond limiting friction, the body begins to move and friction slightly decreases called kinetic friction.

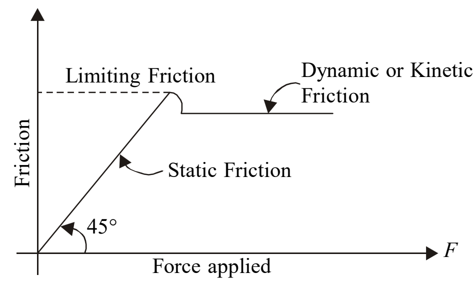


Fig. 5.7 **Friction illustration**

Limiting Friction $F_{fL} = \mu_s N$ where N is normal reaction. $\mu_s = \tan\theta$ where θ is the angle of limiting friction.

Note: $\mu_s > \mu_k > \mu_R$ where μ_s stands for coefficient of static friction, μ_k stands for coefficient of kinetic friction and μ_R stands for rolling friction.

Friction is independent of surface area of contact. However, it depends upon the nature of material of the surfaces in contact, their roughness, smoothness, inclination. Normally friction between too smooth bodies is more. If the bodies are made extra smooth by polishing the bonding force of cohesion or adhesion increases resulting in cold welding.

In practice $0 < \mu < 1$ but $\mu > 1$ is observed. For example; $\mu_s = 1$ for glass/glass, and, $\mu_s = 1.6$ for $Cu - Cu$.

Friction is a non-conservative force.

If force is applied and still the body is at rest then the force of the friction is equal to force applied.

Equation of motion for centre of mass (COM)

$$m\frac{dv_{\text{COM}}}{dt} = \sum F$$

SHORT CUTS AND POINTS TO NOTE

1. Tension is a reaction force produced in a string or rod.
2. In a massless string (if not passing over a pulley) tension is equal at each point.
3. If pulley is massless and smooth and, string is massless and passing over a pulley as shown in Fig. 5.8, then

$$a = \frac{(m_2 - m_1)g}{m_1 + m_2}, \; T = \frac{2m_1m_2g}{m_1 + m_2}$$

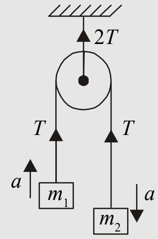


Fig. 5.8

4. If the string changes tension will change. Assume, in Fig. 5.9 Pulley is smooth and massless. String is also massless. Then,

$$a = \frac{[(m_1 + m_3) - m_2]g}{m_1 + m_2 + m_3}, \; T = \frac{2(m_1 + m_3)m_2g}{m_1 + m_2 + m_3}$$

$$T' = m_3(g - a), \; T'' = 2\,T$$

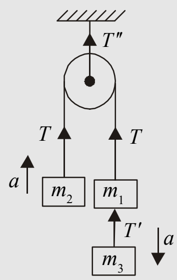


Fig. 5.9

5. If the pulley system of fig. 5.8 moves up with an acceleration a' then,

$$a = \frac{(m_2 - m_1)(g + a')}{m_1 + m_2} \quad \text{and}$$

$$T = \frac{2m_1m_2(g + a')}{m_1 + m_2}$$

6. If the pulley system shown in Fig. 5.9 moves up with an acceleration a'. Then,

$$a = \frac{[(m_1 + m_3) - m_2](g + a')}{m_1 + m_3 + m_2},$$

$$T = \frac{2(m_1 + m_3)m_2(g + a')}{m_1 + m_2 + m_3},$$

$$T' = m_3(g + a' - a)$$

7. If $F > 2T$ in Fig 5.10 is applied on the pulley to move the system upwards.

Then, $a' = \dfrac{F - 2T}{m_1 + m_2}$; $a = \dfrac{(m_2 - m_1)(g + a')}{m_1 + m_2}$

$$T = \frac{2m_1m_2(g + a')}{m_1 + m_2}$$

If $F < 2T$, then $a' = 0$

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

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

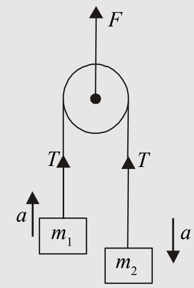


Fig. 5.10

8. If the springs are in parallel then their displacements are equal. For example, in Fig. 5.11 (a) and (b), the springs are in parallel, i.e., $k_{eff} = k_1 + k_2$

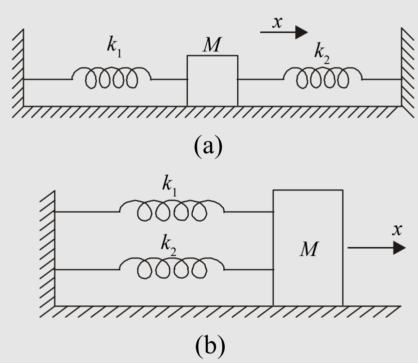


Fig. 5.11

9. If the springs are in series, as shown in Fig. 5.12 streches in spring are un-equal and $x = x_1 + x_2$

or $$\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2}.$$

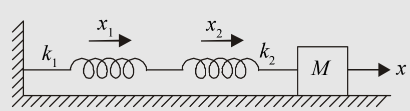


Fig. 5.12

10. If the spring is cut $k \propto \dfrac{1}{l}$. For example, if a spring of spring constant k is cut in the ratio 2 : 3 then shorter spring has $k' = \dfrac{5k}{2}$ and bigger one has spring constant $k'' = \dfrac{5k}{3}$.

11. In Fig. 5.13, if the block or pulley moves down by x, spring moves down by $2x$. Thus $T = F' = k\,(2x)$ and $F = 2T = k\,(4x)$.

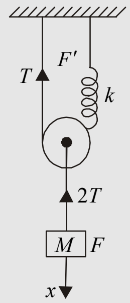


Fig. 5.13

In Fig. 5.14, if the block moves down by x then spring or pulley moves down by $\frac{x}{2}$. $F = T$, $F'' = 2T = k\left(\frac{x}{2}\right)$.

or $\quad F = \frac{F''}{2} = k\left(\frac{x}{4}\right).$

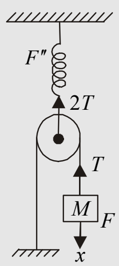


Fig. 5.14

12. As shown in Fig. 5.15, if the pulley moves forward by x then block moves forward by $2x$.

$\therefore a_{\text{block}} = 2\,a_{\text{pulley}}$; $\qquad a_{\text{block}} = \frac{T}{m} = \frac{F}{2m}$

$a_{\text{pulley}} = \frac{F}{4m}$

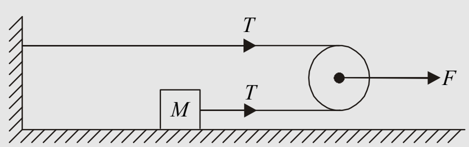


Fig. 5.15

13. Since force is a vector, apply vector algebra whenever there are two or more forces.

14. Draw free body diagram before you solve the problems. They make the problem very simple.

15. If force is applied on the body and body does not move, then, friction = force applied and not μN where N is normal reaction.

16. $\mu_s > \mu_k > \mu_R$. Barring few exception $\mu_s < 1$ and hence $\mu_k < 1$.

17. In conservative forces work done depends upon initial and final position. It is independent of the path followed. Net work done in a closed loop equals zero. Gravitational, electrostatic, magnetic forces are conservative. Friction is not conservative.

18. If there is no friction then acceleration down an incline is $a = g \sin\theta$ as shown in Fig. 5.16 (a).

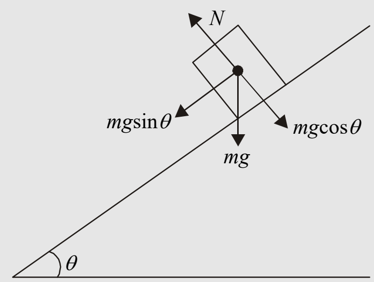


Fig. 5.16 (a)

19. If there is friction and coefficient of friction between the block and the incline is μ then,

$a = g \sin\theta - mg \cos\theta$ down the incline

or $F_{\text{down}} = \text{mg}\,(\sin\theta - \mu\cos\theta)$

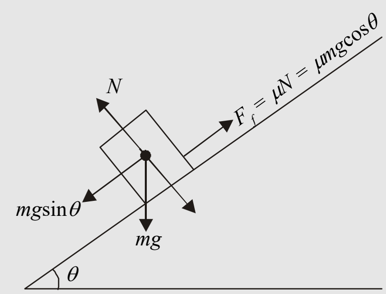


Fig. 5.16 (b)

20. If the block is to move up the incline with a constant velocity then $F_{\text{up}} = mg\,(\sin\theta + \mu\cos\theta)$ (See Fig. 5.17).

If it is to move up with an acceleration 'a' also then

$\text{F}_{\text{up}} = mg\,(\sin\theta + \mu\cos\theta) + ma.$

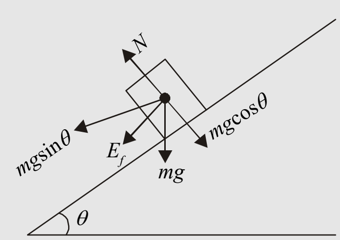


Fig. 5.17

21. On a horizontal plane deceleration due to friction is μg.

22. If a lift moves up with an acceleration a then effective or apparent weight is $m(g + a)$ as ma acting downward is pseudo force to be added to make frame of reference inertial.

Similarly if the pulley is moving down with an acceleration a then apparent weight of the body is $m(g - a)$.

23. If the force is a function of distance or velocity then use:

$$\frac{md^2x}{dt^2} = kx, \quad \frac{mdv}{dt} = kx$$

or $$\frac{mdv}{dt} \cdot \frac{dx}{dt} = kx \text{ or } \frac{mdv}{dx} v = kx.$$

24. It is always helpful to choose axis along the incline as x-axis and axis perpendicular to the incline as y-axis.

25. Remember frictional force and normal force are always perpendicular and F_f = Force applied if body remains stationary; $F_f = \mu_k N$ if the body is in motion.

26. Pulling at an angle decreases the kinetic friction as Normal reaction decreases as illustrated in Fig. 5.18.

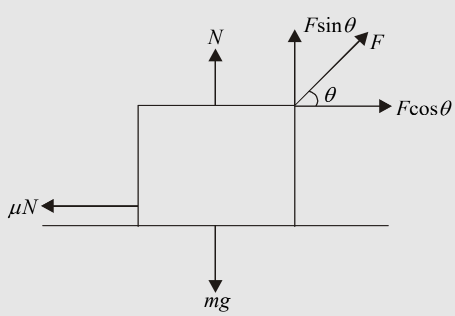


Fig. 5.18

$N = Mg - F \sin \theta$.

or, $F_f = \mu_k N = \mu_k (Mg - F \sin \theta)$.

27. If $\sum F_y = 0 = mg - k v_y$ then $v_y = \frac{mg}{k}$ is terminal velocity as in case of viscosity. $F = 6\pi\eta r v$ (Stoke's law) v is terminal velocity.

28. If a body/particle of mass m moves with a linear velocity v along the diameter of a turn table then an extra force is experienced by the body called coriolis force.

$F_{\text{coroilis}} = 2mv\omega$. Where ω is angular velocity of the turn table.

CAUTION

1. Applying Newton's law without caring about inertial/non-inertial frames.

⇒ In non-inertial frames of reference, first apply pseudo vectors to make the frame of reference inertial, only after that apply Newton's laws.

2. Considering action and reaction always act on different bodies.

⇒ In case of elastic bodies and springs, action and reaction act on same body. That is, in case of restoring force in a spring or deforming force in elastic bodies, action and reaction act on same body. These forces are therefore called internal forces.

3. Considering Newton's third law is always valid.

⇒ In certain cases of electrostatics Newton's third law fails.

4. Assuming friction always acts in a direction opposite to the motion.

⇒ If the friction causes motion then the friction acts in the direction of motion.

5. Considering force constant of a spring does not vary when spring is cut.

⇒ Spring constant $k \propto \frac{1}{l}$.

6. Assuming friction is always equal to μN.

⇒ If the body is moving, friction = $\mu_k N$. If the body is stationary then friction is equal to force applied.

7. Assuming if pulley is massless then tension in the string on two sides of the pulley is unequal as shown in Fig. 5.19.

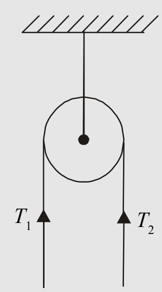


Fig. 5.19

⇒ If pulley is massless and smooth $T_1 = T_2 = T$

If pulley has mass then only T_1 and T_2 are unequal.

8. Not understanding constraints.

⇒ In problems like shown in Fig. 5.20, if the pulley moves forward by x, then thread $2x$ is used x below and x above which will be supplied by the block side as other is fixed. Therefore, block will move $2x$. Hence, $a_{\text{block}} = 2\, a_{\text{pulley}}$

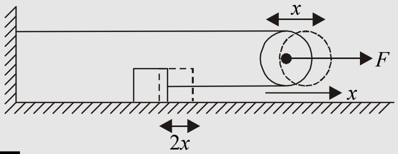


Fig. 5.20

9. Considering in equilibrium body must be at rest.

⇒ In static equilibrium body is at rest. In dynamic equilibrium, it moves with uniform velocity.

10. Assuming there is no tension if the rope is pulled by equal and opposite forces on two ends.

⇒ Tension is equal to either of the force applied.

11. Considering impulse always provides acceleration.

⇒ Sharp impulse only provides velocity.

12. Considering rough surfaces have more friction.

⇒ In general it may be true. But polished surfaces may offer more friction. For example, coefficient of friction between glass/wood is 0.23 and glass and glass is 1.0 and between $Cu - Cu$ is 1.6.

13. Considering horizontal plane as x-axis and therefore normal force N perpendicular to x-axis as shown in Fig. 5.21 (a).

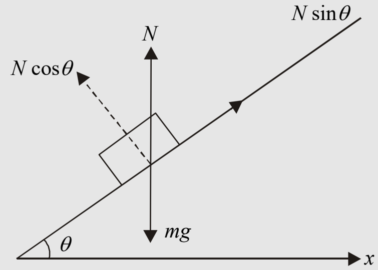


Fig. 5.21 (a)

⇒ Considering axis along the incline plane as x-axis and perpendicular to it as y-axis is more convenient way of solving problems as shown in Fig. 5.21 (b).

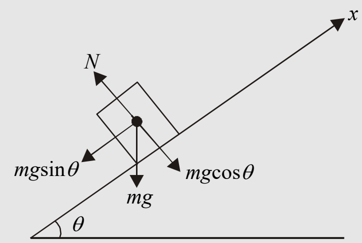


Fig. 5.21 (b)

SOLVED PROBLEMS

1. A smooth block is released at rest on a 45° incline and then slides a distance d. The time taken to slide is n times as much to slide on a rough incline plane than on a smooth incline. The coefficient of friction is

(a) $\mu_k = 1 - \dfrac{1}{n^2}$ (b) $\mu_k = \sqrt{1 - \dfrac{1}{n^2}}$

(c) $\mu_s = 1 - \dfrac{1}{n^2}$ (d) $\mu_s = \sqrt{1 - \dfrac{1}{n^2}}$.

[AIEEE 2005]

Solution (a)

case (i) Without friction $d = \dfrac{g}{2}\sin 45\, t^2$ ... (1)

case (ii) With friction $d = \dfrac{g}{2}\left[\sin 45 - \mu_k \cos 45\right] t^2 n^2$ ... (2)

From (1) and (2) $\mu_k = 1 - \dfrac{1}{n^2}$.

2. The upper half of an inclined plane with inclination ϕ is perfectly smooth. While the lower half is rough. A body starting from rest at the top will again come to rest at the bottom if the coefficient of friction for the lower half is given by

(a) 2 sin ϕ (b) 2 cos ϕ

(c) 2 tan ϕ (d) tan ϕ

[AIEEE 2005]

Solution (c) $mgs \sin\phi = \mu mg \cos\phi \dfrac{s}{2}$ or $\mu = 2\tan\phi$.

3. A block is kept on a frictionless inclined surface with angle of inclination α. The incline is given an acceleration a to keep the block stationary. Then a is equal to

(a) $\dfrac{g}{\tan\alpha}$ (b) g cosec α

(c) g (d) $g \tan\alpha$

[AIEEE 2005]

Solution (d) $ma\cos\alpha = mg\sin\alpha$ or $a = g\tan\alpha$

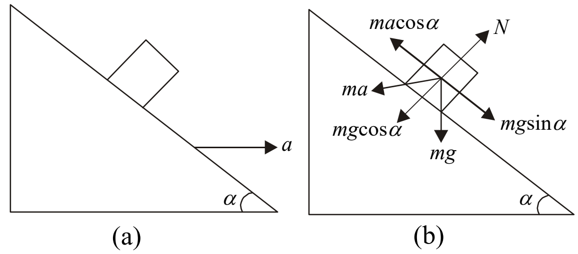


Fig. 5.22

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

(a) $3\ \text{ms}^{-2}$ (b) $15\ \text{ms}^{-2}$
(c) $5\ \text{ms}^{-2}$ (d) $10\ \text{ms}^{-2}$

[AIEEE 2005]

Solution (d) $a = \dfrac{kx}{m} = \dfrac{15(0.2)}{0.3} = 10\ \text{ms}^{-2}$.

5. A. Frictional forces are conservative forces

R. Potential energy can be associated with frictional forces

(a) *A* and *R* both are true and *R* is correct explanation of *A*
(b) *A* and *R* are true but *R* is not correct explanation of *A*
(c) *A* is correct but *R* is wrong
(d) Both *A* and *R* are wrong

[AIIMS 2005]

Solution (d)

6. Which is true for rolling friction (μ_r), static friction (μ_s) and kinetic friction (μ_k);

(a) $\mu_s > \mu_k > \mu_r$ (b) $\mu_s < \mu_k < \mu_r$
(c) $\mu_s < \mu_k > \mu_r$ (d) $\mu_s > \mu_r > \mu_k$

[BHU 2005]

Solution (a)

7. Two weights w_1 and w_2 are suspended to the two ends of a string passing over a smooth pulley. If the pulley is pulled up with *g* then the tension in the string is

(a) $\dfrac{4w_1w_2}{w_1+w_2}$ (b) $\dfrac{2w_1w_2}{w_1+w_2}$

(c) $\dfrac{w_1w_2}{w_1+w_2}$ (d) $\dfrac{w_1+w_2}{2}$

[BHU PMT 2005]

Solution (a) See short cut rule 5 and put $a' = g$.

8. The adjacent Fig. is the part of a horizontally stretched net. Section *AB* is stretched by 10 N. The tensions in the section *BC* and *BG* are

(a) 10 N, 11 N (b) 10 N, 6 N
(c) 10 N, 10 N (d) cannot be determined

[CET Karnataka 2005]

Solution Apply Lami's theorem

$$\frac{T_1}{\sin 120} = \frac{T_2}{\sin 120} = \frac{10}{\sin 120}$$

$$\therefore T_1 = T_2 = 10\ \text{N}$$

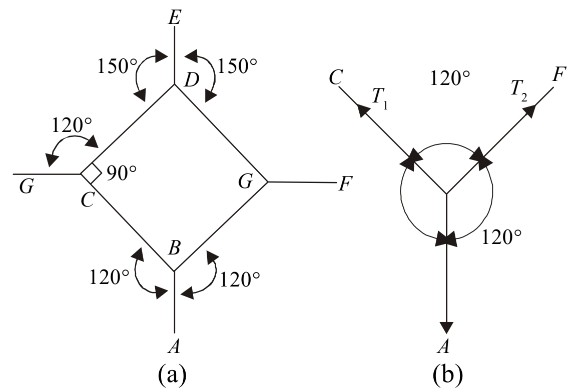


Fig. 5.23

9. In the fig shown, a cubical block is held stationary against a rough wall by applying force F then incorrect statement among the following is

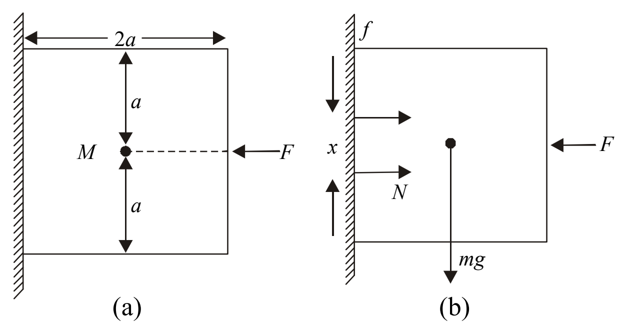


Fig. 5.24

(a) frictional force $f = Mg$
(b) $F = N$, N is Normal reaction
(c) F does not apply any torque
(d) N does not apply any torque.

Solution (d) For equilibrium $f = Mg$ and $F = N$. for maintaining rotational equilibrium *N* will shift downward. Hence, torque due to friction about COM = Torque due to Normal reaction about COM.

10. A block of mass m is placed on a smooth wedge of inclination θ. The whole system is accelerated horizontally so that block does not slip on the wedge. The force exerted by the wedge on the block has a magnitude

(a) mg (b) $mg \cos \theta$

(c) $mg/\cos \theta$ (d) mg tan θ

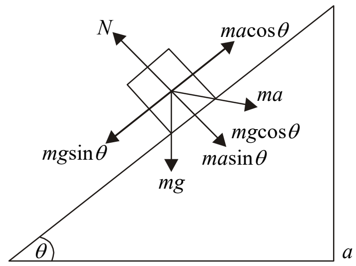


Fig. 5.25

Solution (c) $mg \sin \theta = ma \cos \theta$ or $a = g \tan \theta$

$N = ma \sin \theta + mg \cos \theta = m\,g \tan \theta \sin \theta + m\,g \cos \theta$

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

11. A person standing on the floor of an elevator drops a coin. The coin touches the floor of the elevator in time t, when the elevator is stationary and time t_2 when elevator is moving uniformly then

(a) $t_1 = t_2$ (b) $t_1 > t_2$ (c) $t_1 < t_1$ (d) $t_1 > t_2$ or $t_1 < t_2$ depends whether lift is moving up or down.

Solution (a) An object released from a moving body acquires its velocity also.

