PHYSICS

BOOKS - BHARATI BHAWAN PHYSICS (HINGLISH)

LAWS OF MOTION, FREE BODY DIAGRAM

Example

1. A body of mass 2 kg falls 60 m from rest and is then brought to rest after penetrating 0.6 m into some sand . Find the average thrust of the sand on it .

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2. A body of mass 2 kg makes an elastic collision with another body at rest and continues to move in the original direction but with one - fourth its

original speed . What is the mass of the body it collides with ?

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3. A ball of 1 kg drops vetically on to the floor with a speed of $25ms^{-1}$. It rebounds with an initial velocity of $10ms^{-1}$. (a) What impulse acts on the ball during contact ? (b) If the ball is in contact for 0.02 s , what is the average force exerted on the floor ?

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4. A rocket weighs 13,500 kg when fuelled up on the launching pad . It is fired vertically upward . Gases are exhausted at the rate of 145 kg per second with velocity 1500 ms^{-1} relative to the rocket . What is the thrust on the rocket ?

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5. A block of mass M is pulled along a horizontal frictionless surface by a rope of mass m . A force P is applied to the other end of the rope . (a) Find the acceleration of the block and the rope . (b) Find the force that the rope exerts on the block M in terms of P, M and m .

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6. A gun (of mass M) whose barrel makes an angle α with the horizontal fires a shell (of mass m) . The gun is mounted on a frictionless track , so that recoil takes place with no resistive forces . Find the recoil velocity V of the gun and the absolute velocity of the shell in magnitude and direction if the muzzle velocity of the shell relative to the barrel is v .

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7. A spherical ball falls from a height h on to a floor of coefficient of restitution e . Calculate the total distance described by the ball before it comes to rest .

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8. A heavy mass m slides down a triangular prism of mass M . The prism lies on a horizontal surface and can move along it without friction . What will be the direction of motion of m if the inclination of the hypotenuse of the prism is α with the horizontal ?

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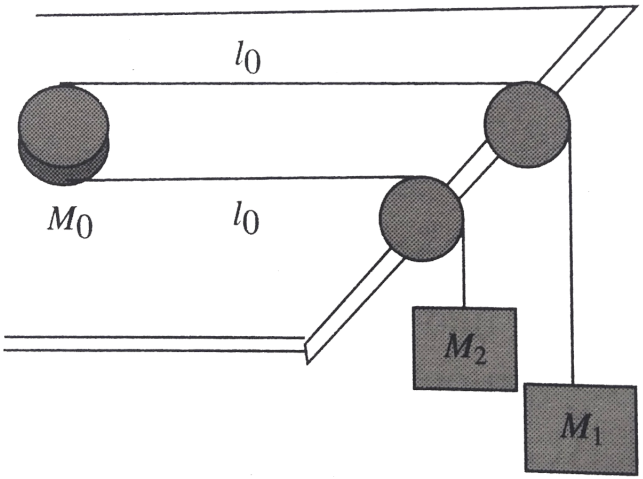
9. A smooth pulley A of mass M_0 is lying on a frictionless table. A massless rope passes round the pulley and has masses M_1 and M_2 tied to its ends, the two portions of the string being perpendicular to the edge of the table so that the masses hang vertically. Find the acceleration

of the pulley.



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10. A dynomometer D (a force meter) is attached to two masses M = 10 kg and m = 1 kg . Force F = 2 kg f and f = 1 kgf are applied to the masses . What will applied to the masses . What will the dynamometer show if :

(a) F is applied to M and f ot m

(b) F is applied to m and f to M

(c) if M = m = 5 kg .

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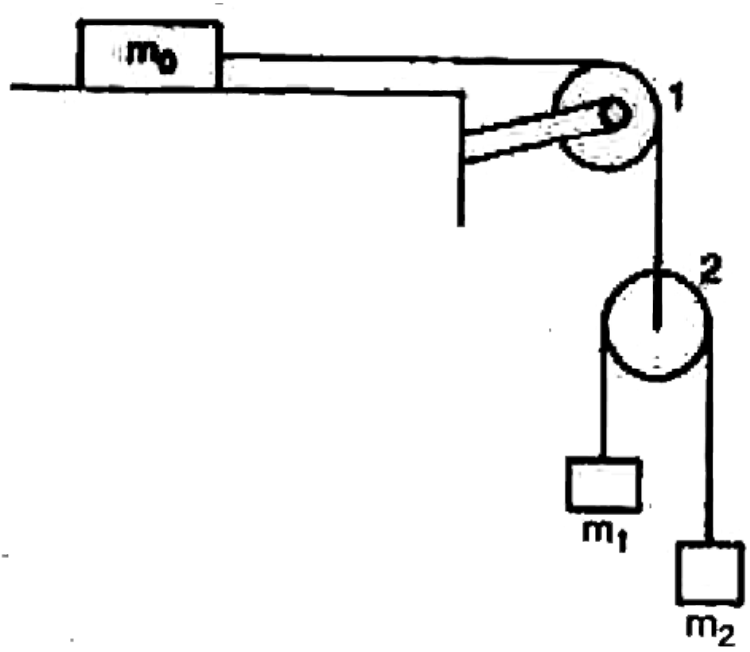
11. In the arrangement shown here the bodies have masses $m_0, m_1 \text{and} m_2$. Find the acceleration of m_2 taking ideal conditions . i.e., pulleys are massless and smooth and threads are light . Look into possible cases .



