# PHYSICS

# BOOKS - BHARATI BHAWAN PHYSICS (HINGLISH)

# FRICTION, WORK POWER AND ENERGY

## Examples

**1.** Starting from rest , a body slides down at $45^{\circ}$ 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

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**2.** A body of mass 5 kg is being pulled up along a rouch inclined plane with an acceleration of $5cms^{-2}$ by means of a weightless string running parallel to the plane. If the inclination of the plane be $45^\circ$ to the horizontal and the coefficient of friction between the body and the plane be 0.3, find the pull in the string. $(g = 9.8ms^{-2})$.

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**3.** A $5kg$ block is projected upwards with an initial speed of $10ms^{-1}$ from the bottom of a plane inclined at $30^\circ$ with horizontal . The coefficient of kinetic friction between the block and the plane is $0.2$

a. How far does the block move up the plane ?

b. How long does it move up the plate ?

c. After time from its projection does the block again come to the bottom ? What speed does it arrive?

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**4.** A man can throw a stone horizontally with velocity $v_1 = 5m/s$. What velocity $v_2$ can he generate in the same stone if he throws it with the same force while standing on stakes on smooth ice ? The mass of the stone $m = 1$ kg, the mass of the man $M = 60$ kg. Will the man produce the same power in each case ?

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**5.** A mass 2 m is fixed at one end of a light rod of length $I$. What horizontal velocity should be imparled to the lower end so that it may just take up the horizontal position ? If the mass is now rearanged with m at the lower end and the other $m$ at the middle, what velocity is required ?

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**6.** A particle of mass m rests on a horizontal floor with which it has a coefficient of static friction $\mu$. It is desired to make the body move by applying the minimum possible force F. Find the magnitude of F and the direction in which it has to be applied.

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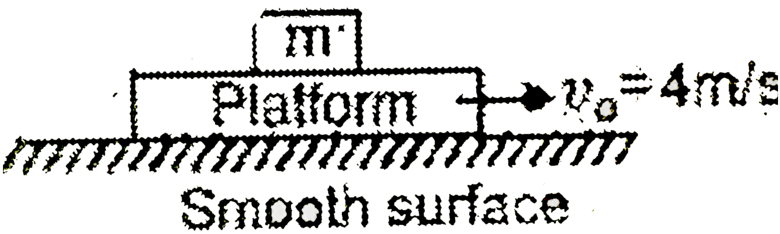
**7.** A stationary body of msas m is slowly lowered onto a rough massive platform moving at a constant velocity $v_0 = 4m/s$. The distance the body will slide with respect to the platform $\mu = 0.2$ is :

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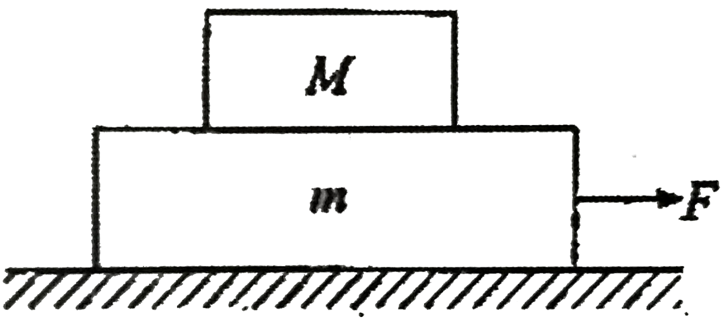
**8.** A board of mass m = 1 kg lies on a table and a weight of M = 2 kg on the board. What minimum force F must be applied on the board in order to pull it out from under the road ? The coefficient of friction between board and table is $\mu_2 = 0.5$ : (Take $g = 10 m / s^2$)

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**9.** What must be the minimum coefficient of friction $\mu$ between the tyres of the drive wheels of a car and the road, if the car and the road, if the car of mass $m = 2$ tons and load $M = 4$ tons, has an acceleration $a = 0.2ms^{-2}$ ? Consider the problem for two cases : (a) all the wheels are driven , (b) only the rear wheels are driven. Assume that the centre of gravity of the car lies at the mid-point between the axes of the wheel and the centre of gravity of the load above the rear axle.

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**10.** A wooden pile of mass $m = 3kg$ is driven into the driven into the ground by suceessive blows from a hammer of mass $M = 10kg$ falling from a height $h = 3$m on the head of the pile. If under the action of a single blow the pile penetrates a distance $\delta = 5$ cm, determine the resistance R to penetration.