12. A boat of mass 300 *kg* moves according to the equation $x = 1.2\,t^2 - 0.2\,t^3$. When the force will become zero?

(a) 2 s (b) 1 s

(c) 6 s (d) 2.8 s

Solution (a) $\frac{dx}{dt} = 2.4\,t - 0.6\,t^2$ and

$$\frac{d^2x}{dt^2} = 2.4 - 1.2\,t = 0 \text{ or } t = 2 \text{ s.}$$

13. A ball falls from a height h in a fluid which offers a resistance $f = -kv$. Find the terminal velocity if mass of the ball is m

(a) $\frac{mg}{k}$ (b) $\sqrt{\frac{mgh}{k}}$

(c) $\frac{mg - B}{k}$ (d) none of these

[*B* is Buoyant force]

Solution (a) $mg = k\,v$ or $v = \frac{mg}{k}$

14. Assuming coefficient of friction 0.25 between block and incline. Find the acceleration of each block in Fig 5.26.

(a) $\frac{g}{5}$ (b) $\frac{g}{7}$

(c) $\frac{g}{6}$ (d) none of these

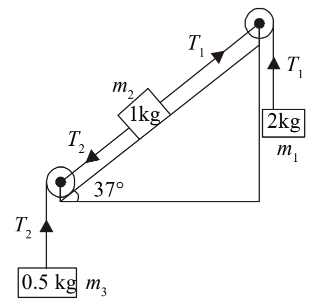


Fig. 5.26

Solution (a) $m_2 a = T_1 - T_2 - m_2 g \sin 37 - \mu m_2 g \cos 37$

or $a = \frac{T_1 - T_2}{m_2} - g \sin 37 - \frac{1}{4}\,g \cos 37$

or $T_1 - T_2 - 0.8g = a$ ... (2)

$T_2 - 0.5\,g = .5\,a$ ... (3)

$m_1 g - T_1 = m_1\,a$

or $2g - T_1 = 2a$ ... (1)

Adding (1), (2) and (3) $3.5a = 0.7g$

or $a = \frac{g}{5}$.

15. An 8 kg block of ice, released from rest at the top of a 1.5 m long smooth ramp, slides down and falls with a velocity 2.5 ms^{-1}. Find angle of the ramp with horizontal.

(a) 12° (b) 18°

(c) 15° (d) 30°

Solution (a) $v^2 = (2g \sin \theta)\,s$

or $\sin \theta = \frac{v^2}{2gs} = \frac{2.5 \times 2.5}{2 \times 10 \times 1.5} = \frac{0.5}{2.4} = 0.20$

or $\theta = 12°$.

16. A 60 kg boy stands on a scale in the elevator. The elevator starts moving and records 450 N. Find the acceleration of the elevator.

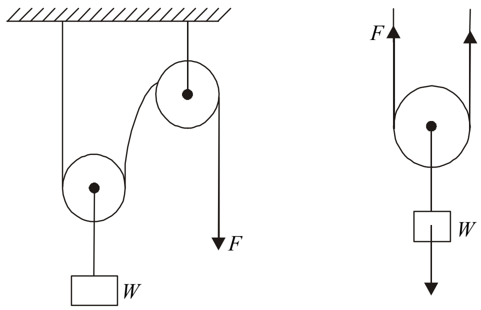
(a) 2.5 ms^{-2} upward (b) 2.5 ms^{-2} downwards

(c) 2.5 ms^{-2} in either direction

(d) none of these

Solution (b) $450 = 60\,(g - a)$ or $60\,a = 150$ $a = 2.5$ ms^{-2} downwards.

17. A weight W is lifted by applying a force F as shown in Fig. Find F in terms of W. Assume constant velocity.



(a) (b)

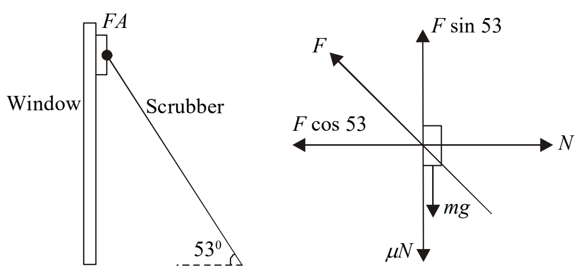
Fig. 5.27

(a) $F = W$ (b) $F = 2W$

(c) $F = \frac{W}{2}$ (d) none of these

Solution (c) $2F = W$ or $F = W/2$.

18. A window scrubber is used to brush up a vertical window as shown in Fig. The brush weigh 12 N and coefficient of kinetic friction of 0.15. Calculate F



(a) (b)

Fig. 5.28

(a) 15 N (b) 10.2 N

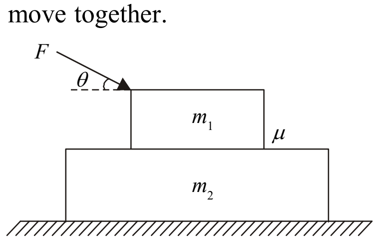
(c) 16.9 N (d) 18.1 N

Solution $\mu N + mg = F \sin 53$; $N = F \cos 53$

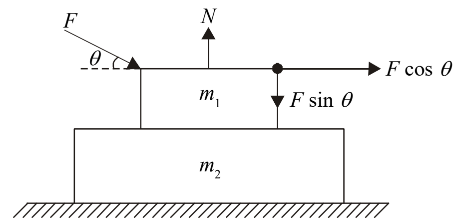
$$F = \frac{mg}{\sin 53 - \mu \cos 53}$$

$$= \frac{12}{0.8 - 0.15 \times (0.6)} = 16.9\ N.$$

19. Two blocks with masses m_1 and m_2 are stacked as shown in fig on a horizontal smooth surface. Coefficient of friction between the blocks is μ. A force F is applied at angle θ with the horizontal on block of mass m_1 as shown in Fig. Find the maximum force F so that the blocks move together.



(a)



(b)

Fig. 5.29

Solution $N = (m_1 g + F \sin \theta)$; $F_f = \mu N$

$= \mu (m_1 g + F \sin \theta)$

$F \cos \theta - F_f = m_1 a$

$F \cos \theta - \mu (F \sin \theta + m_1 g) = m_1 a$ ...(1)

$F \cos \theta = (m_1 + m_2)\, a$ ...(2)

From (1) and (2) $F \cos \theta - \mu (F \sin \theta + m_1 g)$

$$= \frac{m_1 (F \cos\theta)}{m_1 + m_2}$$

or $m_2 F \cos \theta - \mu F \sin \theta (m_1 + m_2) - \mu m_1 (m_1 + m_2)\, g = 0$

or $$F = \frac{\mu m_1 (m_1 + m_2) g}{m_2 \cos\theta - \mu (m_1 + m_2) \sin\theta}.$$

20. A rock of mass m slides down with an initial velocity v_o. A retarding force $F = -k\, v^{\frac{1}{2}}$ acts on the body. The velocity at any instant is given by

(a) $v = v_o - \frac{kt}{m}$ (b) $v = v_o - \left(\frac{kt}{m}\right)^2$

(c) $\sqrt{v} = \sqrt{v_o} - \frac{kt}{m}$ (d) none of these

Solution (c) $\frac{mdv}{dt} = -k\, v^{\frac{1}{2}}$

or $$\int_{v_o}^{v} \frac{dv}{v^{1/2}} = -\int_{o}^{t} \frac{kdt}{m}$$

or $$v^{\frac{1}{2}} = v_o^{1/2} - \frac{kt}{m}$$

or $$\frac{v_o^{1/2} - v^{1/2}}{1/2} = \frac{kt}{m}.$$

21. At $t = 0$, a force $F = kt$ is applied on a block making an angle α with the horizontal. Suppose surfaces to be smooth. Find the velocity of the body at the time of breaking off the plane.

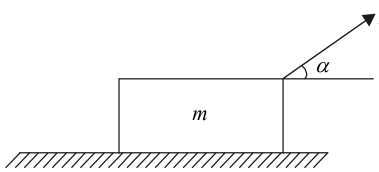


Fig. 5.30

(a) $\dfrac{mg\cos\alpha}{2a\sin\alpha}$ (b) $\dfrac{m^2g^2\cos\alpha}{2a\sin^2\alpha}$

(c) $\dfrac{mg^2\cos\alpha}{2a\sin^2\alpha}$ (d) $\dfrac{mg^2\cos^2\alpha}{2a\sin\alpha}$.

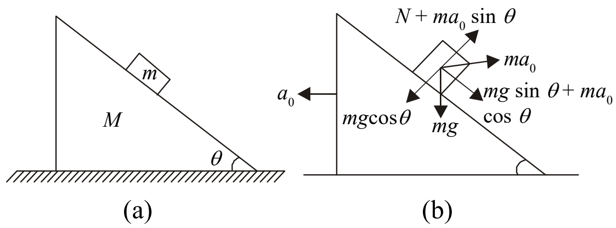
Solution (c) $at\cos\alpha = \dfrac{mdv}{dt}$ or $v = \dfrac{at^2\cos\alpha}{2m}$

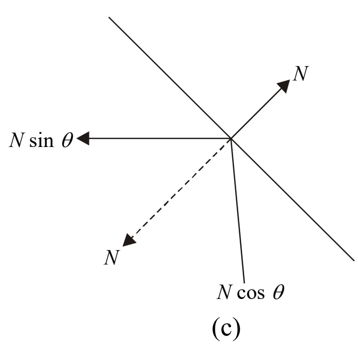
At the break off point $mg = at\sin\alpha$

or $$t = \frac{mg}{a\sin\alpha}.$$

$$\therefore v = \frac{a\cos\alpha}{2m}\left(\frac{mg}{a\sin\alpha}\right)^2 = \frac{mg^2\cos\alpha}{2a\sin^2\alpha}.$$

21. A block of mass m is placed on a wedge of mass m and inclination θ as shown in Fig. All surfaces are smooth. Find the acceleration of wedge.





(c)

Fig. 5.31

(a) $\dfrac{mg\cos^2\theta}{M+m\sin^2\theta}$ (b) $\dfrac{mg\sin^2\theta}{M+m\cos^2\theta}$

(c) $\dfrac{mg\sin\theta\cos\theta}{M+m\sin^2\theta}$ (d) $\dfrac{mg\sin\theta\cos\theta}{M+m\cos^2\theta}$

Solution (c)

$$ma = mg\sin\theta + ma_0\sin\theta$$

or $$a = g\sin\theta + a_0\cos\theta \quad ...(1)$$

$$N = mg\cos\theta - ma_0\sin\theta \quad ...(2)$$

$$N\sin\theta = Ma_0 \quad ...(3)$$

From (2) and (3)

$$\frac{Ma_0}{\sin\theta} = mg\cos\theta - ma_0\sin\theta$$

or $$a_0 = \frac{mg\cos\theta\sin\theta}{M+m\sin^2\theta}.$$

22. The tension T in the thread shown in fig is

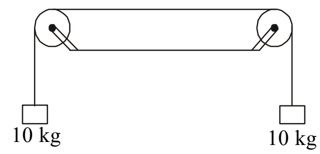


Fig. 5.32

(a) 10 N (b) zero

(c) 98 N (d) 196 N

Solution (c) $T = mg = 10\,(9.8) = 98\,N$

23. A light spring of spring constant k is cut into two equal halves. Each half is connected in Parallel then net spring constant of the combination is

(a) $\dfrac{k}{4}$ (b) $\dfrac{k}{2}$

(c) $2k$ (d) $4k$

(e) k

Solution (d) $k_{eq} = 2k + 2k = 4k \left(\because k \propto \dfrac{1}{l}\right)$.

24. Momentum is closely related to

(a) force (b) impulse

(c) velocity (d) kinetic energy

[DCE 1997]

Solution (c)

25. A force $F = k\,t\,(\tau - t)$ acts on a particle of mass m, which is at rest at $t = 0$ where k is a constant. Find the momentum of the force when the action of the force is discontinued.

(a) $k\tau^3/2$ (b) $k\tau^3/3$

(c) $k\tau^3/6$ (d) $k\tau^3/4$.

Solution (c) $\Delta p = \int F dt = \int_0^\tau kt(\tau - t)dt = \dfrac{k\tau^3}{2} - \dfrac{k\tau^3}{3}$

$$= \frac{k\tau^3}{6}.$$

TYPICAL PROBLEMS

26. The velocity of a bullet changes from v_o to v after the bullet has passed through a distance h in the plank. Assuming resistance offered is proportional to v^2, find the time of motion in the plank.

(a) $\dfrac{t}{t} = \dfrac{v_o - v}{h \log \dfrac{v_o}{ev}}$ (b) $t = \sqrt{\dfrac{h^2}{v_o v} \log \dfrac{v_o}{cv}}$

(c) $t = \dfrac{(v_o - v)h}{v_o v \log_e \dfrac{v_o}{v}}$ (d) $t = \dfrac{(v_o - v)h}{v v_o}$.

Solution (c) $F = -kv^2$, $a = \dfrac{dv}{dx} \cdot \dfrac{dx}{dt} = \dfrac{-k}{m} v^2$

or $$\int_{v_o}^{v} \frac{dv}{v} = \int_0^h \frac{-kdx}{m}.$$

or $$\log_e \frac{v_o}{v} = \frac{k}{m} h \ \ldots (1)$$

$$\int_{v_o}^{v} \frac{dv}{v^2} = \int_0^t \frac{-k}{m} dt \Rightarrow \frac{1}{v} - \frac{1}{v_o} = \frac{k}{m} t \ldots (2)$$

from (1) and (2) $t = \dfrac{(v_o - v)h}{v_o v \log_e \dfrac{v_o}{v}}$.

27. A body of mass m rests on a horizontal plane with a friction coefficient μ. At $t = 0$, a horizontal force is applied ($F = a\,t$) where a is a constant vector. Find the distance traversed in first t sec.

(a) $\dfrac{a}{6m}\left(t - \dfrac{\mu mg}{a}\right)^3$ (b) $\dfrac{a}{6m} t^3$

(c) $\dfrac{a}{6m} t^3 - \dfrac{\mu g t^2}{2}$ (d) $\dfrac{a}{6m} t^3 - \dfrac{\mu g t^2}{3}$.

Solution (a) After the application of force body begins to move after a time t_o such that

$$at_0 = \mu mg \text{ or } t_0 = \frac{\mu mg}{a} \quad \frac{dv}{dt} = \frac{a}{m}(t - t_0)$$

Put $t - t_0 = T$ or $v = \dfrac{a}{m} \displaystyle\int T dt = \dfrac{a}{m} \dfrac{T^2}{2}$.

$$\int dx = x = \frac{a}{m} \int \frac{T^2}{2} dt = \frac{a}{m} \frac{T^3}{6} = \frac{a}{6m} (t - t_0)^3.$$

28. A horizontal disc rotates with a constant angular velocity ω about a vertical axis passing through its centre. A small body m moves along a diameter with a velocity v. Find the force the disc exerts on the body when it is at a distance r located from the rotation axis.

(a) $mr\omega^2 + 2mv\,\omega$

(b) $mg + \sqrt{m^2 r^2 \omega^4 + (2mv\omega)^2}$

(c) $\sqrt{m^2 g^2 + (2mv\omega)^2} + mr\,\omega^2$

(d) $m\sqrt{g^2 + r^2\omega^4 + (2v\omega)^2}$

Solution (d) The force mg is vertical, $2mv\omega$ perpendicular to vertical plane and $mr\,\omega^2$ outward along the diameter. The resultant force is

$$F = m\sqrt{g^2 + r^2\omega^4 + (2v\omega)^2}.$$

29. A bead A can slide freely along a smooth rod bent in the form of a half circle of Radius R. The system is set in rotation with a constant angular velocity ω about a vertical axis OO′. Find the angle θ corresponding to steady position of the bead.

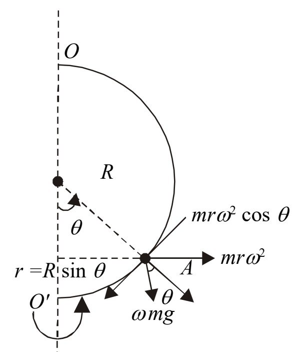


Fig. 5.33

(a) $\cos^{-1}\left(\dfrac{R\omega^2}{g}\right)$ (b) $\cos^{-1}\left(\dfrac{g}{R\omega^2}\right)$

(c) $\sin^{-1}\left(\dfrac{g}{R\omega^2}\right)$ (d) $\sin^{-1}\left(\dfrac{R\omega^2}{g}\right)$.

Solution (b) forces acting along the tangent to the radius $r = R \sin \theta$.

$$mg \sin \theta - mr\,\omega^2 \cos \theta = 0$$

or $$mg \sin \theta \left[1 - \frac{r\omega^2}{g} \cos\theta\right] = 0 \text{ or } \theta = \cos^{-1}\left(\frac{g}{R\omega^2}\right).$$

30. A block of mass m is placed on a wedge of Mass M. coefficient of friction between them is $\mu > \cot \theta$. The wedge is given an acceleration to its left. Find the maximum acceleration at which block appears stationary relative to wedge.

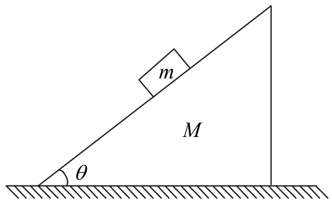


Fig. 5.34

(a) $\dfrac{g(\sin\theta - \mu\cos\theta)}{\cos\theta + \mu\sin\theta}$ (b) $\dfrac{g(\sin\theta + \mu\cos\theta)}{\cos\theta - \mu\sin\theta}$

(c) $\dfrac{g(\cos\theta + \mu\sin\theta)}{\sin\theta - \mu\cos\theta}$ (d) none

Solution (b)

$N = m(g\cos\theta + a\sin\theta)$

$ma\cos\theta = mg\sin\theta + \mu N$

$ma\cos\theta = mg\sin\theta + \mu mg\cos\theta + \mu ma\sin\theta$

$ma(\cos\theta\, \mu\sin\theta) = mg\sin\theta + mg\cos\theta)$

or $a = \dfrac{g(\sin\theta + \mu\cos\theta)}{\cos\theta - \mu\sin\theta}$

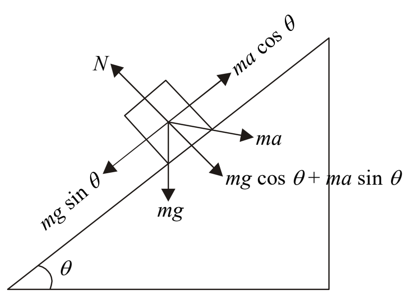


Fig. 5.35

31. In the arrangement shown in Fig. pulleys are smooth and massless. Threads are massless and inextensible. Find acceleration of mass m_1.

(a) $\dfrac{[2m_1m_2 + m_0(m_1 - m_2)]g}{2m_1m_2 + m_0(m_1 + m_2)}$

(b) $\dfrac{[4m_1m_2 + m_0(m_1 - m_2)]g}{4m_1m_2 + m_0(m_1 + m_2)}$

(c) $\dfrac{[4m_1m_2 - m_0(m_1 - m_2)]g}{4m_1m_2 + m_0(m_1 + m_2)}$

(d) none

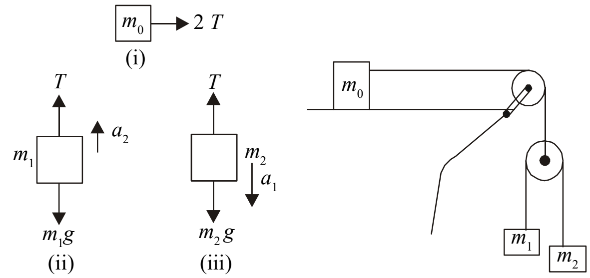


Fig. 5.36

Solution (b) $m_1 g - T = m_1 a_1$ [from Fig Q.31(ii)]

$m_2 g - T = m_2 a_2$ [from Fig Q.31(iii)]

$m_0 a = 2T$ [from Fig Q.31(i)]

$a_1 + a_2 = 2a$

Solving we get $a_1 = \dfrac{[4m_1m_2 + m_0(m_1 - m_2)]g}{4m_1m_2 + m_0(m_1 + m_2)}$.

32. A train of 2000 tonne moves in the lattitude 60° North. Find the magnitude of the lateral force that the train exerts on the rails if it moves with a velocity 54 km h^{-1}.

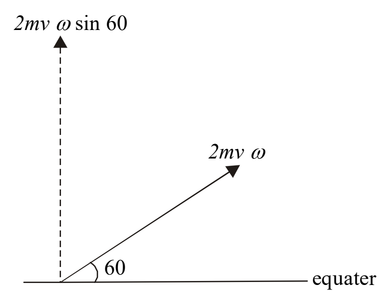


Fig. 5.37

(a) 2.4×10^3 N (b) 3.6×10^4 N

(c) 3.6×10^3 N (d) 2.4×10^4 N

Solution (c) $F = 2\,m\,v\,\omega\sin 60$

$= 2 \times 2 \times 10^6 \times \dfrac{15 \times 2\pi}{24 \times 60 \times 60} \times \dfrac{\sqrt{3}}{2}$.

$= 3.6 \times 10^3$ N.

33. The arrangement shown in Fig. mass of the rod is M and mass of bead is m and $M > m$. The bead slides with some friction. The mass of the pulley and friction in its axle are negligible. At the initial moment the bead was located opposite the lower end. If set free both the bodies move with constant accelerations. Find the frictional force between the bead and the thread so that t second after the release ball reaches the upper end of the rod. Length of the rod is l.