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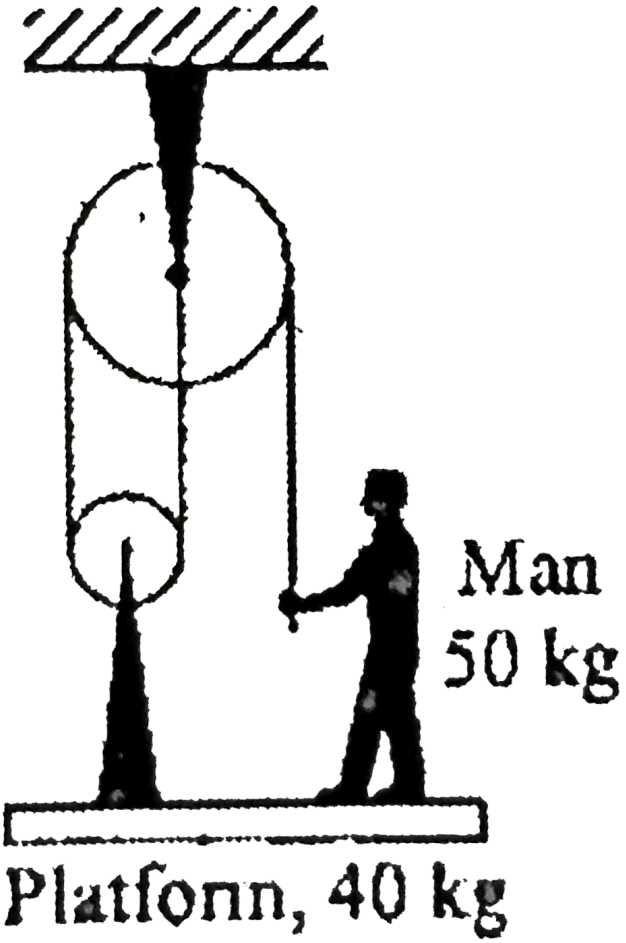
12. What force must man exert on rope to keep platform in equilibrium :

(Take $g = 10m/s^2$)



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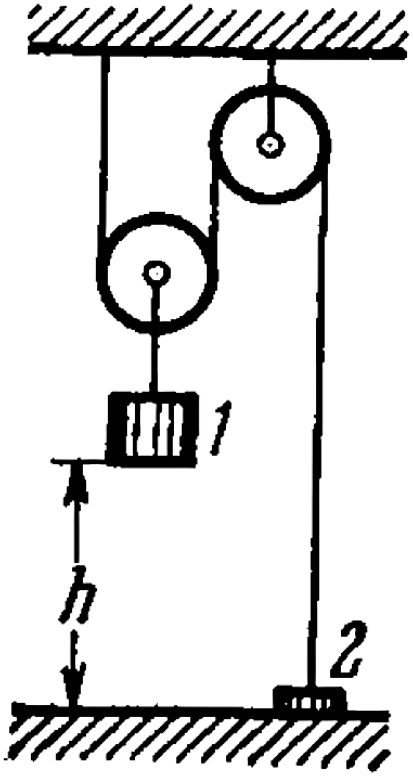
13. In the arrangement shown in figure the mass of body 1 is $\eta = 4.0$ times as great as that of body 2. The height $h = 20cm$. The masses of the pulleys and the threads, as well as the friction, are negligible. At a certain moment body 2 is released and the arrangement set in motion. What is the maximum height that body 2 will go up to?