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**11.** A particle of mass M is dropped vertically into a medium that offers resistance proportional to the velocity of the particle. The buoyancy of the medium is negligible and the resisting force is $f_0$ when the velocity is $1ms^{-1}$. What uniform velocity will the particle finally acquire ?

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**12.** A small ball of mass $m = 1$ g is placed at the bottom of a watch glass of radius $R = 1$

m. It is displaced by $h = 1$ cm along the glass surface and released. Calculate the total distance deseribed by it before it comes to rest at the bottom, if $\mu = 0.1$ is the coefficient of friction between the ball and the watch glass.

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**13.** A triangular loop ABC of string is passed over two small frictionless pulleys A and B. $AB = 2l$ and $BC = AC = \eta l$. Two masses m and M are attached to the mid-point O of AB and C respectively and $m$ is released. Find the condition that m and M may cross each other.

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## Exercises A

**1.** A block weighing 5 kg is pressed against a verticalk wall by a normal force of 150 N the coefficient of friction along being 0.5 . Find the force required to cause the block to move (a) horizontally, (b) vertically upward, (c) vertically downwards.

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**2.** A body of mass 4kg rests in limiting equilibrium on a rouch plane whose slope is $30^\circ$. The slope is subsequently increased to $60^\circ$. Calculate (i) coefficient of limiting friction between the body and the surface, (ii) acceleration down the plane if coefficient of kinetic friction is 0.4, (iii) force required to prevent it from sliding down the plane, (iv) force required to just move it up the plane. $(g = 9.8m / s^2)$.

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**3.** The length of a simple pendulum of 0.4 m. The bob of the pendulum is drawn aside till the string is horizontal, it is then released from this horizontal position, What will be its velocity when it reached the lowest point in its swing ? $(g = 9.8m / s^2)$

[Hint : Loss in potential energy = gain in kinetic energy]

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**4.** A block slides down an inclined plane of slope $\theta$ with constant velocity. It is then projected up the plane with an initial speed $u$. How far up the incline will it move before coming to rest ? Will its slide down again ?

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**5.** A sharp knife of mass $m = 1/2$ kg penetrates $s = 5$cm into fixed wooden block of mass $M = 5$ kg when it falls from a height of $h = 2$ m. How much will it penetrate when thrown horizontally with velocity $v = 10m/s$ ? How much will it penetrate if the block is free to move on smooth surface ?

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**6.** A bullet of mass 20 kg travelling horizontally at $100ms^{-1}$ gets embedded at the centre of a block of wood of mass 1kg, suspended by a light vertical string of 1m in length. Calculate the maximum inclination of the string to the vertical.

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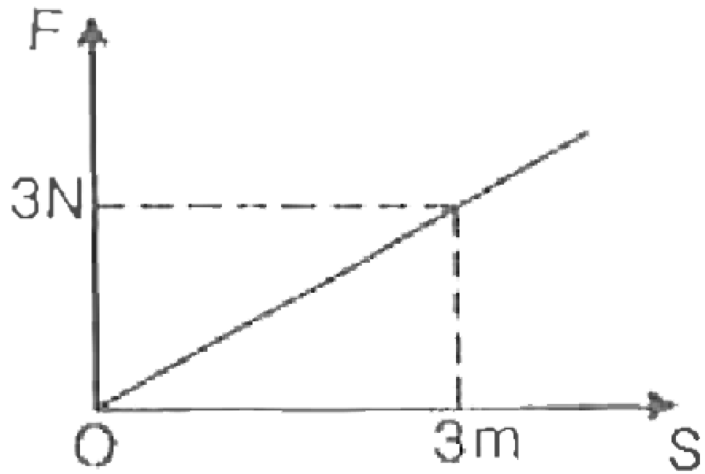
**7.** A body moves in a straight line under the action of a variable force which changes with displacement of the body as shown in the figure. What is the work done when the body has been displaced through (i) 0.2 m, (ii) 0.4 m

?

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**8.** A motor-cyclist is moving up an incline 1 in 100 at the speed of 40 kilometres per hour. What is the horse power of the engine if the motor-cycle and its rider together weigh 200 kg, coefficient of friction between tyre and road is 0.1 and air resistance to the system at this speed is 0.5 N per kg of the system ? (746 watts = 1 H.P.)