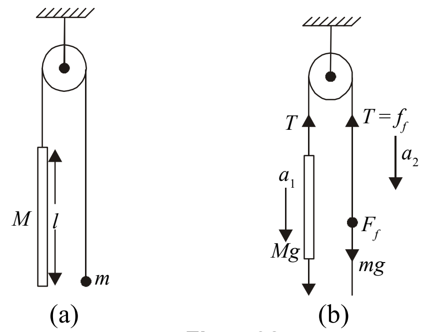


Fig. 5.38

Solution Both rod and bead move down with acceleration a_1 and a_2 such that $a_1 > a_2$. Since both are downwards, relative acceleration is $a_1 - a_2$ for rod.

$$l = \frac{1}{2}(a_1 - a_2)\,t^2 \qquad \ldots(1)$$

$$Mg - F_f = Ma_1 \qquad \ldots(2)$$

$$mg - F_f = ma_2 \qquad \ldots(3)$$

multiply (2) by m and (3) by M and subtract

$$(M - m)\,F_f = mM\,(a_1 - a_2)$$

or $$F_f = \frac{2mMl}{(M-m)t^2}.$$

34. A particle of mass m moves along the internal smooth surface of a vertical cylinder of radius r. Find the force with which the particle acts on the cylinder wall if at $t = 0$, its velocity is v_o and it makes an angle α with the horizontal.

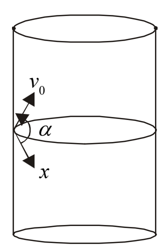


Fig. 5.39

(a) $\dfrac{mv_o^2}{R}$ (b) $\dfrac{mv_o^2}{R}\cos\alpha$

(c) $\dfrac{mv_o^2 \sin\alpha}{R}$ (d) $\dfrac{mv_o^2 \cos^2\alpha}{R}$

Solution $F = \dfrac{mv_x^2}{R} = \dfrac{m(v_o\cos\alpha)^2}{R}.$

35. Find the magnitude and direction of force acting on a particle during its motion in a plane xy according to the law $x = a\sin\omega t$ and $y = b\cos\omega t$ where a, b and ω are constants.

Solution $\vec{r} = x\,\hat{i} + y\,\hat{j} = a\cos\omega t\,\hat{i} + b\sin\omega t\,\hat{j}$

$$v = \frac{dr}{dt} = -a\,\omega\sin\omega t\,\hat{i} + b\,\omega\cos\omega t\,\hat{j}$$

$$a = \frac{d^2r}{dt^2} = -a\,\omega^2\cos\omega t\,\hat{i} - b\,\omega^2\sin\omega t\,\hat{j}$$

$$= -\omega^2\,\vec{r}$$

$$\vec{F} = m\,\vec{a} = -m\,\omega^2\,\vec{r}$$

36. Two blocks one of mass $A = 1$ kg and $B = 2$kg. A force of 5 N is applied on A [see Fig]. Coefficient of friction between A and B is 0.2 and that of between B and horizontal surface is zero. Find (a) acceleration of A and B (b) The time taken for the front surface of A to coincide with that of B.

[CBSE PMT Mains 2005]

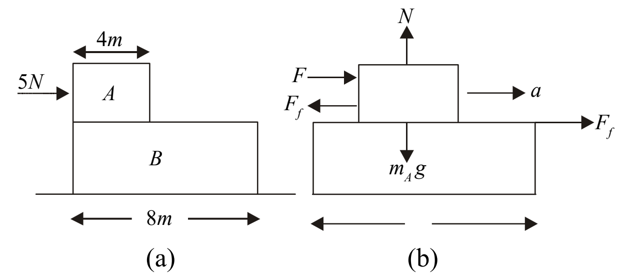


Fig. 5.40

Solution (a) $ma = F - \mu N$

or $1a_A = 5 - (.2) \times 10$

$= a_A = 3\ ms^{-2}.$

$$a_B = \frac{\mu N}{M_B} = 1\ \text{ms}^{-2}.$$

(b) $a_{rel} = a_A - a_B = 2\ \text{ms}^{-2}.$

$$s = \frac{1}{2}\,a_{rd}\,t_2 \qquad t = \sqrt{\frac{4\times 2}{2}} = 2\,s.$$

37. As shown in fig. mass of bodies is equal to m each. If coefficient of friction between horizontal surface and mass is 0.2. Find the acceleration of the system

[CBSE PMT Mains 2005]

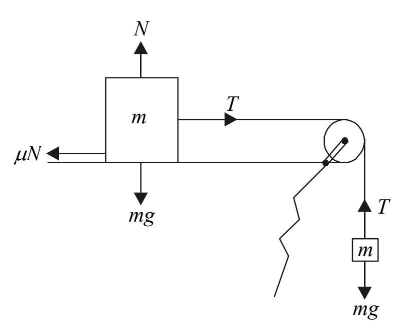


Fig. 5.41

Solution $mg - T = ma \ldots(1)$

$T - \mu mg = ma$ ...(2)

Adding (1) and (2) and solving

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

or $a = 0.4g = 4\ ms^{-2}$.

38. A particle is observed from the frames S_1 and S_2. The frame S_2 moves with respect to S_1 with an acceleration a. Let F_1 and F_2 be two pseudo forces acting on the particle when seen from S_1 and S_2 respectively. Which of the following are not possible.

(a) $F_1 = 0, F_2 \neq 0$ (b) $F_1 \neq 0, F_2 \neq 0$

(c) $F_1 \neq 0, F_2 = 0$ (d) $F_1 = 0, F_2 = 0$

Solution (d)

39. Fig. shows displacement of a particle going along the x-axis as a function of time. The force acting on the particle is zero in the region.

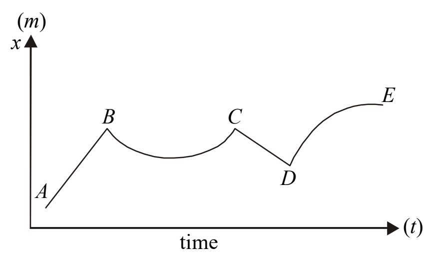


Fig. 5.42

(a) AB (b) BC

(c) CD (d) DE

Solution (a) and (c). In regions AB and CD

$$v = \frac{dx}{dt} = \text{constant}.$$

$$\therefore F = \frac{mdv}{dt} = 0.$$

40. A person says that he mesured acceleration of a particle to be non-zero while no force is acting on the particle. Then,

(a) he is a liar

(b) his clock might have run slow

(c) his meter scale might have been longer than the standard

(d) he might have used non-inertial frame of reference

Solution (d) Pseudo force will act in noninertial frame.

41. In the fig. $m_2 > m_1$. Pulley and string are massless and Pulley is smooth. The system is released from rest. After 2 seconds of motion m_2 was held with the hand.

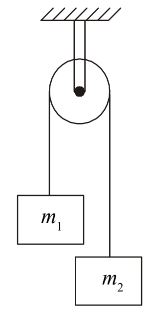


Fig. 5.43

(a) thread on the side of m_1 remains light .

(b) thread on the m_1 becomes slack and it will remain slack until m_2 is released.

(c) thread on m_1 becomes slack and after some time it will again be tight.

(d) just after m_2 is held the tension in the thread is 0.

Solution (c), (d)

42. In the Fig table is smooth. Then

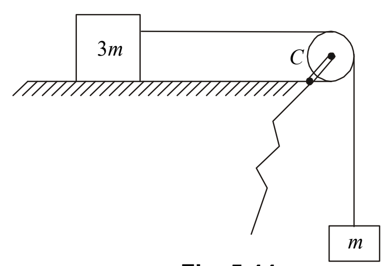


Fig. 5.44

(a) acceleration of the $3m$ block $= \frac{g}{4}$.

(b) the force on the clamp c is $\sqrt{2}\ mg$.

(c) the force on the clamp is $\frac{3}{4}\sqrt{2}\ mg$

(d) the force on the clamp is $3\sqrt{2}\ mg$.

Solution (a) and (c). $ma = mg - T$ and

$T = 3\ ma$ solving $a = \frac{g}{4}$.

$\therefore$ $T = \frac{3}{4}g$ and $F_{clamp} = \sqrt{2}\ \frac{3}{4}$ g

43. In the fig shown

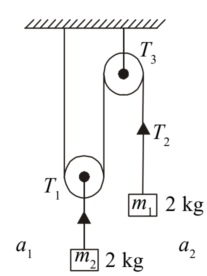


Fig. 5.45

(a) $T_1 = T_3 = T_2$ (b) $T_1 = T_3 > T_2$

(c) $a_1 = a_2$ (d) $a_1 < a_2$

(e) $a_2 < a_1$

Solution (b), (d) $a_2 = 2a_1$ and $T_1 = T_3 = 2\,T_2$.

44. Consider a vehicle going on a horizontal road towards east. Neglect any force by the air. The frictional force on the vehicle by the road

(a) is towards east when vehicle is accelerating.

(b) is zero when vehicle is moving with uniform velocity.

(c) must be towards west.

(d) must be towards east.

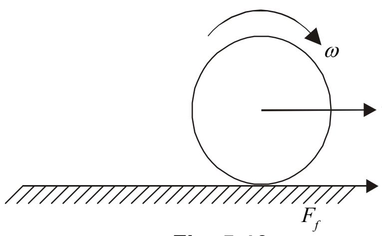


Fig. 5.46

Solution (a), (b). To oppose the rotational torque force should act along east.

45. A man holds a thin stick at its two ends and bend it in an arc like a bow without a string. Which of the following figures correctly show the directions the force exerted by him on the stick. Neglect gravity.

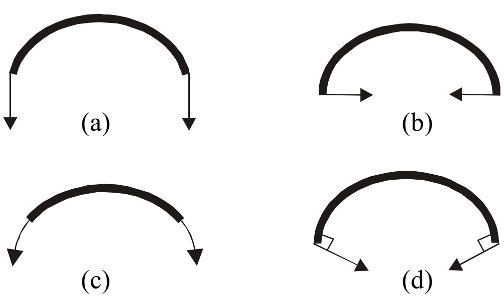


Fig. 5.47

Solution (b) Resultant of forces be zero.

46. Two bodies of masses m and M ($.M >> m$) are attached to the two ends of a light string passing over a pulley (light and smooth). What is the tension in the string when the masses are in motion?

(a) $(M - m)$ g (b) $2\,mg$

(c) Mg (d) $(m + M)\,g$

Solution (b) $T = \dfrac{2Mmg}{M+m}$. As $M >> m$ $\therefore T \approx 2\,mg$

47. A man pulls a block heavier than himself with a light rope. The coefficient of friction is the same between the man and the ground and between the block and the ground. Then

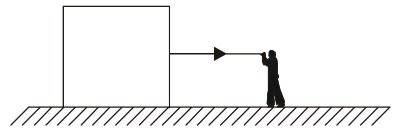


Fig. 5.48

(a) block will never move

(b) the man can move even when the block is stationary

(c) if both move $a_{\text{man}} > a_{\text{block}}$

(d) none of these

Solution (b) and (c)

48. A long block A is at rest on a smooth horizontal surface. A small block B (whose mass is half of A) is placed on A at one end and projected along A with a velocity v. The coefficient of friction is μ.

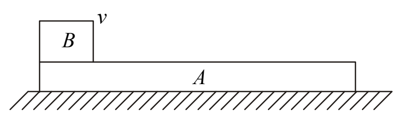


Fig. 5.49

(a) the block will reach a final common velocity $u/3$.

(b) the work done against friction is $2/3$ of initial KE of B.

(c) before the blocks reach a common velocity, the acceleration of A relative to B is $\frac{2}{3}\,\mu g$.

(d) before the blocks reach a common velocity the acceleration of A relative to B is $\frac{3}{2}\,\mu g$.

Solution (a), (b), (d) since F_{ext} of $A + B$ system is zero. Therefore momentum of $A + B$ system is conserved.

$mu = (m - 2m)\,v$ or $v = u/3$.

Work done against friction = Loss in $KE = \dfrac{1}{2}\,mu^2 = \dfrac{1}{2}$

$(3m)\left(u/3\right)^2 = \dfrac{mu^2}{3} = \dfrac{2}{3}\left(\dfrac{1}{2}mu^2\right)$.

Force of friction between the blocks = μmg.

Acceleration of A (towards right) = $\dfrac{\mu mg}{2m} = \dfrac{\mu g}{2}$.

Acceleration of B (towards left) = $\dfrac{\mu mg}{m} = \mu g\; a_{AB} = \dfrac{3}{2}$

μg.

PASSAGE 1

Read the following passage and answer the questions given at the end.

The instrument most commonly employed to measure forces in static procedure is the spring balance. The third law is tacitly used in static procedure because we assume that the force exerted by the spring balance on the body is same in magnitude as the force exerted by the body on the spring. This latter force is the force we wish to measure. First law is also used, because as we assume $F = 0$ when $a = 0$. Note that if $a \neq 0$, the body of weight W will not stretch the spring to the same length as it did when $a = 0$.

1. What will be the force measured by the spring balance if the block (a) is moving horizontally with acceleration a (b) is kept in a lift moving up with 5 ms^{-1}.

Solution (a) ma (b) mg.

2. What is the meaning of static procedure of measuring force.

Solution making the $\sum F = 0$ by applying an equal and opposite force.

PASSAGE 2

Read the following passage and answer the questions given at the end.

Before Galileo's time most of the philosphers thought that some influence or force was needed to keep a body moving. They thought body was in its natural state when the body was at rest. They assumed that some external agent had to continually propel it otherwise it will stop moving. Newton carried to full fruitation the ideas of Galileo and others who preceded him. In 1686 he presented the three laws of motion in his work Principia Mathematica Philosphiae Naturalis. Galileo esserted that some force was needed to change the velocity of a body but no force was necessary to maintain the velocity of the body.

1. The Galileo principle adopted by Newton is known as ....

Solution Law of inertia.

2. In which types of frames Newtons laws can be applied

Solution: Inertial frames

3. Earth is considered to be an inertial frame while it is actually pseudo frame. Why?

Solution Since the lab in which experiment is performed is also situated on earth. Therefore its relative impact on the body is negligible.

4. Why pseudo force is to be added in non-inertial frames?

Solution Non-inertial frame of reference moves with an acceleration. By applying a pseudo force on the body the effect of this acceleration is made zero.

PASSAGE 3

Read the following passage and answer the questions given at the end.

You are riding your motor cycle one day down a wet street which slopes downward at an angle of 20^0 to the horizontal. As you start down the hill, you notice a construction crew has dug a deep hole in the street at the bottom of the hill. A tiger escaped from the city zoo has taken up sheltor in the hole. To save yourself to become his lunch you aplly the brakes and lock your wheels at the top of the hill where your speed is 72 km^{-1} h. The inclined street in front of you is 50 m long. The coefficient of frinction is $\mu_s = 0.9$ and $\mu_k = 0.7$ between the tyres and the wet road.

$g = 10\ ms^{-2}$ (sin 20 = 0.3420, cos 20 = 0.9507)

1. Will you fall into the hole and become tiger's lunch ?

(a) yes (b) no

(c) as the fate will be

(d) insuffiuent data to calculate

2. What must your speed be to stop just before the hole.

(a) 18 ms^{-1} (b) 17.6 ms^{-1}

(c) 17.3 ms^{-1} (d) 16.9 ms^{-1}

Solution **1.** (a) $v^2 = 2\,as$ $a = \mu g \cos 20° - g \sin 20°$

$$a = (0.9307 \times 7 - 0.3420)\,g = 0.31\,g = 3.1$$

$$\therefore \quad s = \frac{20^2}{2\times 3.1} = \frac{400}{6.2} > 60$$

2. (b) $v^2 = 2 \times 3.1 \times 50 = 310$

or $v \le 17.6\ ms^{-1}$

PASSAGE 4

Read the following passage and answer the questions given at the end.

You are part of a design team for future exploration of the planet Mars, where $g = 3.7\ ms^{-2}$. An explorer is to step out of a survey vehicle travelling horizontally at 30 ms^{-1}. When it is 1200 m above the surface and then fall freely for 20 s. At that time, a portable advanced propulsion system (PAPS) will become ON. It will exert a constant force that will decrease the explorer's speed to zero at the instant. She touches the surface the total mass (explorer + suit + PAPS) is 150 kg. Assume change in mass of PAPS negligible and no air resistance.

1. Find the force in vector form.

(a) 2.42 (b) 14.25 (c) 8.5 (d) None

2. How much time explorer takes to reach the surface of mass?

(a) 11.1 s (b) 32.4 s (c) 45.3 s (d) 85.6 s

3. The maximum force exerted on a passenger by the floor of the elevator is not to exceed 1.6 times the weight of the passenger. The elevator accelerates upward with constant acceleration for 3 m. Find the maximum. velocity of the elevator

(a) 4 ms^{-1} (b) 5 ms^{-1}

(c) 6 ms^{-1} (d) 7 ms^{-1}

Solution **1.** (a) $v_y = gt = 3.7 \times 20 = 74\ ms^{-1}$ $h = \frac{1}{2}gt^2 = \frac{1}{2} \times 3.7 \times (20)^2 = 740$ m.

$$a_y = \frac{v_y^2}{2y} = \frac{74\times74}{2\times(1200-740)} = \frac{74\times37}{460} = \frac{1369}{230}$$

$$= 5.91\ ms^{-2}$$

$$\frac{v_y}{a_y} = t = \frac{74}{5.91} = 12.4\ s.$$

$$a_x = \frac{v_x}{t} = \frac{30}{12.4} = 2.42$$

$$F = m(a_x\hat{i} + a_y\hat{j})$$

$$= 150(2.42\hat{i} + 5.91\hat{j})$$

$$= (363\hat{i} + 886.5\hat{j})N$$

2. (b) $t = 20 + 12.4 = 32.4\ s$

3. (c) $1.6\ m = m(g + a)$

$$a = 6.2\ ms^{-2}$$

$$v = \sqrt{2as} = \sqrt{2\times6.2\times3} \approx 6\ ms^{-1}$$

PASSAGE 5

Read the following passage and answer the questions given at the end.

A man is driving a classic 1954 Nash Ambassador with a girlfriend sitting to his left on the passenger side of the front seat. The ambassador has flat bench seats. The man wishes to be closer to his girlfriend and decides to apply physics to achieve his goal for the romance by making a quick turn. The coefficient of static friction between the girlfriend and seat is 0.35 and the man is driving at 20 ms^{-1}.

1. What is the maximum radius of the turn so that she slides the man's way?

(a) 120 m (b) 140 m

(c) 180 m (d) 46 m

2. Which way the man should turn to achieve his romantic goal.

(a) left (b) right

(c) anyway left or right (d) can not say

Solution **1.** (a) $\frac{v^2}{r} = \mu g$, $r = \frac{v^2}{\mu g} = \frac{20\times20}{.35\times9.8} = 120$ m.

2. (b)

QUESTION FOR PRACTICE

1. A toy train consists of three identical compartment A, B and C. It is being pulled by a constant force F along C. The ratio of the tension in the string connecting AB and BC is

(a) 2 : 1 (b) 1 : 3

(c) 1: 1 (d) 1 : 2

2. A block of mass M is pulled along a smooth horizontal surface with a rope of mass m. The acceleration of the block will be

(a) F/(M + m) (b) F/(M – m)

(c) F/M (d) F/m

3. A body of weight 50 N is dragged on a horizontal surface with a force of 28.2 N. The frictional force acting on the body and the normal reactional force will be

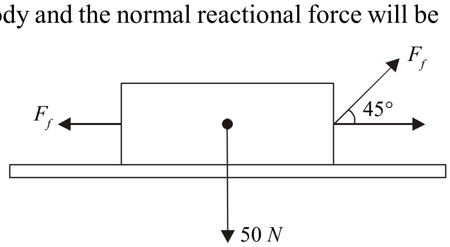


Fig. 5.50

(a) 2N, 3N (b) 5N, 7N

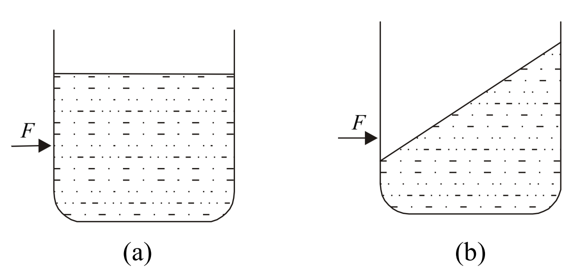
(c) 10 N, 15 N (d) 20 N, 30 N

4. Two blocks of mass 4 kg and 2 kg are placed in contact with each other on a frictionless horizontal surface. If we apply a push of 5N on the heavier mass, the force on the lighter mass will be

(a) 2N (b) 4N

(c) 5N (d) none of these

5. A jar containing water is placed in a train. The train accelerates from left to right. Which of the following shows the water level in a jar correctly?