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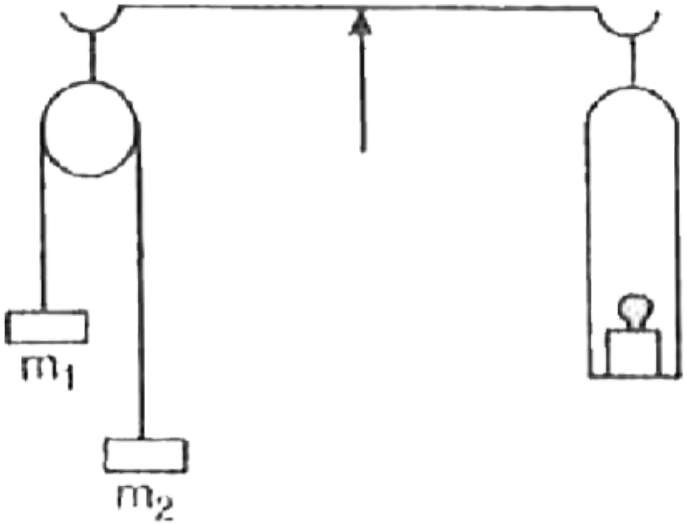
14. A pulley is attached to one arm of a balance and a string passed around it carries two masses m_1 and m_2 . The pulley is provided with a clamp due to which m_1 and m_2 do not move . On removing the clamp m_1 and m_2 start moving . How much counterweight is to be reduced or increased to restore balance ?



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15. Two men A and B each of mass m sit in light cages at the ends of a light flexible rope passing over a smooth pulley . Initially they are at rest .

A being higher than B by it . Suddenly a mass m/10 is handed over to B which he immediately throws up to A . Prove that by the time A catches the thrown mass , he moves up by a distance 2h/19 and that he stops ascending after he has ascended a total distance 59h/361.

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Exercise A

1. A constant force acts on a body of mass 10 g moving with a velocity of $500ms^{-1}$. The body is found to move with same velocity but in the opposite direction after 10 s . Calculate the magnitude of the force .

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2. The metal blocks A and B of masses 2 kg and 1 kg , respectively are in contact on a frictionless table A constant horizontal force of 3 N is applied to the block A . Calculate the force of constant between the two

blocks . If the same force is applied to the block B then what will be the force of contact ? Can you explain the difference ?

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3. Three metal blocks A , B and C of masses 10 kg , 20 kg and 30 kg rest on a frictionless table in a line . A is converted to B and B to C by two pieces of string . With the help of a third string attached to C , the system is pulled to the right with a force of 60 N . Find the tensions of the first and second strings .

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4. Two blocks of masses m and m' are connected by a light spring on a horizontal frictionless table . The spring is compressed and then released . Find the ratio of acceleration of masses .

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5. A constant force acts on a body of mass 1 kg for 5 s and then ceases to work . In the next 5 s the body describes 100 m . Calculate the force that acted on the body.

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6. A uniform rope of length L , resting on frictionless horizontal table is pulled at one end by a force F . What is the tension in the rope at a distance x from the end where the force is applied ?

[Hint : Consider the motion of the entire rope and the motion of x length of rope using P = ma formula and third law of motion]

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7. Water flows through a pipe bent at an angle α to the horizontal with velocity v . Calculate the force exerted by the water on the bend of the pipe of area of cross - section S .

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8. A block of mass $3kg$ which is on a smooth inclined plane making angie of 30° to the horizontal is connected by cord passing over light frictionless pulley to second block of mass $2kg$ hanging vertically. What is the acceleration of each block and waht is the tension of the cord ? .

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9. How can you lower a 100-kg body from the roof of a house using a cord with a breaking strength of 80 kgf (kilogram force) without breaking the rope ?

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10. A machine gun fires 50-g bullets at a speed of 1000 m/s . The gunner , holding the machine in his hands , can exert an average force of 150 N against the gun . Calculate the maximum number of bullets he can fire one minute.

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11. A block slides down a frictionless incline kept on the floor of a chamber . Find the acceleration of the block relative to the incline when the chamber is carried by a helicopter with upward acceleration a at inclination θ with the vertical . Consider the special cases when $\theta = 0^\circ$ and $\theta = 90^\circ$. The inclination of the plane is $90^\circ - \alpha$ to the vertical in the same sense as θ .

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12. A railroad flatcar of mass M can roll without friction along a straight horizontal track. Initially, a man of mass 'm' is standing on the car, which is at rest. What is the velocity of the car if man runs to the left so that his speed relative to the car is v_{rel}.

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13. A box is put on the platform of a spring balance which is adjusted to zero when the box is empty . A stream of pebbles is then poured into the box from height h above its bottom at a constant rate of n pebbles per second . Find the scale reading t seconds after the pebbles begin to fill the box , assuming that the collisions between the pebbles and the box are completely inelastic .