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**9.** A truck can move up a road which has a gradient of 1 m rise every 50 m with a speed of 24 kmph ? How fast will the same truck move down the hill with the same horse power ? The air resistance to the motion of the truck is 1/25 of its weight.

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**10.** A railroad flat car is loaded with crates with coefficient of friction 0.25 with the car. It the car is moving at 30 kmph, in what is the shortest distance over which the car can be stopped without letting the crates slide ?

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**11.** The handle of a floor mop makes an angle $\theta$ with the vertical. If $\mu_k$ and $\mu_s$ be the coefficients of kinetic and static friction between floor and mop, show that if $\theta$ is smaller than certain value $\theta_0$, the mop cannot be made to slide over across the floor, no matter how great a force is directed along the handle towards the centre. What is the angle $\theta_0$ ?

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**12.** A cord is used to lower vertically a block of mass M through a distance $d$ at a constant acceleration $g/4$. Find the work done by the cord on the block.

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**13.** A 2-kg block is dropped from a height of 0.4 m on a spring of force constant $k = 1960N$. Find the maximum distance the spring will be compressed. (Take $g = 9.8ms^{-2}$)

[Hint : Consider conservation of energy]

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**14.** A light spring is hung vertically from a fixed support and a heavy mass is attached to its. lower end. The mass is then slowly lowered to its equilibrium position: This stretches the spring by an amount d. If the same body is permitted to fall instead, through what distance does it stretch the string?

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**15.** 1 kg block collides with a horizontal massless spring of force constant $2N/m$. The block compresses the spring by 4m. If the coefficient of kinetic friction between the block and the· surface is 0.25, what was the speed of the block at the instant of collision? (take $g = 10m/s^2$)

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## Exercises B

**1.** A block of mass 2kg is placed on a trolley of mass 20 kg free to move on a frictionless floor. What are the frictional force, accelerations of the block and trolley if the block is pulled by a force of 3 N ? The coefficient of friction between block and trolley is 0.25. What will be the values of all three if the block is pulled by 8 N force ? At what value of the applied force will the bodies just tend to separate ?

[Hint : So long as the force applied does not produce the limiting frictional force the two will move with common acceleration. When the force applied exceeds that limiting value the block will move on the trolley with a different acceleration]

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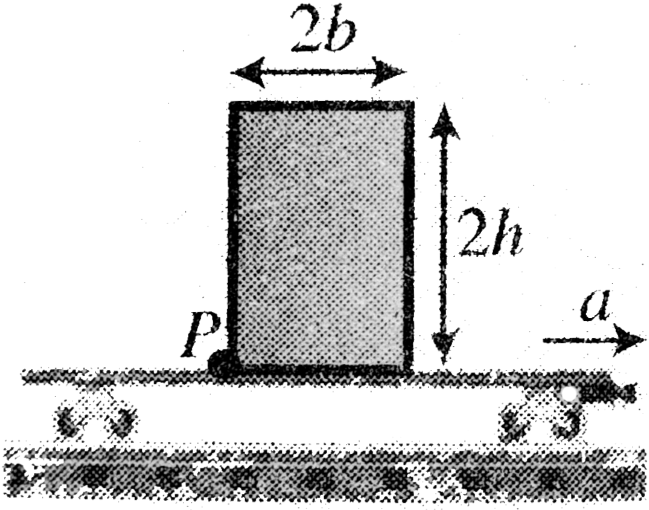
**2.** A block of mass $m$ height $2h$ and width $2b$ rests on a flat car which moves horizontally with constant acceleration a as shown in figure. Determine




a. the value of the acceleration at which slipping of the block on the car starts, if the coefficient of friction is $\mu$.

b. the value of the acceleration at which block topples about $A$, assuming sufficient friction to prevet slipping and

c. the shortest distance in which it can be stopped from a speed of $20ms^{-1}$ with constant deceleration so that the block is not disturbed. The following data are given $b = 0.6m, h = 0.9\mu = 0.5$ and $g = 10ms^{-2}$

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**3.** Assuming that a car whose CG is at a height $b$ from the rear wheel and at a distance c from the front wheel and at a height $h$ above the pavement, has sufficient power and there is sufficient friction, find the maximum acceleration that it would be able to develop without tipping over backward.