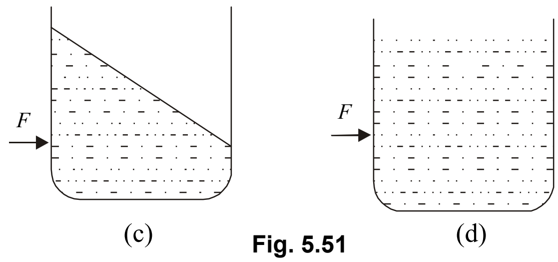


Fig. 5.51

6. A block of mass m is placed on a smooth inclined plane of inclination θ with the horizontal. The force exerted by the plane on the block has magnitude

(a) $mg \tan \theta$ (b) $mg \cos \theta$

(c) $mg/\cos \theta$ (d) mg

7. The work done in dragging a block of mass 5 kg on an inclined plane of height 2 m is 150 Joule. The work done against the frictional force will be

(a) 200 Joule (b) 150 Joule

(c) 100 Joule (d) 50 Joule

8. A boy of mass m with his mass centred at height H is standing in a train moving with constant acceleration a. If his legs are wide spread with a distance $2d$ and he is not taking the help of any support then normal reactions at his feet are given by

(a) $\frac{m}{2}\left(g+\frac{Ha}{d}\right); \frac{m}{2}\left(g-\frac{Ha}{d}\right)$

(b) $m(a+g), mg$

(c) $\frac{Hma}{d}, \frac{m}{2}\left(g-\frac{Ha}{d}\right)$

(d) mg, mg

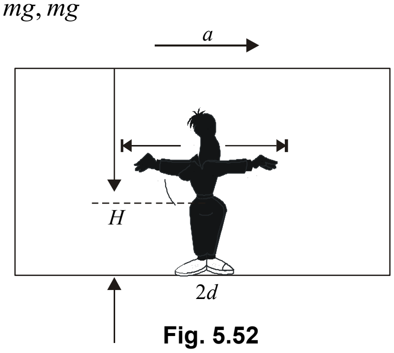


Fig. 5.52

9. Two masses m and M are lying on a surface moving with acceleration a. Only the given supporting and moving surface has coefficient of friction as μ. The frictional forces for $\mu > a/g$ and $\mu < a/g$ are

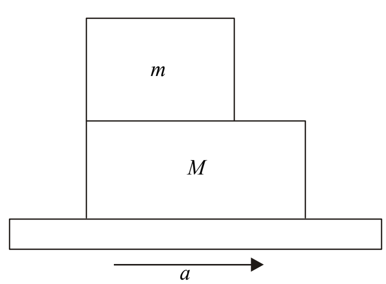


Fig. 5.53

(a) ma, ma (b) $ma, \mu mg$

(c) $\mu mg, \mu mg$ (d) $\mu mg, ma$

10. A small sphere of mass m is attached to a spring of spring factor k and normal length l. If the sphere rotates with radius r at frequency ν then tension in the spring is

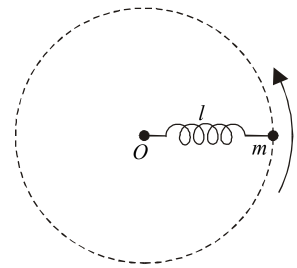


Fig. 5.54

(a) $k^2 l$ (b) $k^2 (r - l)$

(c) $mr(2\pi\nu)^2$ (d) kl

11. Two masses each equal to m are lying on x-axis at $(-a, 0)$ and $(+a, 0)$ respectively. They are connected by a light string. A force F is applied at the origin along y axis resulting into motion of masses towards each other. The acceleration of each mass when position of masses at any instant becomes $(-x, 0)$ and $(+x, 0)$ is given by

(a) $\frac{F}{m} \frac{x}{\sqrt{a^2 - x^2}}$ (b) $\frac{F}{m} \frac{\sqrt{a^2 - x^2}}{x}$

(c) $\frac{Fx}{2m\sqrt{a^2 - x^2}}$ (d) $\frac{F}{2m} \sqrt{\frac{a^2 - x^2}{x}}$

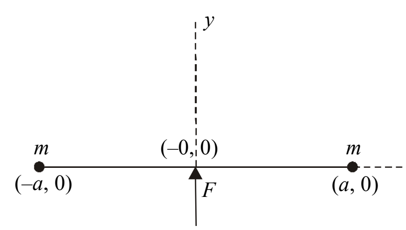


Fig. 5.54

12. A weightless string passes through a slit over a pulley. The slit offers frictional force f to the string. The string carries two weights having masses m_1 and m_2 where $m_2 > m_1$, then acceleration of the weights is

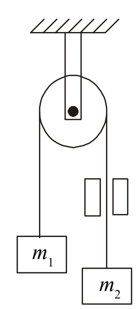


Fig. 5.55

(a) $\dfrac{(m_2 - m_1)g - f}{m_1 + m_2}$ (b) $\dfrac{f - (m_2 - m_1)g}{m_1 + m_2}$

(c) $\dfrac{(m_1 + m_2)g - f}{(m_1 - m_2)}$ (d) $\dfrac{m_2 g - f}{(m_1 + m_2)}$

13. A particle of mass m is suspended from a fixed point O by a string of length l. At $t = 0$, it is displaced from equilibrium position and released. The graph which shows the variation of tension T in string with time t is

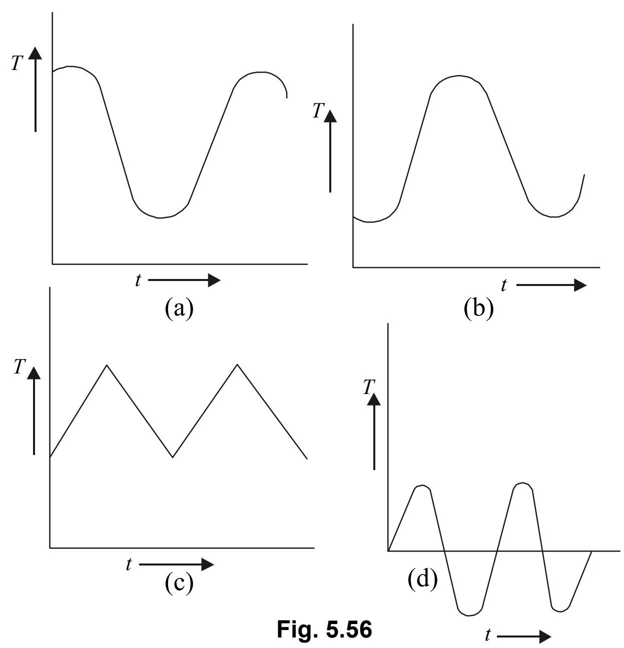


Fig. 5.56

14. Two blocks of masses m_1 and m_2 are connected to each other with the help of a spring. If pushing force is given to mass m_1 providing acceleration a to it, then acceleration of m_2 is

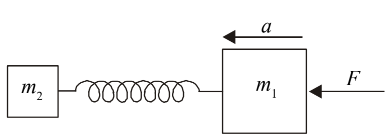


Fig. 5.57

(a) $\dfrac{m_1 a - F}{m_2}$ (b) $\dfrac{F - m_1 a}{m_2}$

(c) a (d) $\dfrac{F - m_1 a}{m_1}$

15. A stone weighing 1/2 kg is tied to a string 1/2 m long having withstand capacity of 20 kg. The stone is in horizontal circular motion over a frictionless table with a speed of 1.5 ms^{-1}. If tension in the string is equal to the breaking force of the spring, the speed attained is

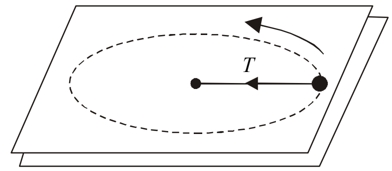


Fig. 5.58

(a) 14 ms^{-1} (b) 11 ms^{-1}

(c) 24 ms^{-1} (d) 17 ms^{-1}

16. A body takes n times, the time to slide down a rough inclined plane as it takes to slide down the same inclined plane when it is perfectly frictionless. The coefficient of kinetic friction between the body and the plane for an angle of inclination of 45° is given by μ

(a) $1 - \dfrac{1}{n}$ (b) $\dfrac{1}{n}$

(c) $\left(1 - \dfrac{1}{n^2}\right)$ (d) $\left(\dfrac{1}{n^2} - 1\right)$

17. Two blocks of masses 2 kg and 5 kg are at rest on ground. The masses are connected by a string passing over a frictionless pulley which is under the influence of a constant upward force $F = 50$ N. The accelerations of 5 kg and 2 kg masses are

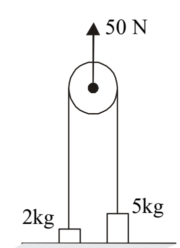


Fig. 5.59

(a) 0, 2.5 ms^{-2} (b) 0, 0

(c) 2.5 ms^{-2}, 2.5 ms^{-2} (d) 1 ms^{-2}, 2.5 ms^{-2}

18. A body starts to slide from P, down an inclined frictionless plane PQ having inclination α with horizontal and then ascends another smooth inclined plane QR with angle of inclination 2α. Neglecting impact at O

(a) $t_{PQ} = t_{QR}$ (b) $t_{PQ} < t_{QR}$

(c) $h' = 2h$ (d) $h' = h$

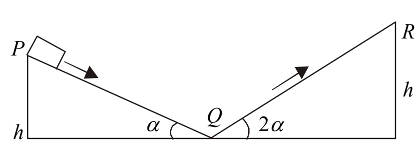


Fig. 5.60

19. A rod of length L is rotated in horizontal plane with constant angular velocity ω. A mass m is suspended by a light string of length L from the other end of the rod. If the angle made by vertical with the string is θ then angular speed, $\omega =$

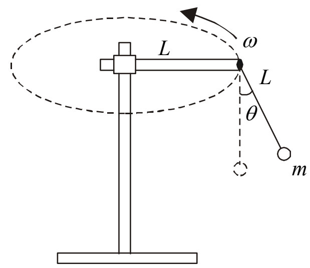


Fig. 5.61

(a) $\left[\dfrac{g\sin\theta}{L(1+\tan\theta)}\right]^{\frac{1}{2}}$ (b) $\left[\dfrac{L(1+\tan\theta)}{g\tan\theta}\right]^{\frac{1}{2}}$

(c) $\left[\dfrac{g\tan\theta}{L+\sin\theta}\right]^{\frac{1}{2}}$ (d) $\left[\dfrac{g\tan\theta}{L(1+\sin\theta)}\right]^{\frac{1}{2}}$

20. A stone of mass 1000 g tied to a light string of length 10/3 m is whirling in a vertical circle. If the ratio of the maximum tension to minimum tension is 4 and $g = 10$ ms^{-2}, then speed of stone at the highest point of circle is

(a) 20 ms^{-1} (b) $10/\sqrt{3}$ ms^{-1}

(c) $5\sqrt{3}$ ms^{-1} (d) 10 ms^{-1}

21. A man tries to remain in steady state by pushing his feet and hands against two parallel walls. Then for equilibrium

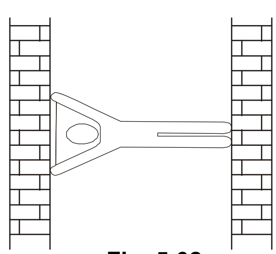


Fig. 5.62

(a) force of friction should be equal on the two walls.

(b) force exerted by him on both walls should be equal and the walls should not be frictionless.

(c) he should press his feet with greater force.

(d) coefficient of friction should be equal for both walls.

22. A machine gun is mounted on a flat railroad car. The gun is firing bullets at the rate of 10 bullets per second each of mass 10 g. The bullets are fired at velocity 500 ms^{-1} relative to the car. Calculate the acceleration and force of car at the instant when its mass is 200 kg.

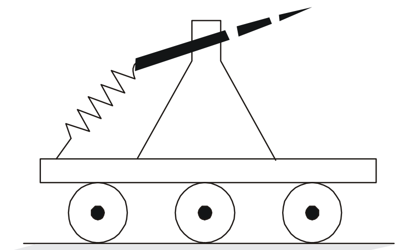


Fig. 5.63

(a) 0.25 ms^{-2}, 50 N (b) 2.5 ms^{-2}, 500 N

(c) 25 ms^{-2}, 50 N (d) 8 ms^{-2}, 1600 N

23. A block of mass 1 kg is connected by a light string passing over two smooth pulleys placed on a smooth horizontal surface as shown. Another block of 1 kg is connected to the other end of the string then acceleration of the system and tension in the string are

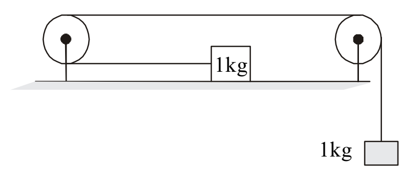


Fig. 5.64

(a) 5 ms^{-2}, 5 N (b) 1 ms^{-2}, 1 N

(c) 1 ms^{-2}, 5 N (d) 5 ms^{-2}, 10 N

24. A mass of 2 kg is placed on a trolley of 20 kg sliding on a smooth surface. The coefficient of friction between the mass and surface of trolley is 0.25. A horizontal force of 2N is applied to the mass. The acceleration of the system and the frictional force between the mass and surface of trolley are

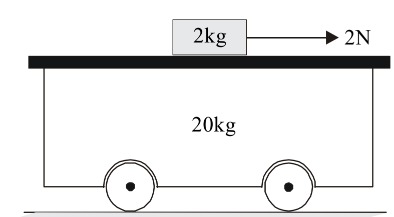


Fig. 5.65

(a) 1.8 ms^{-2}, 0.09 N (b) 0.9 ms^{-2}, 18 N

(c) 0.09 ms^{-2}, 1.8 N (d) 1 ms^{-2}, 2 N

25. In the shown system $m_1 > m_2$. Thread QR is holding the system. If this thread is cut, then just after cutting.

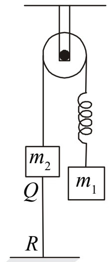


Fig. 5.66

(a) acceleration of mass m_1 is zero and that of m_2 is directed upward

(b) acceleration of mass m_2 is zero and that of m_2 is directed downward.

(c) acceleration of both the blocks will be same.

(d) acceleration of system is given by $\left(\frac{m_1 - m_2}{m_1 + m_2}\right) kg$, where k is a spring factor.

26. Three blocks of masses 3 kg, 6 kg and 1 kg are connected by a string passing over two smooth pulleys attached at the two ends of a frictionless horizontal surface. The acceleration of 3 kg mass is

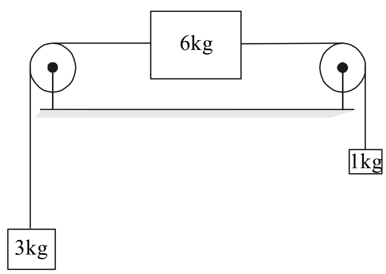


Fig. 5.67

(a) 1 ms^{-2} (b) 2 ms^{-2}

(c) 3 ms^{-2} (d) 4 ms^{-2}

27. A pearl of mass m is in a position to slide over a smooth wire. At the initial instant the pearl is in the middle of the wire. The wire moves linearly in a horizontal plane with an acceleration a in a direction having angle θ with the wire. The acceleration of the pearl with reference to wire is

(a) $g \sin \theta - a \cos \theta$ (b) $g \sin \theta - g \cos \theta$

(c) $g \sin \theta + a \cos \theta$ (d) $g \cos \theta + a \sin \theta$

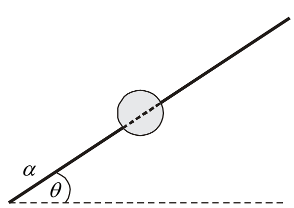


Fig. 5.68

28. A mass is resting on a rough plank. At initial instant a horizontal impulse is applied to the mass. If the velocity of mass at instant t is υ and displacement upto this instant is S then correct graph is

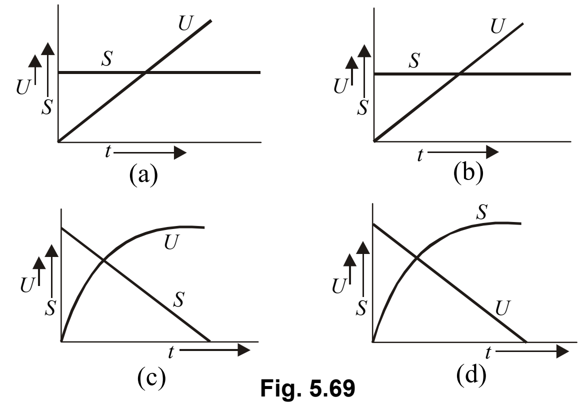


Fig. 5.69

29. A straight tube of length L contains incompressible liquid of mass M and the closed tube is whirled in horizontal plane about one of the ends. If ω is the uniform angular velocity, the force exerted by the liquid on the other end is

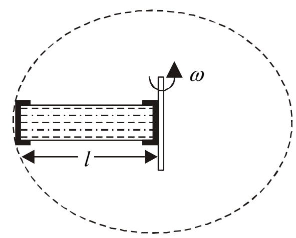


Fig. 5.70

(a) $\frac{ML\omega^2}{4}$ (b) $2\, ML\, \omega^2$

(c) $\frac{ML\omega^2}{4}$ (d) $ML\, \omega^2$

30. A light rope passes over a pulley. One section of the rope is held by a child and the other section by a man, then

Fig. 5.71

(a) the man and the child have same vector acceleration.

(b) the man and the child have same magnitude of acceleration but in opposite direction.

(c) the man and the child have different magnitude of acceleration.

(d) the man and the child have accelerations which keep on interchanging with each other.

31. A trolley is under the action of a constant force F. The sand contained by it is poured out through a hole in the floor at the rate of m per second. If initial mass of sand

and trolley was M and initial speed was u, then acceleration of trolley is given by

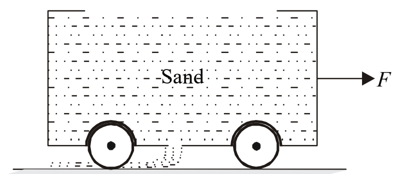


Fig. 5.72

(a) $\dfrac{F}{M-mt}$ (b) $\dfrac{F}{M+mt}$

(c) $\dfrac{F}{M-m}$ (d) $\dfrac{F}{M+m}$

32. A smooth track of incline of length l is joined smoothly with circular track of radius R. A mass of m kg is projected up from the bottom of the inclined plane. The minimum speed of the mass to reach the top of the track is given by, $\upsilon =$

(a) $[2g\,(l\cos\theta + R)\,(1+\cos\theta)]^{1/2}$

(b) $(2g\,l\sin\theta + R)^{1/2}$

(c) $[2g\,\{l\sin\theta + R\,(1-\cos\theta)\}]^{1/2}$

(d) $(2g\,l\cos\theta + R)^{1/2}$

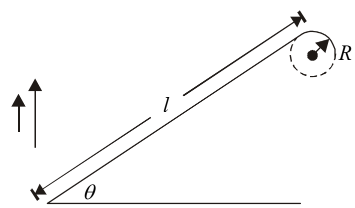


Fig. 5.73

33. A massless string of length l passes over a frictionless pulley with horizontal axis. Two monkeys hang from the ends of the string at the same distance $l/2$ from the pulley, the monkeys start climbing upwards simultaneously. First monkey climbs with a speed υ relative to the string and the second with speed of 2υ. Both monkeys have got same masses. The time taken by the first and second monkeys in reaching the pulleys are respectively.

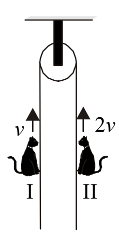


Fig. 5.74

(a) $\left(\dfrac{1}{\upsilon}\right), \left(\dfrac{1}{2\upsilon}\right)$ (b) $\sqrt{\dfrac{2l}{\upsilon}}, \sqrt{\dfrac{l}{\upsilon}}$

(c) $\left(\dfrac{l}{2\upsilon}\right)^{\frac{1}{2}}, \left(\dfrac{1}{\upsilon}\right)^{1/2}$ (d) $\left(\dfrac{1}{3\upsilon}\right), \left(\dfrac{1}{3\upsilon}\right)$

34. Neglecting the masses of the string and pulley and ignoring the friction in the system, we find that

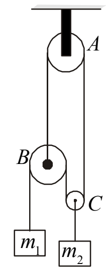


Fig. 5.75

(a) weights fall freely. Pulley B rotates clockwise and pulley A, C rotate anticlockwise.

(b) the two weights have different accelerations. Pulley C rotates clockwise and B, C rotate anticlockwise.

(c) acceleration of masses will be zero and the system will be at rest.

(d) acceleration of masses is equal to g. Pulley A and C rotate clockwise whereas B rotates anticlockwise.

35. A cage revolves around a vertical circle of radius R with constant linear speed $\sqrt{gR}$. The cage is connected to the revolving arm in such a manner that a boy of mass m remains always vertical while standing on a weighing machine kept inside the cage. It is found that

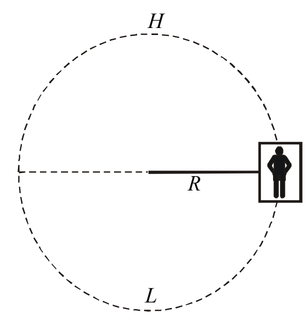


Fig. 5.76

(a) the reading at lowermost point L is greater than the reading at highest point H by two times.

(b) the readings are same at all the points on the vertical circle.

(c) the reading at lowermost point L is less than the reading at highest point H by two third.

(d) the reading at lowermost point L is five times the reading at the highest point H.

36. A simple pendulum is vibrating with an angular amplitude of $\dfrac{\pi}{2}$. The value of α for which the resultant acceleration has a direction along the horizontal is

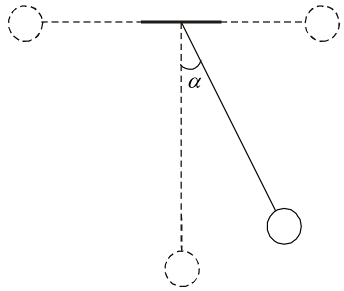


Fig. 5.77

(a) $\frac{\pi}{2}$ (b) 180°

(c) $\cos^{-1}\left(\frac{1}{\sqrt{3}}\right)$ (d) $\cos^{-1}\left(\frac{1}{\sqrt{2}}\right)$

37. A body of mass m starting from rest slides down a frictionless inclined surface of gradient α fixed on the floor of a lift accelerating upward with acceleration a. Taking width of inclined plane as W, the time taken by body to slide from top to bottom of the plane is

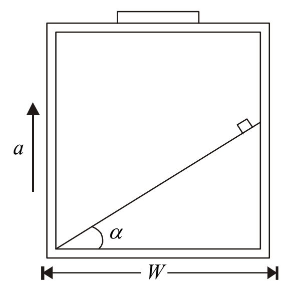


Fig. 5.78

(a) $\left(\frac{2W}{(g+a)\sin\alpha}\right)^{\frac{1}{2}}$ (b) $\left(\frac{4W}{(g-a)\sin\alpha}\right)^{\frac{1}{2}}$

(c) $\left(\frac{4W}{(g+a)\sin 2\alpha}\right)^{\frac{1}{2}}$ (d) $\left(\frac{W}{(g+a)\sin 2\alpha}\right)^{\frac{1}{2}}$

38. A very small mass m is fixed to one end of a massless spring of constant k and normal length l. The spring and the mass are rotated about the other end of the spring with angular speed ω. Neglect the effect of gravity. Extension in the spring is

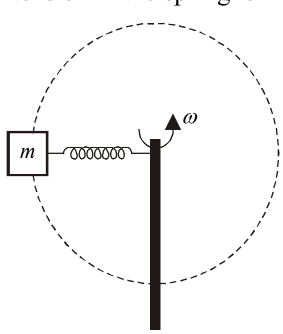


Fig. 5.79

(a) zero (b) $\frac{ml\omega^2}{k+m\omega^2}$

(c) $ml\omega^2$ (d) $\frac{m\omega^2 l}{k-m\omega^2}$

39. A rope is stretched between two boats at rest. A sailor in the first boat pulls the rope with a constant force of 100 N. First boat with the sailor has a mass of 250 kg whereas the mass of second boat is double of that mass. If the initial distance between the boats was 100 m, the time taken for two boats to meet each other is

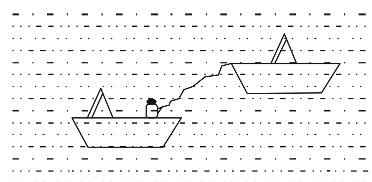


Fig. 5.80

(a) 13.8 s (b) 18.3 s

(c) 3.18 s (d) 31.8 s

40. A block of mass M is situated on a smooth horizontal table. A thread tied to the block passes through a hole in the table and carries a mass m at its other end. If the length of thread above the table is l and M is revolving in horizontal circle with angular speed ω on the table, then value of m so that it remains suspended at a constant height h is

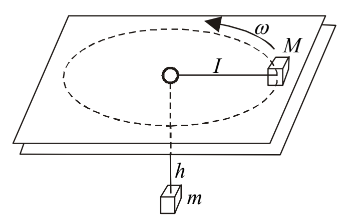


Fig. 5.81

(a) $Mgh\omega^2$ (b) $Mgl\omega^2$

(c) $\frac{Ml\omega^2}{g}$ (d) $Ml\omega^2$

41. A parachute of mass m starts coming down with a constant acceleration a. Determine the ballast mass to be released for the parachute to have an upward acceleration of same magnitude. Neglect air drag.