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14. A scale is adjusted to zero . Particles fall from a height h = 250 m before colliding with the balance pan of the scale . The collisions are elastic . If each particle has a mass of m = 100 mg and collisions occur at the rate n = 1000 particles per second , what is the scale reading in kg ?

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15. An electron of mass m is involved in head-on collision with an atom of mass M , initially at rest . As a result of the collision a certain amount of energy E is stored internally in the atom . What is the minimum initial

velocity that the electron must have ?

[Hint : Since energy is stored in the atom , the collision is essentially inelastic . mv = mv' + Mv'' and $\frac{1}{2}mv^2 = E + \frac{1}{2}mv^2 + \frac{1}{2}Mv'^2$. Solve for v' and apply the condition for real values of v'.)

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16. Two bodies 1 and 2 of masses m and M are kept slightly separated . A third body 3 of mass m coming from left with velocity v makes a head- on elastic collision with m . Show that if $m \geq M$ there are exactly two collisions and find all final velocities and if $m \leq M$ there are three collisions and find all final velocities .

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17. A steel ball weighting 1 kg is fastened to a cord 1 m long and is released when the cord is horizontal . At the bottom of its path the ball strikes a 5-kg steel block initially at rest on a frictionless surface . The collision is elastic . Find the speed of the ball and speed of the block just

after collision . (g = $9.8ms^{-2}$)

[Hint : Apply principal of conservation of momentum and conservation of kinetic energy as the collision is elastic .]

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18. An elevator (a lift) is moving up at the speed of 2 m/s in a shaft . At the instant the elevator is 20 m from the top , a ball is dropped from the top of the shaft . The ball rebounds elastically from the elevators roof . To what height can it rise relative to the top of the shaft ?

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19. An elevator is provided with a weighing machine (making use of principle of spring balance) at its floor . A man weighing 60 kg stands on the platform of the machine and finds that the reading shoots to 62 kg when the elevator starts and then comes down to 60 kg again. How do you explain this ?

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20. A projectile of mass 50 kg is projected vertically upwards with a velocity of 100 m/s . After 5 seconds it explodes into two pieces , one piece of 20 kg moving vertically upward with velocity 150 m/s . Calculate the velocity of the other piece and also the algebraic sum of the momenta of the system 3 s later .

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21. A ball strikes an identical ball with velocity 50 m/s and after the collision which is perfectly elastic it is found to move with velocity 30 m/s . Show that the two balls move at right angles to each other after collision .

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22. A cord is tied at one end to a sprind balance of weight 3 kg supporting a mass of 5 kg . The cord passes over a smooth fixed pulley carrying a load of 10 kg at the other end . What will be the reading of the spring balance when the system moves ? How will the reading vary if the load of 10 kg be replaced by a load of 6 kg ?

[Hint : Consider free-body diagrams of 5 kg , 10 kg and the system (5 kg body + 3 kg spring).]

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23. A ball moving with a speed of $9m/s$ strikes an identical ball at rest, such that after the collision, the direction of each ball makes an angle of 30° with the original line of motion. Find the speeds of the two balls after collision.

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24. A plumb bob hanging from the ceiling of railroad car acts as an accelerometer . Derive the general expression relating the horizontal acceleration a of the car with the angle θ made by the bob with the vertical . Find θ when $a = 1.5ms^{-2}$ and a when $\theta = 10^{\circ}$

[Hint: Apply d' Alembert's principal.]

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25. Show that in the case of an elastic collision between a particle of mass m_1 with a particle of mass m_2 initially at rest , (a) the maximum angle through which m_1 can be deflected is given by $1 - \cos^2\theta_m = \frac{m_2^2}{m_1^2}$ when $m_1 > m_2$ (b) $\theta_1 + \theta_2 = \frac{\pi}{2}$ when $m_1 = m_2$

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26. A 6000 - kg rocket is set for firing . If the exhaust speed is $1000ms^{-1}$, how much gas must be ejected per second to supply the thrust needed ,

(a) to overcome the weight of the rocket , (b) to give the rocket an initial acceleration of $19.6ms^{-2}$?

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27. 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 come out with velocity $500ms^{-1}$ relative to the car . Calculate the acceleration of the car at the instant when its mass is 200 kg . Also calculate the force at that instant.

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Exercise B

1. A train of mass M is travelling with a uniform velocity on a level line . The last carriage whose mass is m gets detached from the train . The driver of the train discovers it only after travelling a distance l and then

he shuts off steam . Show that when both parts come to rest the distance between them is $\left(\frac{Ml}{M-m}\right)$. Assume resistance of motion to be uniform and proportional to mass and the pull of the engine to be a constant .