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**4.** A flexible but inextensible chain of length $l$ is placed on a smooth table with an initial length $1 = nl$ hanging down the table. Calcultae the velocity with which the chain will leave the table if released from rest. Consider two cases : (i) the hanging part does not touch the ground which is at a large distance,

(ii) the lower end of the hanging part initially just touches the ground. Also calculate the time in which the chain leaves the table in the first case

[Hint : Taking the table as the datum and $m$ as the mass per unit length of the chain, apply the principle of conservation of energy].

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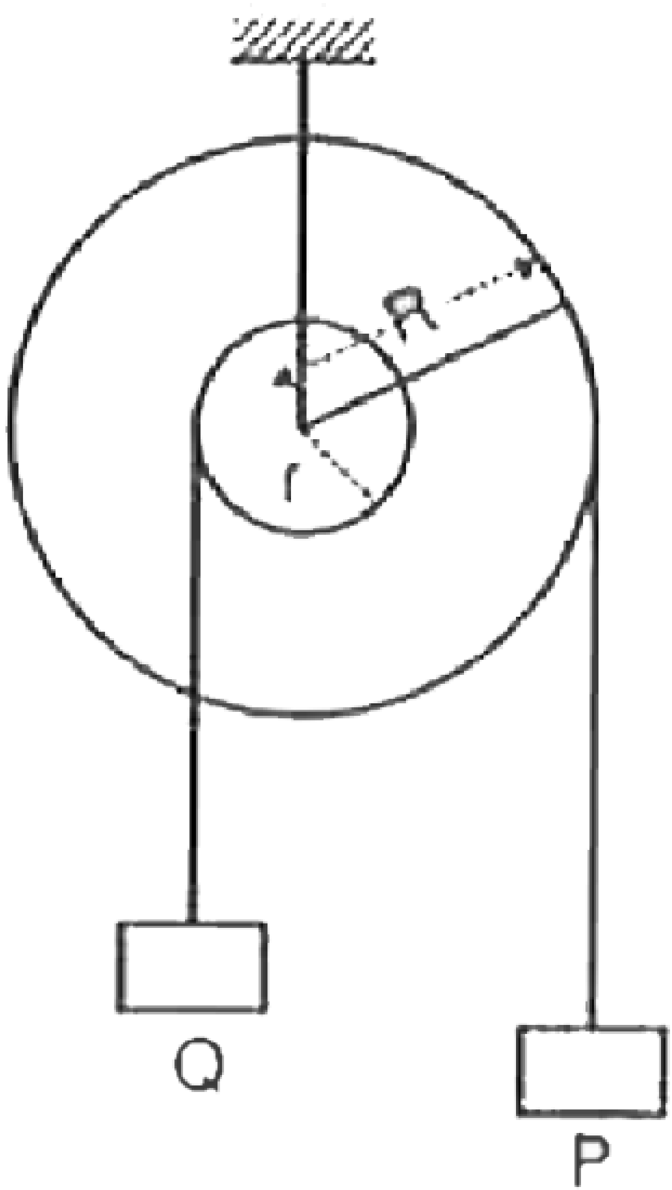
**5.** Calculate of velocity $v$ of the falling masss P after it has gone down by $x$ in an axle and wheel system of radii r and R respectively

(Figure 2.12)



[Hint : Let Q go up by $y$ when P down by x

Then $\frac{x}{y} = \frac{R}{r} \therefore x = \frac{R}{r}y$

Apply work-energy theorem to the system (P+Q+ceiling). Remember that the gravitational pulls are the lone forces external to the system, the tensions and pull of ceiling are internal forces of the system]

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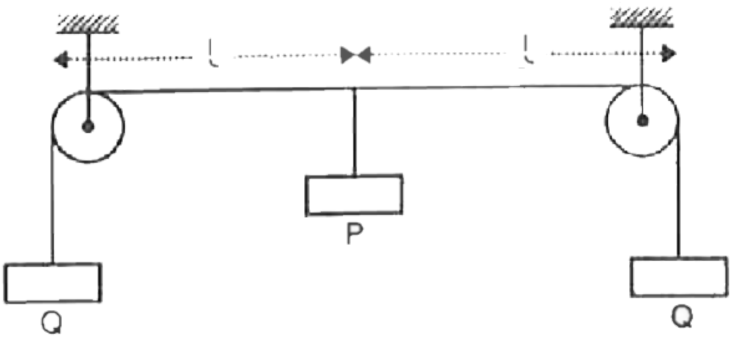
**6.** If the system if Figure 7.13 is released from rest in the configuration shown by solid lines, find the maximum distance $h$ through which the weight will fall. (Neglect friction and masses of pulleys) What will happen if $P = 2Q$ ?