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

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

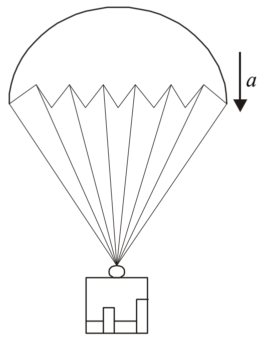


Fig. 5.82

42. Block A is placed on block B (mass of B > mass of A). There is friction between the blocks but the ground is frictionless. A horizontal force F, increasing linearly with time, begins to act on A. Accelerations a_V and a_B of blocks A and B respectively is correctly plotted as

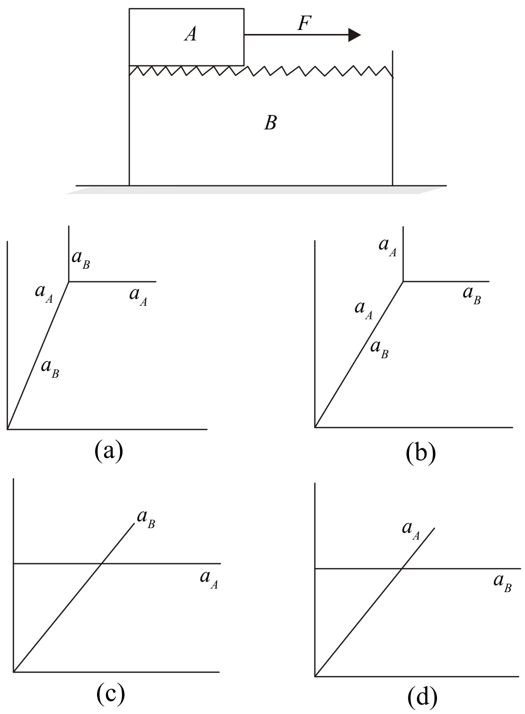


Fig. 5.83

43. A circular table has a radius of 1m and mass 20 kg. It has 4 legs of 1 m each fixed symmetrically on its circumference. The maximum weight which can be placed anywhere on this table without toppling it is

(a) 84.3 kg (b) 34.8 kg

(c) 48.3 kg (d) 43.8 kg

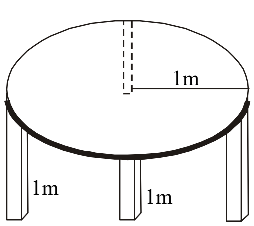


Fig. 5.84

Physics by Saurabh Maurya (IIT-BHU)

44. A board is balanced on a rough horizontal semicircular log. Equilibrium is obtained with the help of addition of a weight to one of the ends of the board when the board makes an angle θ with the horizontal. Coefficient of friction between the log and the board is

(a) $\tan\theta$ (b) $\cos\theta$

(c) $\cot\theta$ (d) $\sin\theta$

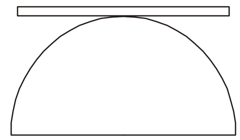


Fig. 5.85

45. Two similar planes of mass m each having failed engines are being pulled by a stronger plane in air.

At $t = 0$, they are travelling at uniform speed producing tension T_A in rope A. The stronger plane then accelerates with acceleration a. Tension in rope B just after the beginning of acceleration is

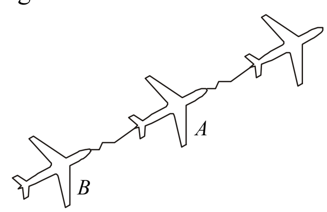


Fig. 5.86

(a) T_A (b) $T_A - ma$

(c) $2T_A + ma$ (d) $\frac{T_A}{2} + ma$

46. Velocity of a bullet changes from u to υ after passing through a board of thickness d. Force of resistance is directly proportional to the velocity. Time of motion of bullet in the board is given by

(a) $\dfrac{d(u-\upsilon)}{u\upsilon \log_e \frac{u}{\upsilon}}$ (b) $\dfrac{du}{\upsilon \log_e \frac{u}{\upsilon}}$

(c) $\dfrac{d\upsilon}{u \log_e \frac{u}{\upsilon}}$ (d) $\dfrac{d(\upsilon-u)}{u\upsilon \log_e \frac{\upsilon}{u}}$

47. A rocket of mass m is fired vertically upward and after the fuel burning it weighs m'. Ejection of fuel gas is at a constant rate of m_0 per second with a constant velocity of u_{rel} relative to the rocket. Final speed of rocket after the complete burn out of fuel is given by $\upsilon =$

(a) $u_{\text{rel}} \log_e \dfrac{m}{m'}$ (b) $u_{\text{rel}} \log_e \dfrac{m_0}{m}$

(c) $-u_{\text{rel}} \log_e \dfrac{m_0}{m'}$ (d) $-u_{\text{rel}} \dfrac{dm}{m}$

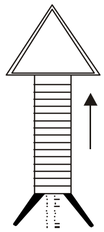


Fig. 5.87

48. A chain of length l is lying in a smooth horizontal tube such that a fraction of its length h hangs freely and the end touches the ground. At a certain moment the other end of chain is set free. The speed of this end of chain when it slips out of the tube is

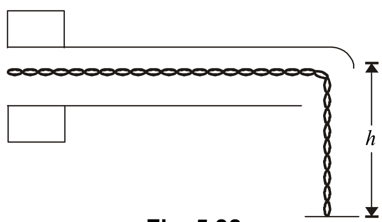


Fig. 5.88

(a) $\left[(2gh)\dfrac{dl}{dh}\right]^{1/2}$ (b) $\sqrt{gh}$

(c) $\sqrt{2gl}$ (d) $\left(2gh\log_e \dfrac{l}{h}\right)^{\frac{1}{2}}$

49. A block of mass M with semicircular track of radius R rests on a horizontal smooth surface. A cylinder of radius r slips on the track. If the cylinder is released from rest from top, the distance moved by block when cylinder reaches the bottom of the track is

(a) $R-r$ (b) $\dfrac{M(R-r)}{M+m}$

(c) $\dfrac{M}{M+m}(R-r)$ (d) $\dfrac{M}{M-m}r$

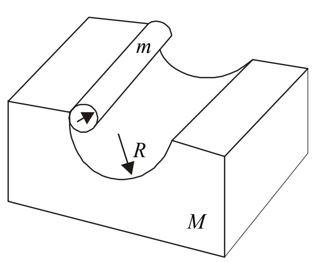


Fig. 5.89

50. Let μ be the coefficient of friction between blocks of mass m and M. The pulleys are frictionless and strings are massless. Accleration of mass m is

(a) $\dfrac{\sqrt{5}mg}{M+\sqrt{5}m+2\mu m}$ (b) $\dfrac{2mg}{m+5M+2\mu m}$

(c) $\dfrac{2\sqrt{5}mg}{M+5m+2\mu m}$ (d) $\dfrac{5\sqrt{2}mg}{m+\sqrt{5}m+\sqrt{2}\mu m}$

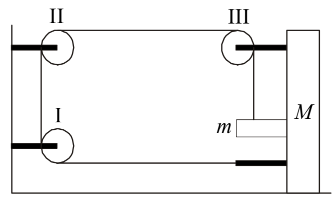


Fig. 5.90

51. A chain of length l is placed on a smooth spherical surface of radius r with one of its ends fixed at the top of the surface. Length of chain is assumed to be $l < \dfrac{\pi r}{2}$. Acceleration of each element of chain when upper end is released is

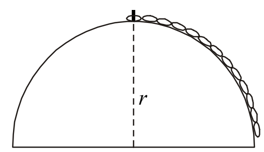


Fig. 5.91

(a) $\dfrac{lg}{r}\left(1-\cos\dfrac{r}{l}\right)$ (b) $\dfrac{rg}{l}\left(1-\cos\dfrac{l}{r}\right)$

(c) $\dfrac{lg}{r}\left(1-\sin\dfrac{l}{r}\right)$ (d) $\dfrac{rg}{l}\left(1-\sin\dfrac{l}{r}\right)$

52. A board of mass M is placed on a rough inclined plane and a man of mass m walks down the board. If the coefficient of friction between the board and inclined plane is μ, the acceleration of the man, such that plank does not slip, is given by

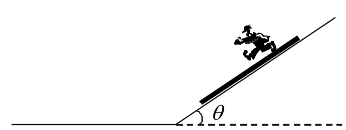


Fig. 5.92

(a) $a \le \left(\dfrac{M-m}{m}\right)(\cos\theta + \mu\sin\theta)\,g$

(b) $a \ge \left(\dfrac{M+m}{m}\right)(\sin\theta + \mu\cos\theta)\,g$

(c) $a \le \left(\dfrac{M+m}{m}\right)(\sin\theta + \mu\cos\theta)\,g$

(d) $a = \left(\dfrac{m}{M+m}\right)(\sin\theta + \mu\cos\theta)\,g$

53. A large free mass M and a small mass m are connected to a string such that m moves in horizontal circle. Length of string is l and θ is the angle this length makes with vertical. The frequency of rotation of mass m so that M remains at rest is

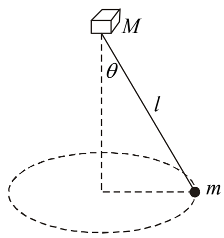


Fig. 5.93

(a) $2\pi\sqrt{\dfrac{ml}{Mg}}$ (b) $\dfrac{1}{2\pi}\sqrt{\dfrac{mg}{Ml}}$

(c) $\dfrac{1}{2\pi}\sqrt{\dfrac{ml}{Mg}}$ (d) $\dfrac{1}{2\pi}\sqrt{\dfrac{Mg}{ml}}$

54. Two blocks connected by a massless string slide down an inclined plane having angle of inclination as 37°. The masses of two blocks are 4 kg and 2 kg with μ as 0.75 and 0.25 respectively.

(a) The common acceleration of two masses is 1.3 ms^{-2} and tension in string is 5.3 N.

(b) Tension in the string is 14.9 N.

(c) Acceleration of the mass is 3 N.

(d) The acceleration of masses is 5.3 ms^{-2} and tension in the string is 1.3 N.

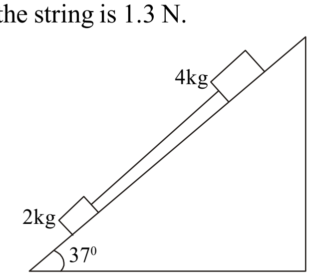


Fig. 5.94

55. Accelerations of the vehicle and mass m_2, when pulleys are light and all surfaces are frictionless, are

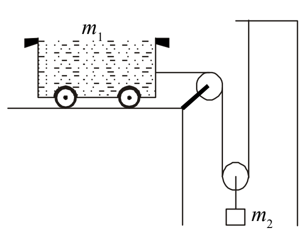


Fig. 5.95

(a) each $\dfrac{m_2 g}{4m_1 + m_2}$ (b) $\dfrac{2m_2 g}{4m_1 + m_2}, \dfrac{m_2 g}{4m_1 + m_2}$

(c) each $\dfrac{2m_1 g}{4m_2 + m_1}$

(d) $\dfrac{m_1 g}{4m_2 + m_1}, \dfrac{2m_1 g}{4(m_2 + m_1)}$

56. A block of mass m slides down an inclined right angled trough. If the coefficient of kinetic friction between the block and the trough is μ_k, acceleration of the block down the plane is

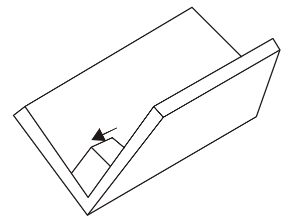


Fig. 5.96

(a) $g(\sin\theta - 2\mu_k \cos\theta)$ (b) $g(\sin\theta + 2\mu_k \cos\theta)$

(c) $g(\sin\theta + \sqrt{2}\,\mu_k \cos\theta)$ (d) $g(\sin\theta - \mu_k \cos\theta)$

57. A cylinder of radius $r = 1$ m and mass $m = 5 \times 10^3$ kg is at rest on the edges of a structure as shown. Distance a is 0.5 m and $b = \dfrac{\sqrt{3}}{2}$ m. Reaction force on edges A and B are

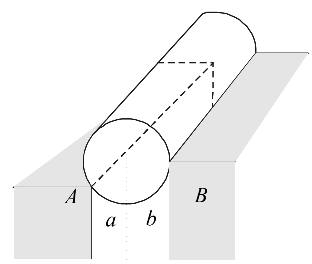


Fig. 5.97

(a) 24.6 kN, 24.6 kN (b) 42.6 kN, 42.6 kN

(c) 42.6 kN, 24.6 kN (d) 52.6 kN, 5.6 kN

58. The force f acting after time t on the bottom of a beaker of area A when water of density ρ falls from a tap at a height h at uniform rate υ $m^3 s^{-1}$ is

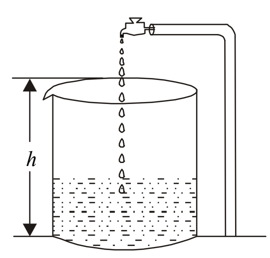


Fig. 5.98

(a) $\upsilon\rho\left[gt + 2g\left(h - \dfrac{\upsilon t}{A}\right)\right]$ (b) $\upsilon\rho\left[gt + \sqrt{2gh}\right]$

(c) $\upsilon\rho gh$

(d) $\upsilon\rho\left[gt + \sqrt{2g\left(h + \dfrac{\upsilon t}{A}\right)}\right]$

59. Two blocks B_1 and B_2 of masses m_1 and m_2 respectively are connected with the help of a pulley and string as shown. Upper surface of vehicle is smooth but vertical surface is rough.

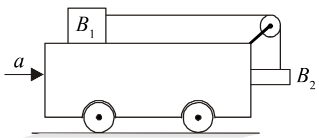


Fig. 5.99

Given $a = g/7$ and $m_1 = 7.5\ m_2$. Coefficient of friction between block B_2 and side of vehicle is

(a) 0.4 (b) 0.5

(c) 0.6 (d) 0.3

60. Sixteen beads in a string are placed on a smooth inclined plane of inclination $\sin^{-1}(1/3)$ such that some of them lie along the incline whereas the rest hang over the top of the plane. If acceleration at first bead is $g/2$, the arrangement of beads is that

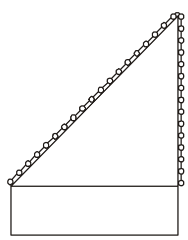


Fig. 5.100

(a) 12 hang vertically.

(b) 10 lie along inclined plane.

(c) 8 lie along inclined plane.

(d) 10 hang vertically.

61. A mass M is hung with a light inextensible string. Tension in horizontal part of string is

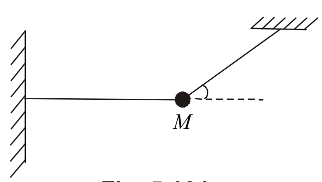


Fig. 5.101

(a) $\sqrt{3}\ Mg$ (b) $\sqrt{2}\ Mg$

(c) $\dfrac{Mg}{\sqrt{3}}$ (d) $\dfrac{Mg}{2}$

(I.I.T. 1990)

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

(a) 0.2 ms^{-1} (b) 0.1 ms^{-1}

(c) 1 ms^{-1} (d) 2 ms^{-1}

(I.I.T. 1990)

63. A bullet of mass M is fired with a velocity of 50 ms^{-1} at an angle θ with the horizontal. At the highest point of trajectory it collides with a bob of mass $3M$ suspended vertically by a massless string of length $\frac{10}{3}$ m and gets embedded into it. After the collision the string moves through an angle 120°, what is the angle of throw θ.

(a) $\cos^{-1}\frac{2}{5}$ (b) $\cos^{-1}\frac{3}{5}$

(c) $\cos^{-1}\frac{4}{5}$ (d) $\cos^{-1}\frac{1}{5}$

(I.I.T. 1991)

64. A car is moving in a circular horizontal track of radius 10 m with a constant speed of 10 ms^{-1}. A plumb bob is suspended from the roof of car by a light rigid rod of length 1 m. The angle made by rod with the track is

(a) zero (b) 30°

(c) 45° (d) 60°

(I.I.T. 1992)

65. A ball weighing 10g hits a hard surface vertically with a speed of 5 ms^{-1} and rebounds with the same speed. The ball remains in contact with the surface for 0.01 s. The average force exerted by the surface on ball is.

(a) 100 N (b) 10 N

(c) 1 N (d) 0.1 N

(Roorkee 1993)

66. Tension in rod of length L and mass M at a distance y from F_1 when the rod is acted on by two unequal forces F_1 and F_2 where ($F_2 < F_1$) at its ends is

(a) $F_1(1 - y/L) + F_2(y/L)$ (b) $F_2(1 - y/L) + F_1(y/L)$

(c) $F_1(1 + y/L) + F_2(y/L)$ (d) $F_2(1 + y/L) + F_1(y/L)$

(I.I.T. 1993)

67. The magnitude of force (in N) acting on a body varies with time t (in μs) as shown. AB, BC and CD are straight line segments. The magnitude of total impulse of force on the body from $t = 4\ \mu$s to $t = 16\ \mu$s is

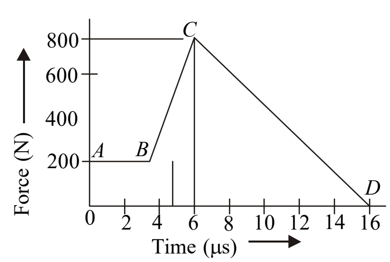


Fig. 5.102

(a) 6×10^{-3} Ns (b) 3×10^{-3} Ns

(c) 5×10^{-3} Ns (d) 6×10^{-3} Ns

(I.I.T. 1994)

68. A smooth semicircular wire track of radius R is fixed in a vertical plane. One end of a massless spring of natural length $3R/4$ is attached to the lowest point O of the wire track. A small ring of mass m which can slide on the track is attached to the other end of the spring. The ring is held stationary at point P such that the spring makes an angle 60° with the vertical. Spring constant $K = mg/R$. The spring force is

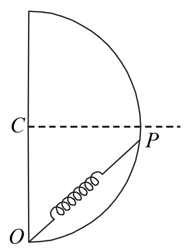


Fig. 5.103

(a) $\frac{mg}{3}$ (b) mg

(c) $\frac{mg}{2}$ (d) $\frac{mg}{4}$

(I.I.T. 1996)

69. Block A of mass m and block B of mass $2m$ are placed on a fixed triangular wedge by means of massless, inextensible string and a frictionless pulley as shown. The wedge is inclined at 45° to horizontal on both sides. The coefficient of friction between block A and wedge is 2/3 and that between block B and wedge is 1/3. If system of A and B is released from rest then acceleration of A is

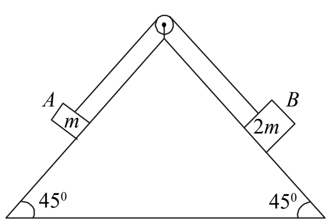


Fig. 5.104

(a) zero (b) 1 ms^{-2}

(c) 2 ms^{-2} (d) 3 ms^{-2}

(I.I.T. 1997)

70. A large heavy box is sliding without friction down a smooth plane of inclination θ. From a point P on the bottom of the box, a particle is projected inside the box. The initial speed of particle with respect to the box is u and the direction of projection makes an angle α with the bottom as shown. Find the distance along the bottom of box between the point of projection P and point Q where the particle lands. (Assume that the particle does not hit any other surface of the box. Neglect air resistance)

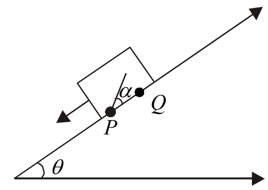


Fig. 5.105

(a) $\frac{u^2 \sin 2\alpha}{g}$ (b) $\frac{u^2 \sin^2 \alpha}{2g\cos\theta}$

(c) $\frac{u^2 \sin 2\alpha}{g\cos\theta}$ (d) $\frac{u^2 \sin\alpha}{g}$

(I.I.T. 1998)

71. A spring of force constant K is cut into two pieces such that one piece is double the length of the other. Then the long piece will have a force constant of

(a) 2/3 K (b) 3/2 K

(c) 3K (c) 6K

(I.I.T. 1999)

72. A cubical block of side L rests on a rough horizontal surface with coefficient of friction μ. A horizontal force F is applied on the block as shown. If the coefficient of friction is sufficiently high so that the block does not slide before toppling, the minimum force required to topple the block is

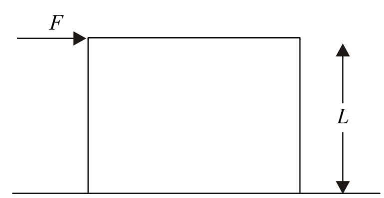


Fig. 5.106

(a) infinitesimal (b) $mg/4$

(c) $mg/2$ (d) $mg(1 - \mu)$

(I.I.T. Screening 2000)

73. An insect crawls up a hemispherical surface very slowly. The coefficient of friction between the surface and the insect is 1/3. If the line joining the centre of the hemispherical surface to the insect makes an angle α with the vertical, the maximum possible value of α is given by

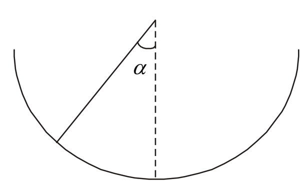


Fig. 5.107

(a) cot $\alpha = 3$ (b) tan $\alpha = 3$

(c) sec $\alpha = 3$ (d) cosec $\alpha = 3$

(I.I.T. Screening 2001)

74. A string of negligible mass going over a clamped pulley of mass m supports a block of mass M as shown in the figure. The force on the pulley by the clamp is given by

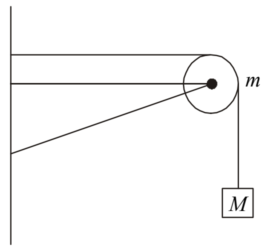


Fig. 5.108

(a) $\sqrt{2}\ Mg$ (b) $\sqrt{2}\ mg$

(c) $g\sqrt{(M+m)^2+m^2}$ (d) $g\ \sqrt{(M+m)^2+M^2}$

(I.I.T. Screening 2001)

75. The pulleys and string shown in figure are smooth and of negligible mass. For the system to remain in equilibrium, the angle θ should be

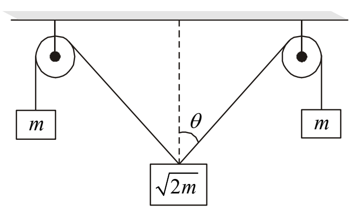


Fig. 5.109

(a) 0° (b) 30°

(c) 45° (d) 60°

(I.I.T. Screening 2001)

76. An ideal spring with spring constant k is hung from the ceiling and a block of mass M is attached to its lower end. The mass is released with the spring *initially unstretched*. Then the maximum extension in the spring is

(a) 4 Mg/k (b) 2 Mg/k

(c) Mg/k (d) $Mg/2k$

(I.I.T. Screening 2002)

77. Let F, F_N and f denote the magnitudes of the contact force, normal force and the friction exerted by one surface on the other kept in contact. If none of these is zero,

(a) $F > F_N$ (b) $F > f$

(c) $F_N > f$ (d) $F_N - f < F < F_N + f$

78. The contact force exerted by a body A on another body B is equal to the normal force between the bodies. We conclude that

(a) the surfaces must be frictionless.