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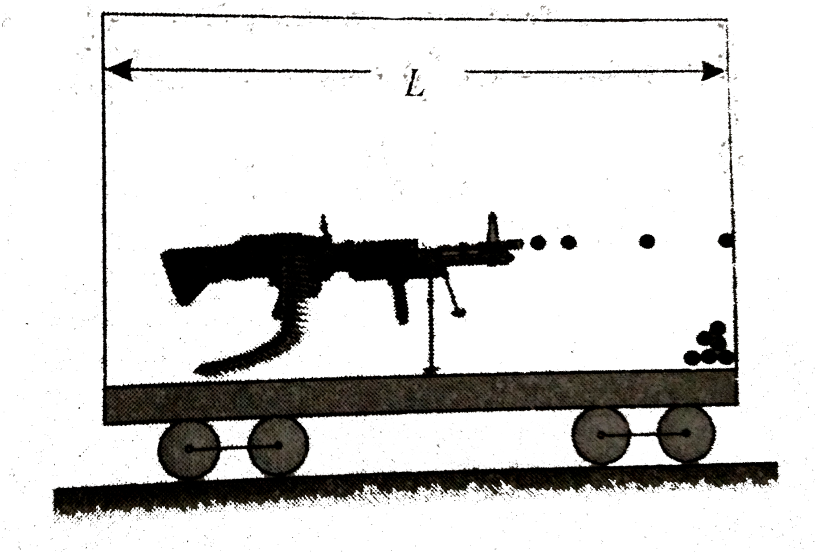
2. A cannon and a supply of cannon balls are inside a sealed rail road car. The cannon fires to the right, the car recoils to the left. The canon balls remain in the car after hitting the far wall. Show that no matter how the cannon balls are fired, the rail road car cannot travel more than L.

assuming it starts from rest.



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3. A jet airplane is travelling at $200ms^{-1}$. The engine of the plane takes in 250 m^3 of air of mass 32 kg each second . The air is used to burn 3 kg of fuel each second . The energy is used to compress the products of combustion to eject them at the rear of the plane at $500ms^{-1}$ relative to the plane . Find the power of the jet plane in H.P.(1 H.P = 746 W).

[Hint : Resultant thrust = forward thrust - backward thrust and power = force $\times$ velocity]

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4. Sand drops from a stationary hopper at the rate of 5 kg s^{-1} on to a conveyor belt moving with a constant speed of $2ms^{-1}$. What is the force required to keep the belt moving and what is the power delivered by the motor moving the belt ?

[Hint: Tangetial force exerted on the belt = $u_{\text{rel}}\frac{dM}{dt}$ where u_{rel} is the tangential relative velocity of the sand .]

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5. A right-angled triangular block of mass M rests on a horizontal table . The inclination of the block is 30° with the table . A cubical block of mass m is placed on the incline of the block . What horizontal force must be applied on M so that m may remain stationery relative to the block ?

[Hint: Apply d' Alember's principal and consider free-body diagrams of m and the system (m+ M).]

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6. A rocket expels mass at the rate of μ kg /s at the exhaust speed u . Find the instantaneous acceleration if its initial mass were M_0 kg ?

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7. A wedge of mass M rests with one face in contact with horizontal , smooth surface . A particle of mass m is placed on the smooth face on it , inclined at an angle $\alpha$to the horizontal and released . Find the velocity of the wedge and that of the particle relative to the wedge when the particle has slipped a distance x down the face of the wedge . Also calculate the acceleration of the wedge and that of the particle relative to the wedge and the smooth surface .

[Hint : Apply principal of conservation of momentum along the horizontal and energy conservation principle . See Example 8)

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8. Two identical buggies 1 and 2 with one man in each move without friction due to inertia along the parallel rails toward each other. When the buggies get opposite each other, the men exchange their places by jumping in the direction perpendicular to the motion direction. As a consequence, buggy 1 stops and buggy 2 keeps moving in the same direction, with its velocity becoming equal to v. Find the initial velocities of the buggies v_1 and v_2 if the mass of each buggy (without a man) equals M and the mass of each man m.

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9. Two identical buggies move one after the other due to inertia (without friction) with the same velocity v_0. A man of mass m rides the rear buggy. At a certain moment the man jumps into the front buggy with a velocity u relative to his buggy. Knowing that the mass of each buggy is equal to M, find the velocities with which the buggies will move after that.