[Hint : Apply work-energy theorem to the compound system consisting of the three masses and ceiling. To find intantaneous velocities of the masses apply the condition that the length of the string remains constant.

Also remember that gravitational pulls are the lone forces external to the system, the tension of the string and pull the internal force ceiling are of the system]

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**7.** A body of mass $m$ starts from rest down a plane of length $l$ at an angle $\theta$ with the horizontal. (a) find the body's speed at the bottom (b) How far will it slide horizontally on a similar surface after reaching the bottom of the incline. The coefficient of friction between the body and the plane is $\mu$.

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**8.** A block A of mass 4 kg is placed on another block B of mass 5 kg , and the block B rests on a smooth horizontal table . For sliding block A on B , a horizontal force of 12 N is required to be applied on A How much maximum force can be applied on B so that both A and B move togrther ? Also find out acceleration produced by this force .

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**9.** A block A of 10 kg rests on a rouch, horizontal table and is connected to another block of mass 5 kg by a string passing over frictionless pulley. This mass hangs vertically (a) Determinem the minimum weight of a third block C which can be placed on A to prevent it from sliding if $\mu_s = 0.2$ (b) The block C is suddenly lifted, then what is the acceleration of the block A ? $(\mu_k = 0.18)$

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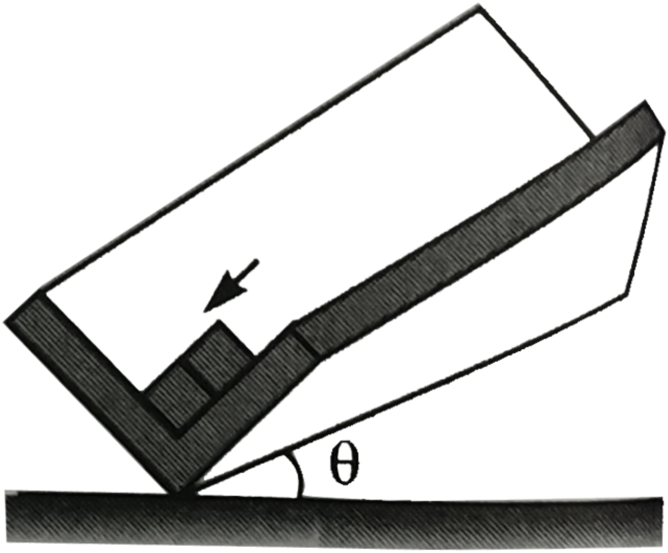
**10.** A block of mass $m$ slides down an inclined right angled trough .If the coefficient of friction between block and the trough is $\mu_k$

acceleration of the block down the plane is

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11. A force of 5 N acts on a 15 kg body initially at rest. The work done by the force during the first second of motion of the body is

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**12.** The force required to tow boat at a constant velocity is proportional to the velocity. If it takes 7460 W to two a certain boat at a speed of 4 kmph, how much horse power (1 H.P = 746 watts) will be required to tow it at a speed of 12 kmph ?

[Hint : Force $\propto$ velocity P = force $\times$ velocity]

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**13.** What power is developed by a grinding machine whose wheel has a radius of 20 cm and runs at 2.5 revolutions per second when the tool to be sharpened is held against the wheel with a force of 20 kg ? The coefficient of friction between the tool and the wheel is 0.3

[Hint : Power $= Fv = F\omega r = \mu N\omega r$ where N is the normal reaction]