(b) the force of friction between the bodies is zero.

(c) the magnitude of normal force equals that of friction.

(d) the bodies may be rough but they don't slip on each other.

79. Mark the correct statements about the friction between two bodies.

(a) Static friction is always greater than the kinetic friction.

(b) Coefficient of static friction is always greater than the coefficient of kinetic friction.

(c) Limiting friction is always greater than the kinetic friction.

(d) Limiting friction is never less than static friction.

80. A block is placed on a rough floor and a horizontal force F is applied on it. The force of friction f by the floor on the block is measured for different values of F and a graph is plotted between them.

(a) The graph is a straight line of slope 45°

(b) The graph is a straight line parallel to the F-axis.

(c) The graph is a straight line of slope 45° for small F and a straight line parallel to the F-axis for large F.

(d) There is a small kink on the graph.

81. Consider a vehicle going on a horizontal road towards east. Neglect any force by the air. The frictional forces on the vehicle by the road

(a) is towards east if the vehicle is accelerating.

(b) is zero if the vehicle is moving with a uniform velocity.

(c) must be towards east.

(d) must be towards west.

82. When Neils Bohr shook hand with Werner Heisenberg, what kind of force they exerted?

(a) Gravitational (b) Electromagnetic

(c) Nuclear (d) Weak

83. Let E, G and N represent the magnitudes of electromagnetic, gravitational and nuclear forces between two electrons at a given separation. Then

(a) N >E > G (b) E > N > G

(c) G > N > E (d) E > G > N

84. The sum of all electromagnetic forces between different particles of a system of charged particles is zero

(a) only if all the particles are positively charged.

(b) only if all the particles are negatively charged.

(c) only if half the particles are positively charged and half are negatively charged.

(d) irrespective of the signs of the charges.

85. A 60 kg man pushes a 40 kg man by a force of 60 N. The 40 kg man has pushed the other man with a force of

(a) 40 N (b) 0

(c) 60 N (d) 20 N

86. A neutron exerts a force on a proton which is

(a) gravitational (b) electromagnetic

(c) nuclear (d) weak

87. A proton exerts a force on a proton which is

(a) gravitational (b) electromagnetic

(c) nuclear (d) weak

88. Mark the correct statements:

(a) The nuclear force between two protons is always greater than the electromagnetic force between them.

(b) The electromagnetic force between two protons is always greater than the gravitational force between them.

(c) The gravitational force between two protons may be greater than the nuclear force between them.

(d) Electromagnetic force between two protons may be greater than the nuclear acting between them.

89. If all matter were made of electrically neutral particles such as neutrons,

(a) there would be no force of friction.

(b) there would be no tension in the string.

(c) it would not be possible to sit on a chair.

(d) the earth could not move around the sun.

90. Which of the following systems may be adequately described by classical physics?

(a) motion of a cricket ball.

(b) motion of a dust particle.

(c) a hydrogen atom.

(d) a neutron changing to a proton.

91. The two ends of a spring are displaced along the length of the spring. All displacements have equal magnitudes. In which case or cases the tension or compression in the spring will have a maximum magnitude?

(a) the right end is displaced towards right and the left end towards left.

(b) both ends are displaced towards right.

(c) both ends are displaced towards left.

(d) the right end is displaced towards left and the left end towards right.

92. Action and reaction

(a) act on two different objects.

(b) have equal magnitude.

(c) have opposite directions.

(d) have resultant zero.

93. A force F_1 acts on a particle so as to accelerate it from rest to a velocity v. The force F_1 is then replaced by F_2 which decelerates it to rest.

(a) F_1 must be equal to F_2 (b) F_1 may be equal to F_2

(c) F_1 must be unequal to F_2 (d) none of these

94. Two objects A and B are thrown upward simultaneously with the same speed. The mass of A is greater than the mass of B. Suppose the air exerts a constant and equal force of resistance on the two bodies.

(a) the two bodies will reach the same height.

(b) A will go higher than B.

(c) B will go higher than A.

(d) any of the above three may happen depending on the speed with which the objects are thrown.

95. A smooth wedge A is fitted in a chamber hanging from a fixed ceiling near the earth's surface. A block B placed at the top of the wedge takes a time T to slide down the length of the wedge. If the block is placed at the top of the wedge and the cable supporting the chamber is broken at the same instant, the block will

(a) take a time longer than T to slide down the wedge.

(b) take a time shorter than T to slide down the wedge.

(c) remain at the top of the wedge.

(d) jump off the wedge.

96. In an imaginary atmosphere, the air exerts a small force F on any particle in the direction of the particle's motion. A particle of mass m projected upward takes a time t_1 in reaching the maximum height and t_2 in the return journey to the original point. Then

(a) $t_1 < t_2$ (b) $t_1 > t_2$

(c) $t_1 = t_2$

(d) the relation between t_1 and t_2 depends on the mass of the particle.

97. A person standing on the floor of an elevator drops a coin. The coin reaches the floor of the elevator in a time t_1 if the elevator is stationary and in time t_2 if it is moving uniformly. Then

(a) $t_1 = t_2$ (b) $t_1 < t_2$

(c) $t_1 > t_2$

(d) $t_1 < t_2$ or $t_1 > t_2$ depending on whether the lift is going up or down.

98. A free ^{238}U nucleus kept in a train emits an alpha particle. When the train is stationary, a nucleus decays and a passenger measures that the separation between the alpha particle and the recoiling nucleus becomes x at time t after the decay. If the decay takes place while the train is moving at a uniform velocity v, the distance between the alpha particle and the recoiling nucleus at a time t after the decay as measured by the passenger is

(a) $x + vt$ (b) $x - vt$

(c) x

(d) depends on the direction of the train.

99. A reference frame attached to the earth

(a) is an inertial frame by definition.

(b) cannot be an inertial frame because the earth is revolving around the sun.

(c) is an inertial frame because Newton's laws are applicable in this frame.

(d) cannot be an inertial frame because the earth is rotating about its axis.

100. A particle stays at rest as seen in a frame. We can conclude that

(a) the frame is inertial.

(b) resultant force on the particle is zero.

(c) the frame may be inertial but the resultant force on the particle is zero.

(d) the frame may be noninertial but there is a nonzero resultant force.

101. A particle is found to be at rest when seen from a frame S_1 and moving with a constant velocity when seen from another frame S_2. Mark out the possible options.

(a) Both the frames are inertial.

(b) Both the frames are noninertial.

(c) S_1 is inertial and S_2 is noninertial.

(d) S_1 is noninertial and S_1 is inertial.

102. Figure shows the displacement of a particle going along the X-axis as a function of time. The force acting on the particle is zero in the region

(a) AB (b) BC

(c) CD (d) DE

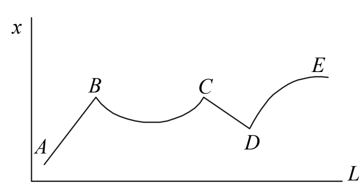


Fig. 5.110

103. Figure shows a heavy block kept on a frictionless surface and being pulled by two ropes of equal mass m. At $t = 0$, the force on the left rope is withdrawn but the force on the right end continues to act. Let F_1 and F_2 be the magnitudes of the forces by the right rope and the left rope on the block respectively.

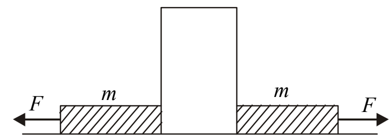


Fig. 5.111

(a) $F_1 = F_2 = F$ for $t < 0$

(b) $F_1 = F_2 = F + mg$ for $t < 0$

(c) $F_1 = F, F_2 = F$ for $t > 0$

(d) $F_1 < F$, $F_2 = F$ for $t > 0$.

104. A monkey of mass 20 kg is holding a vertical rope. The rope can break when a mass of 25 kg is suspended from it. What is the maximum acceleration with which the monkey can climb up along the rope?

(a) 7 ms^{-2} (b) 10 ms^{-2}

(c) 5 ms^{-2} (d) 2.5 ms^{-5}

105. A force of 5 Newton acts on a body of weight 9.8 Newton. What is the acceleration produced in ms^{-2}?

(a) 0.51 (b) 1.46

(c) 49.00 (d) 5.00

106. A body of mass m is released from the top of a rough inclined plane of length l. If the frictional force is f then the velocity of the body of the bottom in ms^{-1} will be

(a) $\sqrt{\frac{2}{m}(mgh - l)}$ (b) $2\,gh - f/l$

(c) $\sqrt{\frac{2}{m}\ gh}$ (d) zero

107. A block of mass 2 kg is lying on a floor.The coefficient of static friction is 0.54. What will be the value of frictional force if the force is 2.8 N and $g = 10\ ms^{-2}$

(a) zero (b) 2 N

(c) 2.8 N (d) 8 N

108. A cube weighing 10 N is lying on a rough inclined plane of slope 3 in 5. The coefficient of friction between the plane and the cube is 0.6. The force necessary to move the cube up the plane will be

(a) 6.4 N (b) 10.8 N

(c) 21.6 N (d) 108 N

109. A block of metal is lying on the floor of a bus. The maximum acceleratin which can be given to the bus so that the block may remain at rest, will be

(a) μg^2 (b) $\mu^2 g$
(c) μg (d) μ/g

110. A body of weight w is lying at rest on a rough horizontal surface. If the angle of friction is θ, then the minimum force required to move the body along the surface will be

(a) $w \cos\theta$ (b) $w \tan\theta$
(c) $w \sin\theta$ (d) $w \cot\theta$

111. A block of mass 0.5 kg. rests against a wall exerting a horizontal force of 10 N on the wall. If the coefficient of friction between the wall and the block is 0.5 then the frictional force acting on the block will be

(a) 49.9 N (b) 9.8 N
(c) 4.90 N (d) 0.49 N

112. A rope of length l is pulled with a constant force f. T is the tension in the rope at a point distant x from the end where the force is applied. Then T is

(a) $f(l-x)/l$ (b) $fl/(l-x)$
(c) $\dfrac{(f-x)}{l-x}$ (d) $\dfrac{fl}{x}$

113. Two masses m_1 asnd m_2 are attached to a string which pass over a frictionless fixed pully. Given that $m_1 = 10$ kg asnd $m_2 = 6$ kg and $g = 10\ ms^{-2}$. What is the acceleration of the masses?

(a) 2.5 ms^{-2} (b) 5 ms^{-2}
(c) 20 ms^{-2} (d) 40 ms^{-2}

114. A block is lying on the table. What is the angle between the action of the block on the table and the reaction of the table on the block?

(a) 180° (b) 90°
(c) 45° (d) 0°

115. A parachutist of weight w strikes the ground with his legs fixed and comes to rest with an upward acceleration of magnitude 3 kg. Force exerted on him by ground during landing is

(a) 4 w (b) 3 w
(c) 2 w (d) w

116. The force that prevents the relative motion between the layers of a liquid is called

(a) static friction (b) sliding friction
(c) contact friction (d) none of these

117. Gravels are dropped on a conveyer belt at the rate of 0.5 kgs^{-1}. The extra force required in newtons to keep the belt moving at 2 $ms^{-1}$is

(a) 0.5 (b) 1
(c) 2 (d) 4

118. Starting from rest, a body slides down a 45° inclined plane in twice the time it takes to slide down the same distance in the absence of friction. The coefficient of friction between the body and the inclined plane is

(a) 0.25 (b) 0.33
(c) 0.75 (d) 0.80

119. When we walk once, we should take small steps to avoid slipping. This is because smaller steps ensure

(a) larger friction (b) smaller friction
(c) larger normal force (d) smaller normal force

120. A chain of length L and mass m is allowed to fall on a table such that the part falling on the table comes to rest instantaneously. The force acting on the table when l part of it has lied on the table is

(a) $\dfrac{3mlg}{L}$ (b) $\dfrac{2mlg}{L}$
(c) $\dfrac{mlg}{L}$ (d) $\dfrac{3mlg}{2L}$

121. Two balls of mass 1kg and 2 kg respectively are connected to the two ends of the spring. The two balls are pressed together and placed on a smooth table. When released, the lighter ball moves with an acceleration of 2 ms^{-2}. The acceleration of the heavier ball will be

(a) 0.2 ms^{-2} (b) 1 ms^{-2}
(c) 2 ms^{-2} (d) 4 ms^{-2}

122. A fireman wants to slide down a rope. The breaking load for the rope is 3/4th of the weight of the man. With what minimum acceleration should the fireman slide down? Acceleration due to gravity is g.

(a) zero (b) $\dfrac{g}{4}$
(c) $\dfrac{3g}{4}$ (d) $\dfrac{g}{2}$

123. A rain drop of mass 0.1g is falling with uniform speed of 10 cm^{-1}. What is the net weight of the drop?

(a) 10^{-2} N (b) 10^{-3} N
(c) 2×10^{-3} N (d) zero

124. A heavy unifrom bar is being carried by two men on their shoulders. The weight of the bar is w. If one man lets it fall from the end carried by him, what will be the weight experienced by the other?

(a) none of these (b) $w/4$
(c) $w/2$ (d) w

125. The coefficient of friction of an inclined plane is $1/\sqrt{3}$. If it is inclined at angle 30° with the horizontal. What will be the downward acceleration of the block placed on the inclined plane?

(a) 0 (b) $\sqrt{2}$ ms^{-2}

(c) $\sqrt{3}$ ms^{-2} (d) 3 ms^{-2}

126. A body is projected upwards with a kinetic energy of 100 J. Taking the friction of air into account, when it returns on earth, its kinetic energy will be

(a) more than 100 J (b) less than 100 J

(c) 100 J (d) none of these

127. Which of the following is a self adjusted force?

(a) sliding friction (b) static friction

(c) limiting friction (d) dynamic friction

128. A body is placed over an inclined plane of angle $\pi - \theta$. The angle between normal reaction and the weight of the body is

(a) equal to the angle of friction (b) more than θ

(c) less than θ (d) θ

129. The frictional force due to air on a body of mass 0.25 kg falling with an accelerationof 9.2 ms^{-1} will be

(a) 0.15 N (b) 1.5 N

(c) 15 N (d) zero

130. If a rough surface is polished beyond a certain limit than the magnitude of frictional force will

(a) nothing can be said

(b) some time increases and some time decreases

(c) increase

(d) decrease

131. A car is moving on a straight horizontal road with a speed of 72 kmh–1. If the coefficient of static friction between the tyre of the car and the road is 0.5, then the minimum distance, within which the car can be stopped will be

(a) 72 m (b) 40 m

(c) 30 m (d) 20 m

132. When we kick a stone, we get hurt. Due to which one of the following properties does it happens?

(a) velocity (b) momentum

(c) inertia (d) reaction

133. A cricket player catches a ball of mass 100 g and moving with a velocity of 25 ms^{-1}. If the ball is caught 0.1*s*, the force of the blow exerted on the hand of the player is

(a) 4 N (b) 40 N

(c) 25 N (d) 250 N

PASSAGE 1

Read the following passage and answer the questions given at the end.

Suppose that you were called upon to give some advice to a lawyer concerning the physics involved in one of his cases. The policeman has charged a driver for breaking speed limit of 60 km/h and had arrested him. The length of the skid marks are 15 m when he made an emergency stop with brakes locked. The policeman had made a reasonable assumption that the maximum deceleration of the car could not exceed *g*.

1. Is the policeman right in arresting the driver to break speed limit?

(a) Yes (b) No

(c) insufficient data to reply

(d) the policeman demanded bribe

2. Can deceleration of car exceed '*g*'?

(a) Yes (b) No

(c) depends upon friction coefficient

(d) none

Solution

1. (a) Since the deceleration will be due to friction. Frictional force $F_f = \mu N$. Assuming level road $F_f = \mu Mg$ or $a = \mu g$. Since $\mu \le 1$

$\therefore$ deceleration normally cannot exceed *g*.

Distance covered by speeding car due to skidding *s*

$$= \frac{v^2}{2a} = \frac{v^2}{2\mu g}$$

$$= \frac{\left(50/3\right)^2}{2\times 10} = 14 \text{ m.}$$

2. (b) $a > g$ if $\mu > 1$ which occurs only in extreme cases.

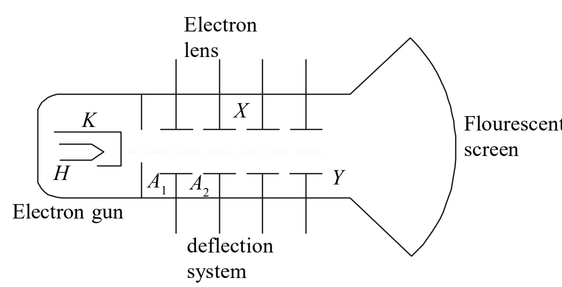


Fig. 5.112

PASSAGE 2

Read the following passage and answer the questions given at the end.

In a cathode ray tube as shown in fig. 5.136 electrons are emitted by heating the cathode and focussed using focussing system on the flourescent screen. *B* is the magnetic field applied. *E* is the electric field acting. The electrons go undeviated when both electric and magnetic fields are applied. Under this condition a voltage is applied on *y* plates and the spot shifts down by 2 cm. The separation between deflection plates and screen is 20 cm and separation between y-plates is 2 cm. $B = 2\ mT$ and $E = 2.0\ kV\ m^{-1}$

1. What voltage on y-plate will give such a deflection.

(a) 0.11 V (b) 1.1 V

(c) 11 V (d) none

2. If cathode has potential –200 V, what should be the potential on A_2.

(a) +300 V (b) +500 V

(c) –100 V (d) –200 V

3. The path with which electron travels from y plate to screen is

(a) parabolic (b) hyperbolic

(c) circular (d) straightline

(e) helix

Solution

1. (a) $y = \frac{1}{2}\frac{eE}{m}t^2$

or $2 \times 10^{-2} = \frac{1}{2} \times \frac{1.6\times10^{-19} V \times 10^{-14} \times 4}{9\times10^{-31}\times2\times10^{-2}}$

$$t = \frac{0.2}{E/B} = 10^{-7} s$$

2. (c) $V_{A2} < V_{cathode}$, so that electrons are replaced.

3. (a) as horizontal velocity is constant and vertically electric force acts.

PASSAGE 3

Read the following passage and answer the questions given at the end.

An adventurous archaeologist crosses between two rock cliffs by slowly going hand-over-hand along a rope stretched between the cliffs. He stops to rest at the middle of the rope as shown in Fig. The rope will break if the tension in it exceeds 2.5×10^4 N. The mass of the archeaologist is 90 kg. The rope makes an angle $\phi = 10°$

[sin 10 = .1736; cos 10 = .9848]

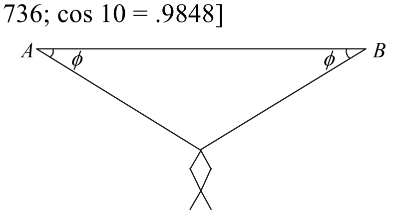


Fig. 5.113

1. Find the tension in the rope.

(a) 3210 N (b) 2970 N

(c) 2867 N (d) 2580 N

2. What should be minimum value of θ so that rope does not break?

(a) 1° (b) 2°

(c) 1.5° (d) 2.2°

Solution

1(d) $2\,T \sin\phi = \text{Mg}$

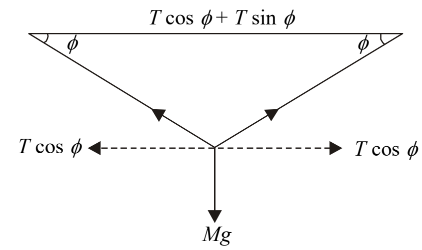


Fig. 5.113

$$T = \frac{Mg}{2\sin\phi} = \frac{900}{2\sin 10}$$

$$T = \frac{450}{0.1736} = 2580\,\text{N}$$

2(a) $\sin\phi = \frac{Mg}{2T} = \frac{900}{2\times25000} = .018$

or $\phi = 1°$

PASSAGE 4

Read the following passage and answer the questions given at the end.