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10. Assuming that the car in problem 12 is initially at rest and holds n men, each of mass m, prove that if the men run with relative velocity v_{rel} and jump in succession they can impart to the car a greater velocity than if they all run and jump simultaneously.

[Hint : When the men run together, the effect is the same as for one man of mass nm.

$$\therefore \Delta v = \frac{nm}{M+nm} v_{rel}.$$

When they run and jump in succession,

$$\Delta v = \sum_{i=1}^{i=n} = \frac{mv_{rel}}{M+im} = mv_{rel}\left(\frac{1}{M+m} + \frac{1}{M+2m} + \frac{1}{M+3m} + \ldots\right.$$

]

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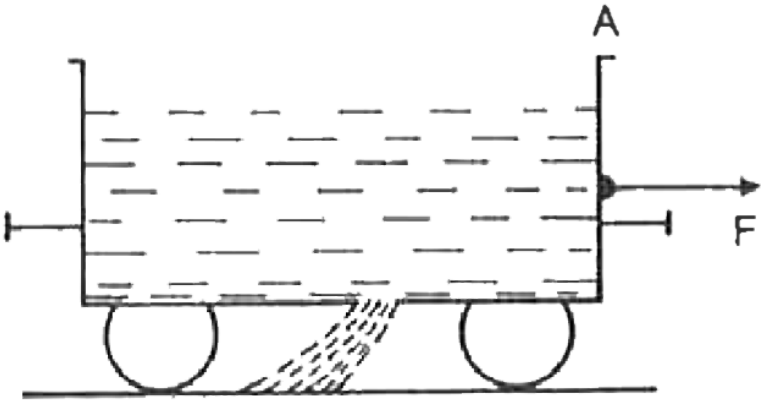
11. Find an expression for, the acceleration and speed of a trolley A under the action of a constant force F if it contains sand that pours out through the floor at the rate of μ per second. The speed of the trolley at

t=0 was v=0 and the initital mass of sand and trolley was M_0



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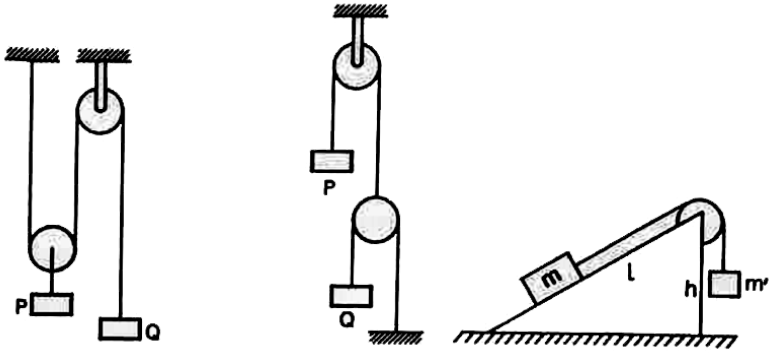
12. Two masses P and Q are connected by the arrangement shown inFigure 5.19. Find the downward acceleration of the mass Q.



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13. Neglecting friction and the mass of the pulleys, find the acceleration of the mass Q assuming that P=Q (Figure 5.20).

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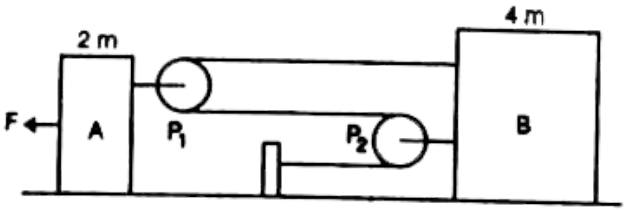
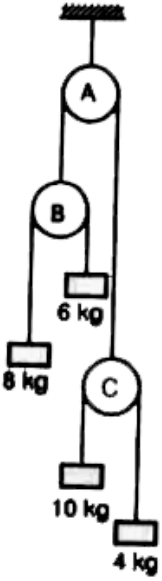
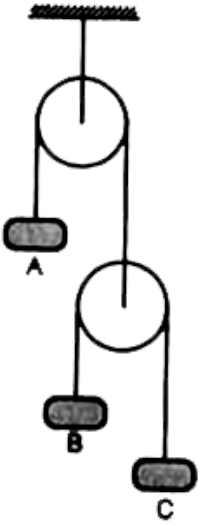
14. A body of mass m is drawn up a smooth inclined plane (Figure 5.21) of height h and length l by means of a string passing over the vertex of the plane. From the other end of the string hangs a mass m'. Show that in order that m may just reach the top of the plane, m' msut be deteched

after m has moved through a distance $\frac{m+m'}{m'}\frac{hl}{h+l}$







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15. Calculate the accelerations of the pulleys B and C and the tension in the string passing over the pulley A of the figure Figure 5.22.