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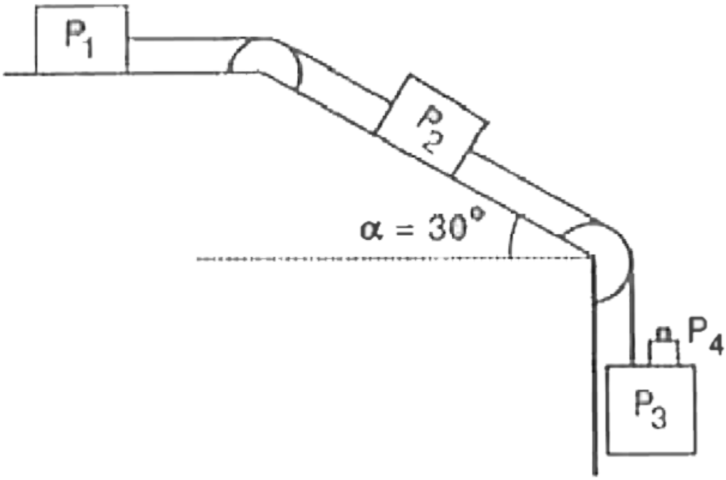
**14.** Consider the system of weights $P_1 = 1kg$, $P_2 = 2kg$, $P_3 = 5kg$ and $P_4 = 0.5kg$ as shown in Figure 7.14. $\alpha = 30^\circ$, $g = 9.8ms^{-2}$ and the coefficient of friction between the weights and the planes is 0.2 Find (a) the acceleration of the system (b) tensions in the strings between $P_1$ and $P_2$ and that between $P_2$ and $P_2$ respectively and (c) the force with which $P_4$ presses down on $P_3$




[Hint : Make free-body diagrams and apply Newton's law of motion after resolving the forces acting on a body along and perpendicular to the plane on which it lies]

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**15.** A plane surface, incline at $37^\circ$ to the horizontal is accelerated horizontally till a block of mass $m$ originally at rest with respect to the plane, just starts to slip up the plane. The coefficient of static friction between surfaces in contact is $\mu = \frac{5}{9}$ Find the acceleratiobn of the plane

[Hint : Applying D' Alembert's principle bring the system to rest. Make free-body diagram adn apply second law of motion]

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**16.** A weight of mass $m = 1$ kg attached to a spring of force constant $k = 20Nm^{-1}$ is able to oscillate on a rouch $(\mu = 0.05)$ steel rod. The displacement from the initial position of equilibrium is $a = 30$ cm. Find how many swings (i.e., movement from maximum to the equilibrium or back) will it make before coming to rest ? Take $g = 10ms^{-2}$

[Hint : Use energy conservation to find $a_n$ and hence have number of swings]

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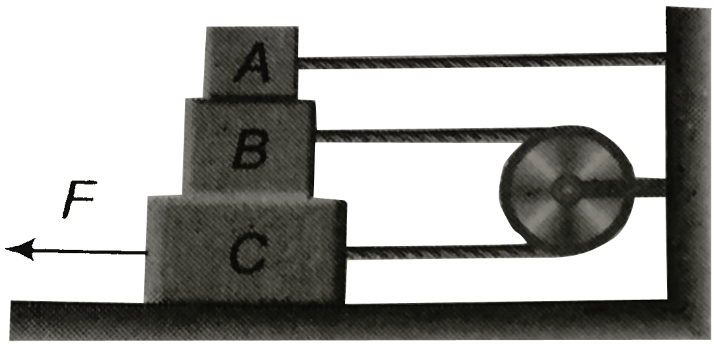
17. $M_A = 3kg, M_B = 4kg, M_C = 8kg.$

Coefficient of friction between any two surface is $0.25$ pulley is frictionless and string is massless .A is connected to wall through a massless right rod.

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**18.** The total mass of an elevator with a 80 kg man in it is 1000 kg. This elevator moving upward with a speed of 8 $m/\sec$, is brought to rest over a distance of 16m. The tension T in the cables supporting the elevator and the force exerted on the man by the elevator floor will respectively be-

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**19.** Two masses 1.65 kg and 3.30 kg are joined together by a massles rod parallel to an incline to $30^{\circ}$, over which both slide down, with the 1.65-kg mass trailing behind the 3.30-kg mass. The coefficient of friction between the first mass and the plane is 0.226 and that between the second mass and the plane is 0.113 Find (a) the tension in the rod, (b) the common acceleration of the two masses

[Hint : Make free-body diagram of the two bodies and consider their motion along and perpendicular to the plane]