A man is working for a shipping company. His job is to stand at the bottom of a 8 m long ramp that is inclined at 37^0 above the horizontal. He grabs packages off conveyer belt and propel them up the ramp. The coefficient of static friction is 0.5 and coefficient of kinetic friction is 0.3 between the packages and the ramp. His coworker is a lady whose job is to grab the packages as they arrive the top of the ramp with zero velocity. She misses one and it slides down back and reaches back to the man.

1. Find the speed with which man should push the package?

(a) 15.4 ms^{-1} (b) 14.3 ms^{-1}

(c) 12.8 ms^{-1} (d) 11.6 ms^{-1}

2. With what speed the package returns back to the man?

(a) 5.5 ms^{-1} (b) 7.3 ms^{-1}

(c) 11.6 ms^{-1} (d) 8.4 ms^{-1}

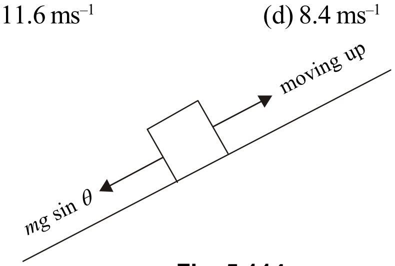


Fig. 5.114

Solution

1(d) deceleration $a = (g\sin\theta + \mu g\cos\theta)$

$$v = \sqrt{2as} = \sqrt{2(g\sin\theta+\mu g\cos\theta)8}$$

$$= \sqrt{2\times10(.6+.3\times8)8}$$

$$v = \sqrt{16\times8.4} = 4(2.9) = 11.6\ \text{ms}^{-1}$$

2(b) $$v = \sqrt{2(g\sin\theta-\mu g\cos\theta)S}$$

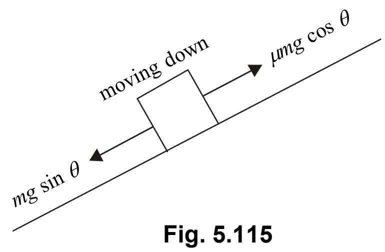


Fig. 5.115

$$= \sqrt{2\times10(.6-.3\times.8)8} = \sqrt{16\times3.4}$$

$$= 7.3\ \text{ms}^{-1}$$

Answers to Questions for Practice

1.	(d)	2.	(a)	3.	(d)	4.	(d)	5.	(c)	6.	(b)	7.	(c)
8.	(a)	9.	(b)	10.	(c)	11.	(c)	12.	(a)	13.	(b)	14.	(b)
15.	(a)	16.	(c)	17.	(a)	18.	(d)	19.	(d)	20.	(d)	21.	(b)
22.	(a)	23.	(a)	24.	(c)	25.	(a)	26.	(b)	27.	(a)	28.	(d)
29.	(c)	30.	(b)	31.	(a)	32.	(c)	33.	(d)	34.	(a)	35.	(a)
36.	(c)	37.	(c)	38.	(d)	39.	(b)	40.	(c)	41.	(a)	42.	(a)
43.	(c)	44.	(a)	45.	(d)	46.	(a)	47.	(a)	48.	(d)	49.	(b)
50.	(c)	51.	(b)	52.	(c)	53.	(d)	54.	(a)	55.	(b)	56.	(c)
57.	(c)	58.	(a)	59.	(b)	60.	(d)	61.	(a)	62.	(b)	63.	(c)
64.	(c)	65.	(b)	66.	(a)	67.	(c)	68.	(d)	69.	(a)	70.	(c)
71.	(b)	72.	(c)	73.	(a)	74.	(d)	75.	(c)	76.	(b)	77.	(a,b,d)
78.	(b,d)	79.	(b,c,d)	80.	(c,d)	81.	(a,b)	82.	(b)	83.	(d)	84.	(d)
85.	(c)	86.	(a,c)	87.	(a,b,c)	88.	(b,c,d)	89.	(a,b,c)	90.	(a, b)	91.	(a, d)
92.	(a,b,c,d)	93.	(b)	94.	(b)	95.	(c)	96.	(b)	97.	(a)	98.	(c)
99.	(b,d)	100.	(c,d)	101.	(a, b)	102.	(a,c)	103.	(a)	104.	(d)	105.	(d)
106.	(a)	107.	(c)	108.	(b)	109.	(c)	110.	(b)	111.	(c)	112.	(a)
113.	(a)	114.	(a)	115.	(a)	116.	(d)	117.	(d)	118.	(c)	119.	(b)
120.	(a)	121.	(b)	122.	(b)	123.	(d)	124.	(a)	125.	(a)	126.	(b)
127.	(b)	128.	(d)	129.	(a)	130.	(c)	131.	(b)	132.	(d)	133.	(c)

EXPLANATION

8. (a) If N_1 and N_2 are the normal reactions at one foot and the other foot, then

$N_1 + N_2 = mg$ ... (i)

For equilibrium,

$(ma)\,H = dN_1 - dN_2 = d\,(N_1 - N_2)$

(taking moments about centre of mass)

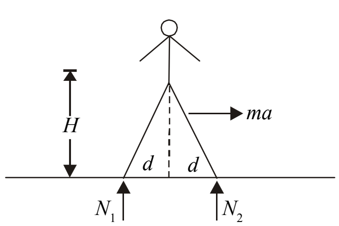


Fig. 5.116

or $$N_1 - N_2 = (ma)\frac{H}{d} \quad \text{... (ii)}$$

From (i) and (ii)

$$2N_1 = mg + ma\frac{H}{d} = m\left(g+\frac{aH}{d}\right)$$

or $$N_1 = \frac{m}{2}\left(g+\frac{aH}{d}\right)$$

and $$N_2 = \frac{m}{2}\left(g-\frac{aH}{d}\right)$$

9. (b) The maximum force of friction,

$$f_{\max} = \mu mg$$

or $\quad a_{max} = \dfrac{f_{max}}{m} = mg$

or $\quad m = \dfrac{a_{max}}{g}$

Taking a less than a_{max}, friction f is also less than f_{max}. Here, if the value of $\mu > a/g$ then $f \neq \mu mg$ rather $f = ma$.

10. (c) Tension in the spring is actually the centripetal force given by $mr\omega^2$ *i.e.*, $mr\,(2\pi v)^2$.

11. (c) Let F be applied at origin from figure

$$F = 2\,T\cos\theta$$

or $\quad T = \dfrac{F}{2\cos\theta}$

Then force causing motion is given by T

$$T\sin\theta = \left(\frac{F}{2\cos\theta}\right)\sin\theta$$

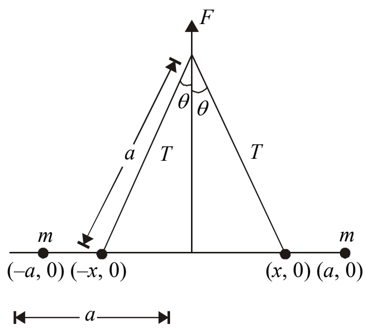


Fig. 5.117

$$= \frac{F}{2}\tan\theta = \frac{F}{2}\,\frac{x}{\sqrt{a^2 - x^2}}$$

$$\therefore \text{ acceleration} = \frac{F}{2m}\cdot\frac{x}{\sqrt{a^2 - x^2}}$$

12. (a) Here $m_2g - T_2 = m_2\,a$, —— (1)

and $T_1 - m_1g = m_1a$ —— (2)

Also $(T_1 + f) - T_2 = 0$ —— (3)

($\because$ tension below the slit is T_2 and above the slit is T_1).

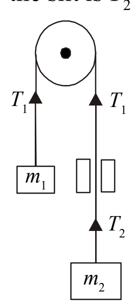


Fig. 5.118

Solving the above equations,

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

13. (b) The particle is displaced from mean position and then released, i.e., at t = 0, the tension is minimum because the particle is at the extreme position where the tension has to balance only the radial component of the weight of the particle. Tension is maximum at mean position because it has to provide the weight as well as centripetal force also.

14. (b) The force on mass m_1 is

$F_1 = m_1a$ and force on m_2 is, $F_2 = m_2a'$

but $F = F_1 + F_2 = m_1a + m_2a'$

$$\therefore a' = \frac{F - m_1a}{m_2}$$

15. (a) Here, $20 \times 9.8 = \dfrac{m\upsilon^2}{r} = 20 \times 9.8$

or $\quad \upsilon = \sqrt{20 \times 9.8} = 14\text{ ms}^{-1}$

16. (c) Let a be the acceleration down the rough plane and a' be the acceleration down the frictionless plane. Taking L as the length of the inclined plane, we get

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

$$= g\left(\frac{1}{\sqrt{2}} - \frac{\mu}{\sqrt{2}}\right) \quad (\because\ \theta = 45°)$$

and $\quad a' = g\sin\theta = g\,\dfrac{1}{\sqrt{2}}$

Then $L = \dfrac{1}{2}\,at_1^2 = \dfrac{1}{2}\,a'\,t_2^2$

or $\quad \dfrac{1}{2}\,g\left(\dfrac{1}{\sqrt{2}} - \dfrac{\mu}{\sqrt{2}}\right)t_1^2 = \dfrac{1}{2}\,\dfrac{g}{\sqrt{2}}\,t_2^2$

But $t_1 = nt_2$ (given)

$$\therefore \frac{1}{2}\,g\left(\frac{1}{\sqrt{2}} - \frac{\mu}{\sqrt{2}}\right)n^2\,t_2^2 = \frac{1}{2}\,\frac{g}{\sqrt{2}}\,t_2^2$$

or $\quad 1 = (1 - \mu)\,n^2$ or $\mu = \left(1 - \dfrac{1}{n^2}\right)$

17. (a) The masses will be lifted if the tension of the string is greater than the gravitational pull on masses.

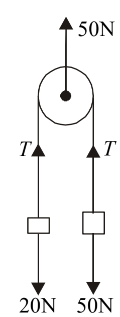


Fig. 5.119

Weight of 5 kg mass = 5 × 10 = 50 N and 2 kg mass = 2 × 10 = 20 N

From free body diagram

$50 - 2T = 0$ or $T = 25$ N

So 5 kg weight can not be lifted ($\because$ acceleration = 0) but 2 kg weight will be lifted.

$\therefore\ 25 - 20 = 2a$ or $a = \frac{5}{2} = 2.5\ \text{ms}^{-2}$

18. (d) Planes PQ and QR are frictionless and impact is neglected, so mechanical energy will conserve,

$\therefore\ h' = h$

19. (d) Radius of horizontal circle of ball

$= (L + L\sin\theta)$

$\therefore$ C.P. Acceleration $= (L + L\sin\theta)\,\omega^2 \quad (\because\ a = r\omega^2)$

Here $mg = T\cos\theta$ ... (i)

and $m\omega^2 (L + L\sin\theta) = T\sin\theta$ ... (ii)

Dividing (ii) by (i)

$$\tan\theta = \frac{\omega^2 (L + L\sin\theta)}{g}$$

or
$$\omega^2 = \frac{g\tan\theta}{L(1+\sin\theta)}$$

20. (d) $T_{max} = \frac{m\upsilon_l^2}{L} + mg$

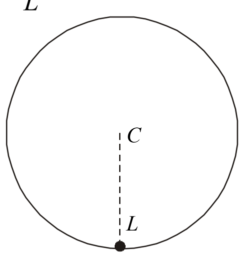


Fig. 5.120

and
$$T_{min} = \frac{m\upsilon_h^2}{L} - mg$$

Then
$$\frac{T_{max}}{T_{min}} = \frac{\frac{m\upsilon_l^2}{L} + mg}{\frac{m\upsilon_h^2}{L} - mg}$$

$$= \frac{\upsilon_l^2 + gL}{\upsilon_h^2 - gL} \quad \text{... (i)}$$

Using $\upsilon^2 - u^2 = 2aS$, we get

$$\upsilon_h^2 - \upsilon_l^2 = -2g(2L) = -4gL$$

or
$$\upsilon_l^2 = \upsilon_h^2 + 4gL$$

Then from (i) $\frac{T_{max}}{T_{min}} = \frac{\upsilon_h^2 + 4gL + gL}{\upsilon_l^2 - gL}$

or
$$4 = \frac{\upsilon_h^2 + 5\times10\times\frac{10}{3}}{\upsilon_h^2 - 10\times\frac{10}{3}}$$

or $3\upsilon_h^2 = 300 =$ or $\upsilon_h = 10\ \text{ms}^{-1}$

21. (b) For equilibrium, the forces exerted by both walls on the man should be equal so as the horizontal forces may balance but the vertical forces can be balanced even if the forces of friction on the two walls are unequal.

22. (a), Here, reacting force = relative velocity × $\frac{\text{mass}}{\text{time}}$

$$= 500 \times \left(\frac{10\times10}{1000}\right) = 50\ \text{N}$$

(*taking time = 1 s*)

Using $F = ma$, we get

$$a = \frac{F}{m} = \frac{50}{200} = 0.25\ \text{ms}^{-2}$$

23. (a) Considering free body diagram,

$mg - T = ma$ (*for hanging mass*)

and $T = ma$

(for mass lying on surface)

Adding $mg = (m + m)\,a$

or $a = \frac{mg}{2m}$

$\therefore\ a = \frac{g}{2} = \frac{10}{2} = 5\ \text{ms}^{-1}$

and $T = 1 \times 5 = 5$ N

24. (c) Limiting frictional force = μmg

$= 0.25 \times 2 \times 10 = 5$ N

So the block and trolley will not have relative motion for a force of 2N.

Here, $2 = (20 + 2)\,a$

or $a = \frac{2}{22} = \frac{1}{11} = 0.09\ \text{ms}^{-2}$

Then frictional force

= 20 × 0.09 = 1.8 N

25. (a) On cutting of string QR, the resultant force of m_1 remains zero because its weight $m_1 g$ is balanced by the tension in the spring but on block m_2 a resultant upward force $(m_1 - m_2)\,g$ is developed. This block m_1 will have no resultant acceleration whereas m_2 does have an upward acceleration given by $\dfrac{(m_1 - m_2)g}{m_2}$.

26. (b) Here $T_1 - T_2 = 6a$,

$T_2 - 1g = 1a$ and $3g - T_1 = 3a$

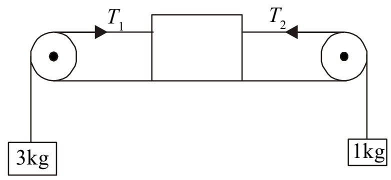


Fig. 5.121

Addition of the above three equations give

$10a = 3g - 1g = 2g$

or $a = \dfrac{2}{10}\,g = \dfrac{2}{10} \times 10 = 2\ \text{ms}^{-2}$

27. (a) Let a_x, a_y and a_r be the net leftward horizontal acceleration of bead, net downward vertical acceleration of bead and relative acceleration of bead with reference to rod respectively. Then

$a_y = a_r \cos\theta + a$

and $a_x = a_r \sin\theta$

Projecting forces vertically and horizontally

$mg - N\cos\theta = ma_r \sin\theta$ ... (i)

and $N\sin\theta = m\,(a_r \cos\theta + a)$ ... (ii)

From (i) and (ii)

$mg\sin\theta = ma_r + ma\cos\theta$

i.e., $a_r = g\sin\theta - a\cos\theta$

28. (d) Velocity of block at time t is given by $\upsilon = \upsilon_0 - \mu gt$, where υ_0 is initial velocity and μ is the coefficient of friction. Thus, $\upsilon - t$ graph is a straight line having negative slope and a positive intercept on υ axis. $s - t$ curve will be having a decreasing slope till it reduces to zero because velocity of block decreases continuously and remains positive till the block comes to rest position.

29. (c) Let there be a small element of length dl at a distance L from the end of rotational axis.

Mass of the element $dl = \dfrac{M}{L}\ dl$

Small radial force on this element

$= \left(\dfrac{M}{L}dl\right) l\omega^2$

$\therefore$ Total force $= \displaystyle\int_0^L \left(\frac{M}{L}dl\right) l\omega^2$

$= \dfrac{M}{L}\ \omega^2 \displaystyle\int_0^L l\,dl\ = \dfrac{ML\omega^2}{2}$

30. (b) Consider the man and the child to be simple masses hung from two ends of a string passing over pulley. Being a system, the man and child both have same magnitude of acceleration but opposite directions.

31. (a) Instantaneous acceleration,

$$a = \frac{d\upsilon}{dt} = \frac{\text{Constant force}}{\text{Instantaneous mass}}$$

or $a = \dfrac{F}{M - mt}$

($\because$ rate of fall of sand per second is m)

32. (c) Using $\upsilon^2 - u^2 = 2aS$ we get

$\upsilon^2 - u^2 = 2\,(-g)\,H$

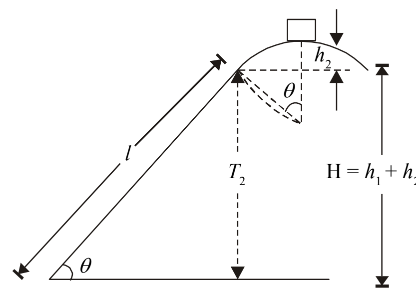


Fig. 5.122

i.e., $-u^2 = 2\,(-g)\,(h_1 + h_2)$

but $h_1 = l\sin\theta$

and $h_2 = R\,(1 - \cos\theta)$

$\therefore\ u^2 = 2g\,(l\sin\theta + R\,(1 - \cos\theta))$

or $u = [2g\,\{l\sin\theta + R\,(1 - \cos\theta)\}]^{1/2}$

33. (d) Relative velocity of monkeys

$= \upsilon + 2\upsilon = 3\upsilon$

Total distance covered $= \dfrac{l}{2} + \dfrac{l}{2} = l$

$\therefore$ time taken by each monkey $= \dfrac{l}{3\upsilon}$

34. (a) Here $m_1 g - T = m_1 a_1$

(*taking* a_1 *as downward acceleration of* m_1)

$2T - m_2 g = m_2 a_2$

(taking a_2 as upward acceleration of m_2)

and $2T - T = 0$ ($\because$ *mass of pulley is zero*)

Thus, $T = 0\ \ \therefore\ a_1 = a_2 = g$

Thus, the masses will have free fall.

Clearly pulley B rotates clockwise and the other pulleys in anticlockwise direction.

35. (a) At highest point $\upsilon = \sqrt{Rg}$ and radial acceleration, a_r

$$= \frac{\upsilon^2}{R} = \frac{Rg}{R} = g$$

Thus, the weighing machine will not record the weight of the man.

At lowest point, the boy has a resultant force equal to mg acting upward so the normal reaction has to balance the weight of the boy mg and also to provide net upward force also. Hence, the machine will record double the weight of the boy.

36. (C) Here $a_r = \frac{\upsilon^2}{l} = \frac{(\sqrt{2g(l\cos\alpha)})^2}{l}$

$$= \frac{2gl\cos\alpha}{l} = 2g\cos\alpha$$

and $\tan\alpha = \frac{a_r \sin 90°}{a_t + a_r \cos 90°} = \frac{2g\cos\alpha}{g\sin\alpha}$

($\because$ $a_t = g\sin\alpha$)

$$= \frac{2}{\tan\alpha}$$

i.e., $\tan^2\alpha = 2$ or $\sec^2\alpha = 3$

or $\cos\alpha = \frac{1}{\sqrt{3}}$

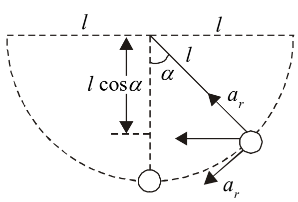


Fig. 5.123

or $\alpha = \cos^{-1}\left(\frac{1}{\sqrt{3}}\right)$

37. (c) $\cos\alpha = \frac{W}{OA}$ or $OA = \frac{W}{\cos\alpha}$

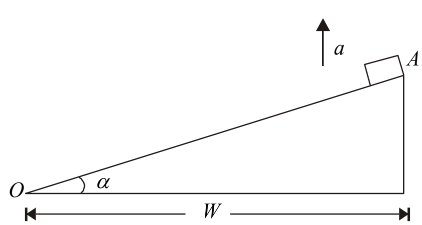


Fig. 5.124

Also $OA = \frac{1}{2}(g+a)\sin\alpha\, t^2$

$\left(\text{by using } S = ut + \frac{1}{2}at^2\right)$

$$\therefore \frac{W}{\cos\alpha} = \frac{1}{2}(g+a)\sin\alpha\, t^2$$

$$t = \left[\frac{2W}{\cos\alpha(g+a)\sin\alpha}\right]^{\frac{1}{2}}$$

$$= \left[\frac{4W}{(2\cos\alpha\sin\alpha)(g+a)}\right]^{1/2}$$

$$= \left[\frac{4W}{(g+a)\sin 2\alpha}\right]^{1/2}$$

38. (d) Here spring force = centripetal force

$\therefore$ $kx = m(l+x)\omega^2$ (*where x is the extension in the length of the spring*)

i.e., $x = \frac{ml\omega^2}{k - m\omega^2}$

39. (b) The force of 100 N acts on both the boats

$\therefore$ $250\, a_1 = 100$ and $500\, a_2 = 100$

or $a_1 = 0.4 \text{ ms}^{-2}$

and $a_2 = 0.2 \text{ ms}^{-2}$

Then relative acceleration

$= a_1 + a_2 = 0.6 \text{ ms}^{-2}$

Using $S = ut + 1/2\, at^2$, we get

$100 = (1/2) \times 0.6 \times t^2$

or $t = 18.3$ s.