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16. Calculate the acceleration of the block B of the figure Fig. 5.23, assuming surfaces and pulleys to be smooth.

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17. A system of masses and pulleys is arranged in a vertical plane as shown in Figure 5.24 her. If $m_A : m_B : m_C$=3:2:1. Find their accelerations.

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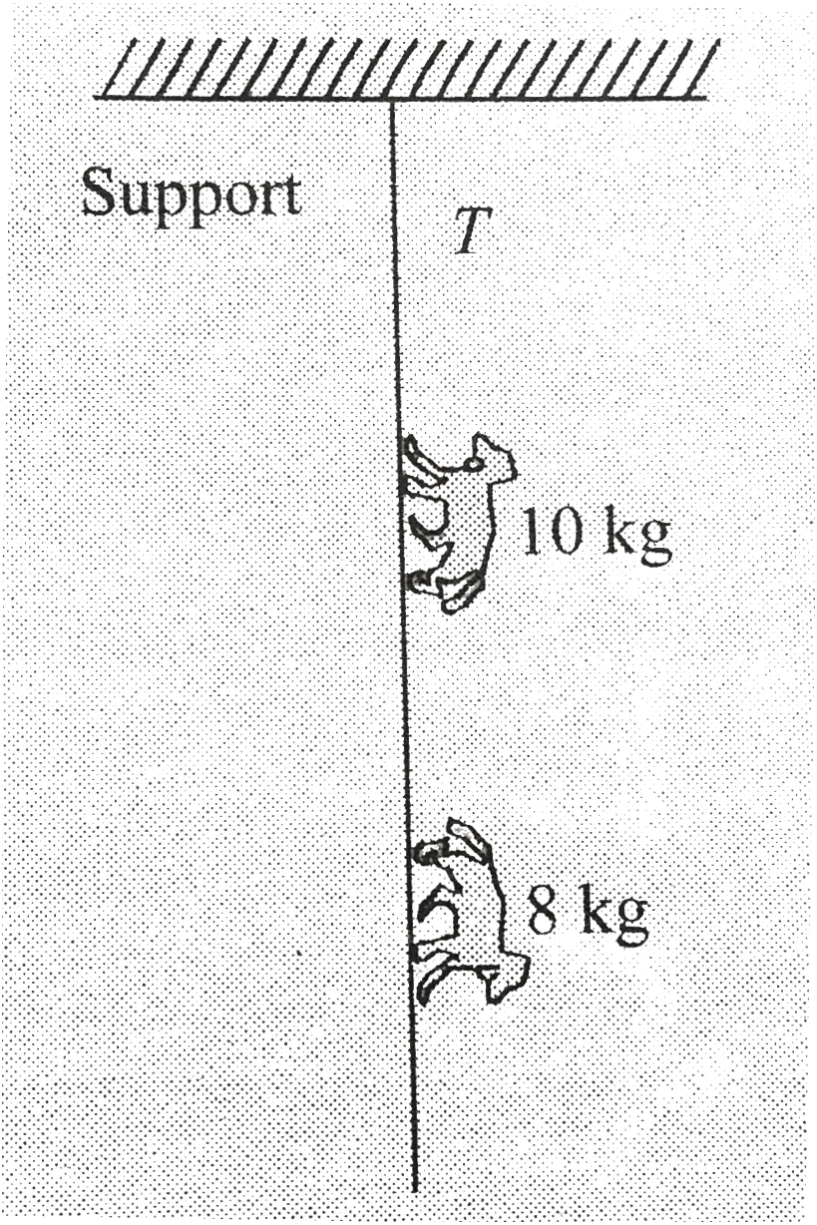
18. Two monkey of masses 10 kg and 8 kg are moving along a verticle rope as shown in fig. the former climbing up with an acceleration of $2ms^{-2}$, while the later coming down with a uniform velocity of $2ms^{-1}$. Find the

tension in the rope at the fixed support.



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19. A rope is stretched between two stationary boats on the surface of a lake. A man in the first boat pulls the rope with a constant force of 100 N. The distance between the boats is 100 m in the beginning. The mass of the first boat with the man is 250 kg ,while the mass of the other is 500 kg. Find :(i) the velocity of approach of the two boats 15 s after the start, (ii) the time taken for the two boats to meet each other. [Hint: Consider relative acceleration and apply kinematic equations.]

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20. A thin, uniform chain is hanging vertically and its bottom end is touching a table . The mass of the chain is m and its length is l . At the moment t=0, the chain is released. Calculate the force that the chain exerts on the table after t seconds.