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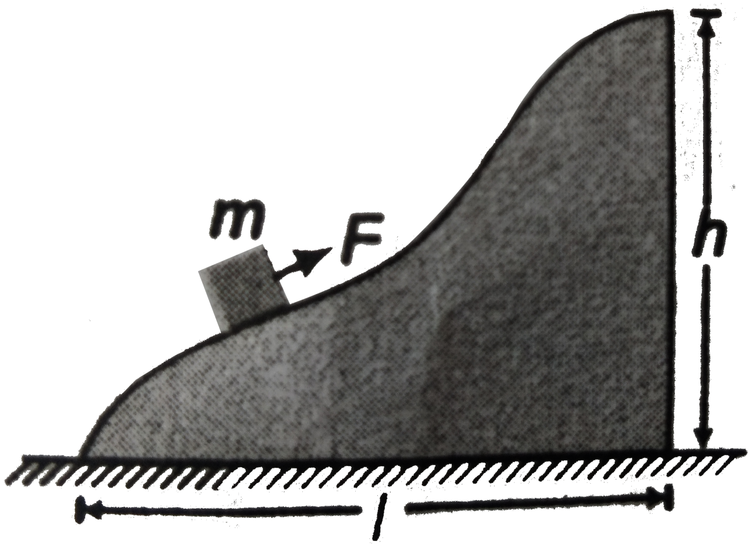
**20.** A body of mass m was slowly hauled up the hill as shown in the fig. by a force F which at each point was directed along a tangent to the trajectory. Find the work performed by this force, if the height of the hill is h, the length of its base is l and the coefficient ot friction is $\mu$.

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**21.** Following are three equations of motion

$S = ut + \frac{1}{2}at^2$ $\quad v(s) = \sqrt{u^2 + 2as}$

$v(t) = u + at$ Where $, S, u, t, a, v$ are respectively the displacement ( dependent variable ), initial ( constant ), time taken ( independent variable ), acceleration ( constant ) and final velocity ( dependent variable ) of the particle after time $t$. Find the velocity of the particle after 10 seconds if its acceleration is zero in interval (0 to 10s) $-$

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**22.** An escalator joins one floor with another 10 m above. The escalator is 20 m long and moves along its length at $1.0ms^{-1}$. (a) What power must its motor deliver if it is required to carry a maximum of 100 persons per minute of average mass 60 kg ? (b) If a man walks up the escalator in 10 s, how much work does the motor do on him ? (c) If this man turned around at the middle and walked down the escalatir so as to stay at the same floor, would the motor do work on him ?

[Hint : Apply work energy theorem]

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**23.** A ball of mass $m$ is projected horizontally with velocity $v$ into the barrel of a spring gun of mass M initially at rest on a frictionless table. The mass $m$ sticks in the barrel at the point of maximum compression of the spring. What fraction of the initial energy of the ball is stored in the spring ?

[Hint : Apply energy conservation principal to the system to obtain the maximum work done on the spring which is stored as potential energy of the spring. The spring will be progressively compressed till the two acquire a common velocity]

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**24.** A block of mass 2kg slides on a frictionless table with with a speed of $10ms^{-1}$. Directly in front of it and moving in the same direction is a block of mass 5 kg moving at $3ms^{-1}$. A massless spring with force constant $k=1120Nm^{-1}$ is attached to its back (the side facing 2 kg mass) When the blocks collide, what is the maximum compression of the spring ?

[Hint : Apply 'work energy' theorem to the system of block and principle of conservation of momentum]

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**25.** An ideal massless spring is compressed by 1 m by a force of 100 N. The same spring is placed at the bottom of a frictionless inclined plane $(\theta = 30^{\circ})$. A 10-kg mass is released from the top of the incline and is brought to rest momentarily after compressing the spring by 2m. Through what distance does the mass slide before coming to rest ?

[Hint : Apply work-energy theorem]

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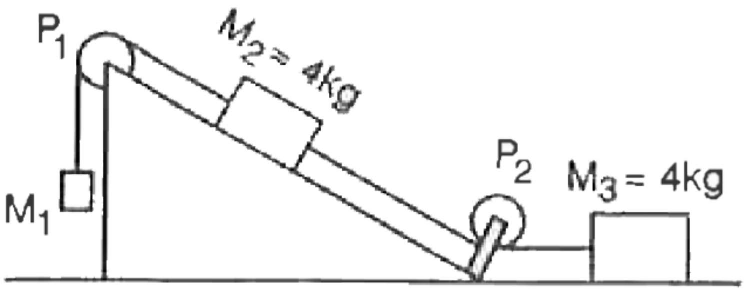
**26.** Masses $M_1$, $M_2$ and $M_3$ are connected by string of negligible mass which pass over massless and frictionless pulleys $P_1$ and $P_2$ as shown in figure 7.15. The masses move such that the string between $P_1$ and $P_2$ is parallel to the incline and the portion of the string between $P_2$ and $M_3$ is horizontal. The masses