40. (c) The centripetal force is provided by the hanging weight *i.e.*,

$Ml\,\omega^2 = mg$

or $m = \frac{Ml\omega^2}{g}$

41. (a) If T is the upward thrust on parachute, then

$ma = mg - T$ ... (i)

Let m' be the mass to be released, then

$T - (m - m')g = (m - m')a$ ... (ii)

Adding (i) and (ii)

$m'g = 2ma - m'a$

or $m' = \frac{2ma}{a+g}$

42. (a) The two blocks move with same acceleration till force of friction between them is not reaching the limiting value. After reaching this value, acceleration of B becomes constant but acceleration of A continues to increase at faster rate.

43. (c) Let the weight W be placed on the nearer edge.

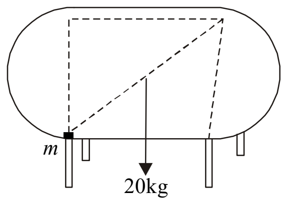


Fig. 5.125

Distance between two adjacent legs,

$d = \sqrt{2} \times 1 = \sqrt{2} \times 1 = \sqrt{2}$ m

Then $mg \times 1 = (20\,g + mg) \times \dfrac{\sqrt{2}}{2}$

or $\quad mg = \dfrac{20g}{\sqrt{2}-1}$

$\quad = 20(\sqrt{2}+1)\,g$

or $\quad mg = 48.3\,g$ kg

or $\quad m = 48.3$ kg

44. (a) Let m_b be the mass of board and m be the mass placed at one end of the board.

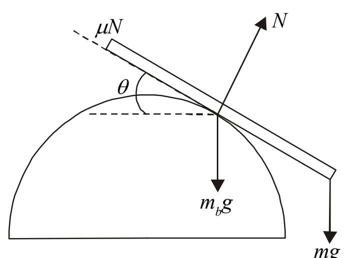


Fig. 5.126

Then for equilibrium

$\mu N \cos\theta = N \sin\theta$

i.e., $\mu = \tan\theta$

45. (d) Before accelerating, tension at rope B is $T = \dfrac{1}{2} \times$ tension at rope $A = \dfrac{T_A}{2}$.

Just after acceleration, total tension in rope B is given by $T_{\text{total}} = \dfrac{T_A}{2} + ma$

46. (a) force of resistance, $f = -c\upsilon^2$

i.e., $m\dfrac{d\upsilon}{dt} = -c\upsilon^2$ *i.e.,* $\dfrac{md\upsilon}{\upsilon^2}$

i.e., $\displaystyle\int_u^\upsilon \frac{d\upsilon}{\upsilon^2} = \int_0^t \frac{-c}{m}dt$

i.e., $t = \left(\dfrac{u-\upsilon}{u\upsilon}\right)\dfrac{m}{c} \quad$ ... (i)

Also $m\dfrac{d\upsilon}{dt}\,ds = -k\upsilon^2\,ds$

i.e. $m\upsilon\,d\upsilon = -k\upsilon^2\,ds$

i.e. $md\upsilon = -k\upsilon ds$

i.e. $\displaystyle\int_u^\upsilon m\frac{d\upsilon}{\upsilon} = -c\int_0^d ds$

i.e. $\log_e \dfrac{\upsilon}{u} = -\dfrac{cd}{m}$ i.e. $\log_e \dfrac{u}{\upsilon} = \dfrac{cd}{m}$

i.e. $d = \dfrac{m}{c}\log_e \dfrac{u}{\upsilon} \quad$ ... (ii)

From (i) and (ii) $t = \dfrac{d(u-\upsilon)}{u\upsilon\left(\log_e \dfrac{u}{\upsilon}\right)}$

47. (a) $\dfrac{md\upsilon}{dt} + u_{\text{rel}}\dfrac{dm}{dt} = 0$

or $\quad \dfrac{md\upsilon}{dt} = -u_{\text{rel}}\dfrac{dm}{dt}$

i.e., $d\upsilon = -u_{\text{rel}}\dfrac{dm}{m}$

i.e., $\upsilon = -u_{\text{rel}}\displaystyle\int_m^{m'}\frac{dm}{m} = -u_{\text{rel}}\log_e\frac{m'}{m}$

$= u_{\text{rel}}\log_e \dfrac{m}{m'}$

48. (d) For hanging part,

$mgh - T = mha \quad$ ... (i)

and for part in tube,

$T = mxa \quad$ ... (ii)

Adding the above equations, we get

$mgh = m(h+x)\,a$

or $\quad a = \dfrac{gh}{h+x}$ or $\dfrac{d\upsilon}{dt} = \dfrac{gh}{h+x}$

or $\quad \dfrac{d\upsilon}{dx}\dfrac{dx}{dt} = \dfrac{gh}{h+x}$ or $\dfrac{\upsilon d\upsilon}{dx} = \dfrac{gh}{h+x}$

or $\quad \upsilon d\upsilon = \dfrac{gh}{h+x}\, dx$

$\therefore \displaystyle\int_0^{\upsilon} \upsilon d\upsilon = \int_0^{l-h} \frac{gh}{h+x} dx$

i.e., $\upsilon = \left[2gh \log_e \dfrac{1}{h}\right]^{1/2}$

49. (b) Let x be the distance moved by the block when cylinder moves from top to the bottom.

Here $(M + m)\, x = m\, (R - r)$

or $\quad x = \dfrac{m(R-r)}{M+m}$

50. (c) acceleration of mass m is

$a = \sqrt{a_x^2 + a_y^2}$

Various force equations are

$2T - N = Ma_x$

$N = ma_x$

and $\quad mg - \mu N - T = ma_y$

Solving $a_x = \dfrac{2mg}{M + 5m + 2\mu m}$

and $\quad a_y = \dfrac{4mg}{M + 5m + 2\mu m}$

$\therefore\ a = \sqrt{a_x^2 + a_y^2}$

$= \dfrac{2\sqrt{5}mg}{M + 5m + 2\mu m}$

51. (b) Let mass per unit length of chain $= \dfrac{m}{l}$

Consider an element of chain of length dl subtending an angle of $d\theta$ at the centre of spherical surface.

Mass of element $dm = \dfrac{m}{l}\, dl = \dfrac{m}{l}\, rd\theta$

Force acting on element, $dF = dm\, g \sin\theta$

$= \dfrac{m}{l}\, rg \sin\theta\, d\theta$

$\therefore\ F = \dfrac{m}{l}\, rg \displaystyle\int_0^{\alpha} \sin\theta d\theta$

$= \dfrac{m}{l}\, rg\, (1 - \cos\alpha)$

$= \dfrac{m}{l}\, rg \left(1 - \cos\dfrac{l}{r}\right)$

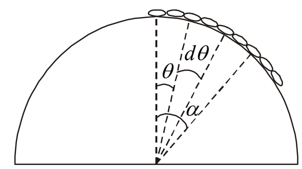


Fig. 5.127

Then $a = \dfrac{F}{m} = \dfrac{rg}{l}\left(1 - \cos\dfrac{l}{r}\right)$

52. (c) Let F_1 be the force between the man and the board and F_2 be the force of friction between the inclined plane and the board.

Here F_1 can have a value between $Mg \sin\theta - \mu\,(M + m)\, g \cos\theta$ and $Mg \sin\theta + \mu\,(M + m)\, g \cos\theta$ ...(i)

Limiting value of $F_2 = \mu N_2$

$= \mu\,(M + m)\, g \cos\theta$

the force equations are

$F_1 + mg \sin\theta = ma$

i.e., $F_1 = ma - mg \sin\theta$

From (i)

$Mg \sin\theta - \mu\,(M + m)\, g \cos\theta \le F_1 \le$

$Mg \sin\theta + \mu\,(M + m)\, g \cos\theta$

i.e., $Mg \sin\theta - \mu\,(M + m)\, g \cos\theta \le ma - mg \sin\theta \le mg \sin\theta + \mu\,(M + m)\, g \cos\theta$

i.e., $\left(\dfrac{M+m}{m}\right)(\sin\theta - \mu\cos\theta)\, g \le a \le$

$\left(\dfrac{M+m}{m}\right)(\sin\theta + \mu\cos\theta)\, g$

53. (d) Here $T = Mg$ and $T\cos\theta = Mg$

Also $T \sin\theta = m\omega^2 l \sin\theta \qquad (\because\ radius = l \sin\theta)$

i.e., $T = m\omega^2 l$

or $\quad Mg = m\omega^2 l$ i.e., $\omega = \sqrt{\dfrac{Mg}{ml}}$

i.e., $2\pi\nu = \sqrt{\dfrac{Mg}{ml}}$ i.e., $\nu = \dfrac{1}{2\pi}\sqrt{\dfrac{Mg}{ml}}$

54. (a) *For mass* M_1

$T + M_1 g \sin 37 - \mu_1 M_1 g \cos 37 = M_1 a$ ... (i)

and for mass M_2

$M_2 g \sin 37 - T - \mu_2 M_2 g \cos 37 = M_2 a$ ... (ii)

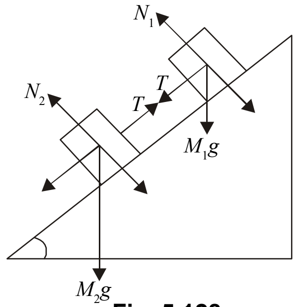


Fig. 5.128

Adding the substituting the given values, we get

$2g \times 0.6 + 4g \times 0.6 - 0.25 \times 2g \times 0.8 - 0.75 \times 4g \times 0.8$

$= (4 + 2)\, a$

$g\,(1.2 + 2.4 - 0.4 - 2.4)\, 6a$

or $a = 1.3\ \mathrm{ms}^{-2}$

Using (ii)

$2 \times 9.8 \times 0.6 - T - 0.25 \times 2 \times 9.8 \times 0.8 = 2 \times 1.3$

or $T = 11.76 - 3.98 - 2.6$

$= 5.29\ \mathrm{N}$

55. (b) If mass m_1 travels s, m_2 travels by $s/2$.

$\therefore$ if acceleration of m_1 is a, then acceleration of mass m_2 is $\frac{1}{2}\, a$

Here $T = m_1 a$ and $m_2 g - 2T = m_2\, \frac{a}{2}$

Solving $a = \dfrac{2m_2 g}{4m_1 + m_2}$

56. (c) Note

(i) mg acts downward

(ii) frictional forces up the plane

(iii) reactions N as shown

Then $mg \sin \theta - 2\, \mu_k N = ma$ ... (i)

($\because$ *there are 2 surfaces*)

also $mg \cos \theta - \sqrt{2}\ N = 0$

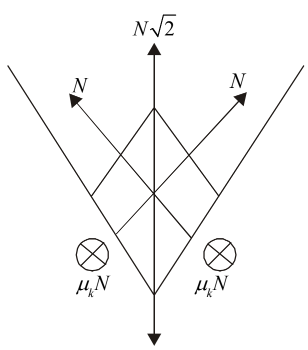


Fig. 5.129

From (i) and (ii)

$$mg \sin \theta - 2\mu_k \frac{mg \cos\theta}{\sqrt{2}} = ma$$

or $a = g\,(\sin \theta - \sqrt{2}\ \mu_k \cos \theta)$

57. (c) $\sin \alpha = \dfrac{a}{r} = \dfrac{0.5}{1} = \dfrac{1}{2}$

or $\alpha = 30°$

and $\sin \beta = \dfrac{\sqrt{3}}{2} \Big/ 1$

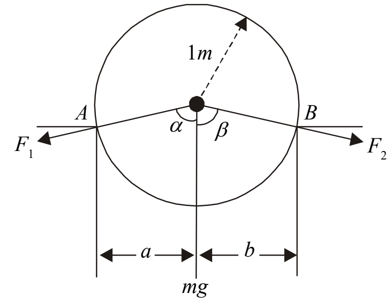


Fig. 5.130

or $\beta = 60°$

Then $F_1 = mg \cos \alpha$

$= 5 \times 10^3 \times 9.8 \times \cos 30$

$= 42.6\ k\mathrm{N}$

and $F_2 = mg \cos \beta$

$= 5 \times 10^3 \times 9.8 \cos 60$

$= 24.5\ k\mathrm{N}.$

58. (a) Height through which water falls in time dt after t second is $(h - h')$, where h' is the height of water already collected.

Mass of water collected $= \upsilon\rho\, dt$

and velocity of water $= \sqrt{2g(h - h')}$

Total force = weight of water already collected + impact force

$= \upsilon t \rho g + \upsilon\rho\, 2g\,(h - h')$

$$= \upsilon\rho \left[gt + 2g\left(h - \frac{\upsilon t}{A} \right) \right]$$

59. (b) For equilibrium

$T = m_1 a$ ...(i)

and $T = m_2 g + \mu m_2 a$ ... (ii)

From (i) and (ii)

$m_1 a = m_2 g + \mu\, m_2 a$

or $\mu = \dfrac{m_1 a - m_2 g}{m_2 a}$

$$= \frac{m_1\left(\frac{g}{7}\right) - m_2 g}{m_2\left(\frac{g}{7}\right)} = \frac{m_1 - 7m_2}{m_2}$$

$$= \frac{7.5m_2 - 7m_2}{m_2} = 0.5$$

60. (d) If n balls each of mass m are hanging vertically

then, $nmg - T = nma = \dfrac{nmg}{2}$

or $\quad T = \dfrac{nmg}{2}$ $\quad$ ... (i)

also $T - (16 - n)\, mg \sin\theta$

$= (16 - n)\, mg/2$

on $\dfrac{nmg}{2} - (16 - n)\, mg\, \dfrac{1}{3} = (16 - n)\, \dfrac{mg}{2}$

(*using (i)*)

or $\quad n\, \dfrac{4}{3} = \dfrac{80}{6}$

or $\quad n = \dfrac{80}{6} \times \dfrac{3}{4} = 10$

61. (A) Here $T_1 = T_2 \cos 30 = T_2\, \dfrac{\sqrt{3}}{2}$

i.e., $T_2 = \dfrac{2}{\sqrt{3}}\, T_1$

Also $Mg = T_2 \sin 30° = \dfrac{T_2}{2}$

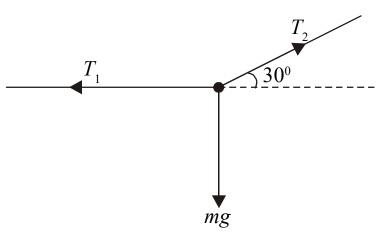


Fig. 5.131

i.e., $Mg = \dfrac{2}{\sqrt{3}}\, \dfrac{T_1}{2} = \dfrac{T_1}{\sqrt{3}}$

i.e., $T_1 = \sqrt{3}\, Mg$

62. (b) Using $F = ma$, we get

$$a = \frac{F}{m} = \frac{5\times10^4}{3\times10^7} = \frac{5}{3} \times 10^{-3}$$

again using $2\,as = \upsilon^2 - u^2$, we get

$$2 \times \frac{5}{3} \times 10^{-3} \times 3 = \upsilon^2$$

63. (c) Velocity at highest point $= u \cos\theta$

Then $Mu \cos\theta = (M + 3M)\, \upsilon$

or $\quad \upsilon = \dfrac{u\cos\theta}{4}$

and $4\, Mg\, h = \dfrac{1}{2}\, 4\, M \left(\dfrac{u\cos\theta}{4}\right)^2$

Using the given values we get

or $\quad \cos^2\theta = \dfrac{16}{25}$ or $\cos\theta = 4/5$

or $\quad \theta = \cos^{-1} 4/5$

64. (c) $T \sin\theta = \dfrac{m\upsilon^2}{R}$

and $T \cos\theta = mg$

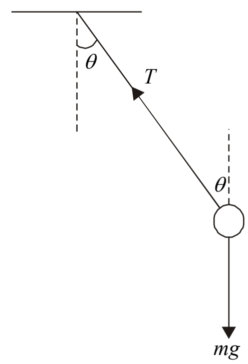


Fig. 5.132

$\therefore \tan\theta = \dfrac{\upsilon^2}{Rg} = \dfrac{10}{10\times10}$

or $\quad \tan\theta = 1$ or $\theta = 45°$

65. (b) Impulse $= Ft =$ change in momentum

$= m\upsilon - (-m\upsilon)$

$= 2m\upsilon = 2 \times 0.01 \times 5$

$= 0.1$

$\therefore F = \dfrac{0.1}{0.01} = 10\ \text{N}$

66. (a) Acceleration along F_1,

$a = \dfrac{F_1 - F_2}{M}$

Mass of length $y = m = \dfrac{M}{L}\, y$

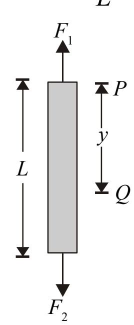


Fig. 5.133

If T is tension in this length, then

$$F_1 - T = ma = \left(\frac{M}{L}y\right)\left(\frac{F_1 - F_2}{M}\right)$$

$= (F_1 - F_2)\, y/L$

$\therefore\ T = F_1 - (F_1 - F_2)\, y/L$

or $\quad T = F_1(1 - y/L) + F_2(y/L)$

67. (c) Impulse = $\int F dt$ = area under graph

$\therefore$ Total impulse from $4\mu s$ to $16\mu s$

= Area $EBCD$

$= 1/2\,(200 + 800)^2 \times 10^{-6} + \frac{1}{2} \times 800 \times 10 \times 10^{-6}$

$= 5 \times 10^{-3}$ Ns

68. (d) $CP = CO = R$

$\angle CPO = \angle POC = 60°$

Thus ΔOCP is an equilateral Δ

$\therefore\ OP = R$

$\therefore$ Extension = R – natural length of spring

$= R - \frac{3R}{4} = \frac{R}{4}$

Thus spring force $= kx = \left(\frac{mg}{R}\right)\left(\frac{R}{4}\right)$

$= \frac{mg}{4}$

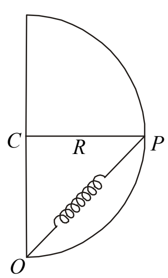


Fig. 5.134

69. (a) f_{max} for $A = \mu_1\,(mg \cos 45°)$

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

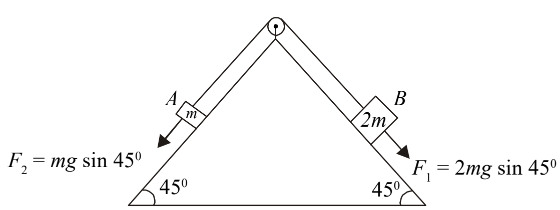


Fig. 5.135

Also f_{max} for $B = \mu_2\,(2mg \cos 45)$

$= 1/3\,(2mg\,\sqrt{2}) = \frac{\sqrt{2}}{3}\, mg$

Total frictional force

$= \frac{\sqrt{2}}{3}\, mg + \frac{\sqrt{2}}{3}\, mg = \frac{2\sqrt{2}}{3}\, mg$

But pulling force

$= F_1 - F_2 = \frac{2mg}{\sqrt{2}} - \frac{mg}{\sqrt{2}} = \frac{mg}{\sqrt{2}}$

$\therefore$ system can not accelerate.

70. (c) Acceleration of particle w.r.t. block

= Acceleration of particle – acceleration of block

$= (g \sin\theta\, \hat{i} + g \cos\theta\, \hat{j}) - g \sin\theta\, \hat{i}$

$= g \cos\theta\, \hat{j}$

Motion of particle with reference to block is parabolic

$\therefore\ PQ = \text{range} = \frac{u^2 \sin 2\alpha}{g \cos\theta}$

71. (b) $l_1 = 2l_2 = \frac{2}{3}\, l$

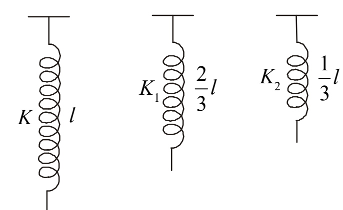


Fig. 5.136

Force constant $K \propto \frac{1}{\text{length of spring}}$

$\therefore\ K = \frac{3}{2}\, K.$

72. (c) Block will topple if

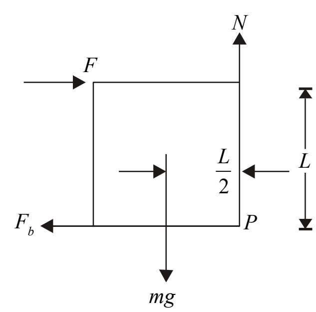


Fig. 5.137

$(F \times L) > (mg \times \frac{L}{2})$

or $\quad F > \frac{mg}{2}$

$\therefore$ least force $= \frac{mg}{2}$

73. (a) For equilibrium

$\sum$ horizontal forces = 0

i.e., $N \sin \alpha = \mu N \cos \theta$

i.e., $\cot \alpha = 1/\mu$

or $\cot a = 3$

74. (d) Force applied by clamp = resultant of T and $(mg + T)$

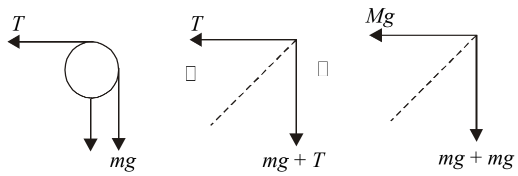


Fig. 5.138

But $T = Mg$

$\therefore$ Force applied by clamp

$= \sqrt{(Mg)^2 + (mg + Mg)^2}$

$= g\sqrt{M^2 + (M+m)^2}$

75. (c) Here $T = mg$ ... (i)

and $2T \cos \theta = (\sqrt{2}\, m)\, g$ ... (ii)

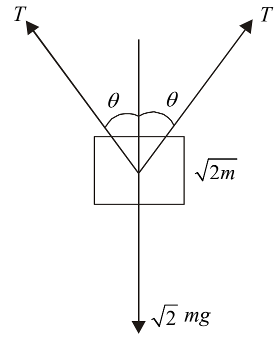


Fig. 5.139

Dividing (ii) by (i)

$\cos \theta = \dfrac{1}{\sqrt{2}}$ or $\theta = 45°$

76. (b) Here P.E. $= \dfrac{1}{2} kx^2$

i.e., $mgx = \dfrac{1}{2} kx^2$

or $x = \dfrac{2mg}{k}$