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21. A mass M attached to the end of a small flexible rope of diameter d=1 cm is raised vertically by winding the rope on a reel. If the reel is turned uniformly ay the rate of n=2 rps, what will be the tension T in the rope? Neglect inertia of the rope and slight lateral motion of the suspended mass. (Fig.5.25)

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22. A sphere of mass $m_1$collides with a sphere of mass m_2 which is at rest. Prove that whatever be the initial direction of the first sphere, it will move off at right angles to the line of centres at the time of collision if the coefficient of restitution is m_1 / m_2.

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23. Two equal smooth sphere of radius a are moving with equal speed u in opposite directions along parallel lines which are a distance a apart.

The coeficient of restitution between them is 1/3.Find their velocities after impact.

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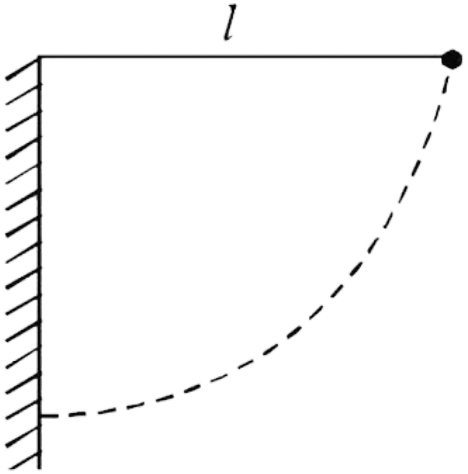
24. A simple pendalum is suspended from a peg on a verticle wall . The pendulum is pulled away from the well is a horizental position (see fig) and released . The bell his the well the coefficient of resitution being $\frac{2}{\sqrt{5}}$



what is the miximum number of colision after which the amplitube of secillections between less that 60 digree ?

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25. A small metal ball falls vertically and strickes a smooth plane inclined at an angle θ to the horizontal $(\theta < 45^\circ)$. The ball rebounds horizontally. Show that a fraction (l-e) of the kinetic energy is lost during the impact and that if m is the mass and μ the speed of the ball before impact, the impulse on the plane is $\mu \sec\theta$. Here e isi the coefficient of restitutuon.

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26. A body projected at an angle α to the horizontal lands at the same point after hitting a verticle wall. This time it makes an angle β with the horizontal. Show that $e\tan\beta = \tan\alpha$ where e is the coefficient of restitution between the body and the wall.

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27. A small body slides from a height h down a smooth plane inclined at 45° to the horizontal. How will the body move if at the end of the plane it

encounters (a) a completely elaatic plane, (b) an inelastic but smooth plane.

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28. A ball is projected from a given point with velocity u at some angle with the horizontal and after hitting a vertical wall returns to the same point. Show that the distance of the point from the wall must be less than $\frac{eu^2}{(1+e)g}$, where e is the coefficient of restitution.

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29. A particle of mass $1.0g$ moving with velocity $v_1 = 3.0i - 2.0j$ experiences a perfectly inelastic collision with another particle of mass $2.0g$ and velocity $v_2 = 4.0j - 6.0k$. Find the velocity of the formed particle (both the vector v and its modulus), if the components of the vectors v_1 and v_2 are given in the SI units.

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30. A ball moving translationally collides elastically with another, stationary, ball of the same mass. At the moment of impact the angle between the straight line passing through the centres of the balls and the direction of the initial motion of the striking ball is equal to $\alpha = 45^\circ$. Assuming the balls to be smooth, find the fraction η of the kinetic energy of the striking ball that turned into potential energy at the moment of the maximum deformation.

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31. The masses of A,B and C in the figure (Fig. 5.24) are m_A=4 kg, m_B=2 kg and m_C=3 kg. The mass of the movable pulley is 1 kg. Show that the acceleration of A is $\frac{9g}{49}$

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32. To raise a weight which is half as much again as his weight a man fastens a rope to it and passes over a smooth pulley, he then climbs up the rope with an acceleration $\frac{6g}{7}$ relative to the rope. Show that the weight rises with acceleration $\frac{8}{7}$, and find the tension of the rope.

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33. A hoop of mass M and radius R is placed on an absolutely smooth level surface. An insect of mas m begins to alight along the hoop from the highest point with speed v relative to the hoop. Find the velocity of the centre of the hoop aftert.

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34. A chain of length l and mass m is lumped over the hole in a horizontal plate and a short length hangs down the hole when the chain is at rest. If it is released from this position find the velocity when the last link of the chain leaves the hole.

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