$M_2$ and $M_3$ are 4.0 kg each and the coefficient of kinetic friction between the masses and the surfces is 0.25. The inclined plane makes an angle of $37^\circ$ with the horizontal. If the mass $M_1$ moves downwards with a uniform velocity, find (i) the mass of $M_1$, (ii) the tension in the horizontal portion.

$$\left(g = 9.8ms^{-2}, \sin 37^\circ = \frac{3}{5}\right)$$

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**27.** The handles of a table-drawer are equidistant from the sides of the drawer and are distant c from each other. Show that it will be impossible to pull the drawer out by pulling one handle if $l \leq \mu c$ where $l$ is the length of the drawer from back to front and $\mu$ is the coefficient of friction

[Hint : Consider a force applied at inclination $\theta$ with the knob of the handle. Apply conditions for translational and rotational equilibrium. Hence show it is possible to draw when

$$\tan\theta \geq \frac{l - \mu c}{\mu^2 c + 2\mu^2 x + 2\mu I}$$

Since $\tan\theta$ is positive, $l \geq \mu c$]

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**28.** A fixed pulley carries a weightless thread with masses $m_2$ and $m_1$ at its ends $(m_2 > m_1)$. There is friction between the thread and the pulley. If it is such that the thread starts slipping when the ratio of $m_2$ to $m_1$ is $n_0$. Find :

(a) the friction coefficient

(b) the acceleration of the masses when

$$\frac{m_2}{m_1} = n > n_0$$

[Hint : Consider an element of the thread of width $d\theta$ at angular distance $\theta$from the horzontal diameter of the pulley. The forces at the ends are T and T = dT. If dN is the normal reaction of the pulley on the element than df (frictional force on the element) $= \mu dN$ Resolving the tensions at the ends along and perpendicular to the radius vector of the element, we have for equilibrium of the element $dT = df$ and $dN = Td\theta$ Integrate from $T_1$ to $T_2$. $T_1 = m_1 g$ and $T_2 = m_2 g$.

These are obtained by considering equilibrium of $m_1$ and $m_2$]

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**29.** A block of mass $m$ is placed on the rough incline of a wedge of mass M and inclination $\alpha$ to the horizontal. Calculate the maximum and minimum acceleration that can be imparted to the wedge so that the block may remain stationary relative to the wedge. The coefficient iof friction between the block and the wedge is $\mu$.

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**30.** A car starts moving from rest along the circumference of a horizontal circle of radius $R = 49$ m with a constant tangential acceleration $a_t = 0.62ms^{-2}$. The coefficient of sliding friction is $\mu = 0.2$. What distancem will the car describe without sliding ?

[Hint : The car will start sliding when the frictional force attains its upper bound]

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**31.** A block of mass $m = 37.5kg$ is placed on a table of mass $M = 12.25kg$ which can move without friction on a levelm floor. A particle of mass $m_0 = 0.25kg$ moving horizontally with velocity $v_0 = 302ms^{-1}$ strikes the block completely inelastically. Calculate the distance through which the block moves relative to the table before they acquire a common velocity and also calculate that common velocity ($\mu$ between block and table = 0.25)

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**32.** Water from the bottom of a dam of depth $h$ comes out through a narrow pipe and strikes continuousy the tips of the blades of a water turbine. The length of each blade is R. Calculate the most advantaneous speed of rotation of the turbine

[Hint : The most advantageous speed corresponds to the development of maximum power in the turbine]

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**33.** A 60 kg man leaps vertically from a crouching position when his centre of mass is 40 cm above the ground. As his feet leave the floor his centre of mass is 90 cm above the ground and rises to 120 cm at the top of his leap. Calculate up upward froce, assumed constant, that the ground exerts on the man.

[Hint : Human body is a system of particles]

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**34.** What work should a man do to walk up a subway escalator moving down with speed $v$ ? The height of the escalator is $h$, and the man walks up the escalator at a speed u.

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**35.** An object of mass m slides down a hill of height h and of arbitrary shape and stops at the bottom because of friction. The coefficient of friction may be different for different segments of the path. Work required to return the object to its position along the same path by a tangential force is

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**36.** A skater standing on a perfectly floor holds on the nearby railing and then pushes himself away from the railing. By the time his arms are fully stretched and are about to leave the railing the gains velocity by $10m/s$. If his armlength is 0.9 m, what is the work done by the force of the railing on him ? Is any pseudo work done by it ? Find the exerted by the railing on the skater. Assume skater's mass 70 kg.

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