MODULE 3
FRICTION

- **Friction:**

  In reality, perfectly frictionless surface does not exist. The biggest gift to mankind given by science is 'FRICTION'. It is boon and curse for human being. In machines, friction is both a liability and an asset. It causes loss of power and/or wear which is undesirable. On the other hand, friction is essential for various holding and fastening devices as well as for friction drives and brakes. When subject to load, it acts opposite to the direction of motion. In this chapter, we shall consider the application of the principles of friction to engineering problems.

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- **Friction:**

  Knowledge of fundamentals of physics (forces and motion) and mathematical formulation learnt at higher secondary level of education (trigonometry), understanding of concepts of equilibrium of forces, knowledge of drawing Free Body Diagrams etc.

- **Friction:**

  1) Understanding theory and laws of friction
  2) Understanding Angle of friction, coefficient of friction, Angle of repose and cone of friction
  3) Understanding application of friction to blocks, wedges & blocks and ladder
  4) Understanding Conditions of tipping and sliding

Notations:

μ = Coefficient of friction

μ_s = Coefficient of static friction

μ_k= Coefficient of kinetic friction

$F_{(Limiting)}$ = Limiting frictional force

N = Normal reaction

Φ = Angle of friction

α= Angle of repose

F = Frictional force

w = Weight of block, wedge, ladder etc.

P = Power transmitted in kW

Formulae:

- Limiting frictional force,

  $F_{(Limiting)} = \mu_S N$ where μ_S = coefficient of static friction and N = Normal reaction

- $\tan\phi = \frac{F}{N} = \frac{\mu N}{N} = \mu$ where ϕ = Angle of friction, F = Frictional force and N = Normal reaction

- $\tan\phi = \tan\alpha = \tan\theta$

  so, $\phi = \alpha = \theta$ where ϕ = Angle of friction, α = Angle of repose

  and θ = Angle of inclined plane with horizontal

Definitions:

- **Friction:**

  Friction may be defined as a contact resistance exerted by on body upon a second body when the second body moves or tends to move past the first body. From this definition, it should be observed that friction is a retarding force always acting opposite to the motion or the tendency to move.

- **Static Friction:**

  It is the friction experienced between surfaces in contact when there is no sliding between them relative to each other under the action of external forces.

- **Limiting Friction**

  It is the maximum possible static friction. It is frictional force when sliding between the surfaces is about to start under the action of external forces. Limiting friction is directly proportional to normal reaction between the surfaces in contact, corresponding constant of proportionality is known as coefficient of static friction (μ_S).

$$F_{(Limiting)} = \mu_S N$$

- **Kinetic Friction**

  It is the friction experienced during the sliding motion between the surfaces in contact after attaining limiting friction under the action of external force. Kinetic friction is directly proportional to normal reaction between the surfaces in contact.

$$F_{(Kinetic)} = \mu_K N$$

- **Angle of Friction (ϕ)**

  It is the angle made by the resultant reaction (force) of normal reaction and limiting frictional force to the normal reaction. It is denoted by (ϕ).

- **Angle of Repose (α)**

  The term" angle of repose" is used with reference to an inclined surface. It is the maximum angle made by the inclined plane with the horizontal for which a body kept on the incline remains in impending sliding motion without any external force acting on it other than its own weight only.

Friction:

- **Laws of Friction:**

1. For the given two surfaces, the limiting frictional force depends on the normal reaction. Limiting frictional force is directly proportional to the normal reaction.
2. The friction is dependent on the degree of surface and kind of material of the two surfaces in contact.
3. Frictional force is independent of the area of contact between two surfaces and the speed of the body.

4. Coefficient of static friction μ_s is always greater than the coefficient of kinetic friction μ_k.

- **Theory of friction:**

  The following experiment is useful in explaining theory of friction as applied to dry unlubricated surfaces. Let a block of weight 'W' rest on a rough horizontal surface and assume a horizontal force 'P' to be applied to the block as shown in figure 3.1.

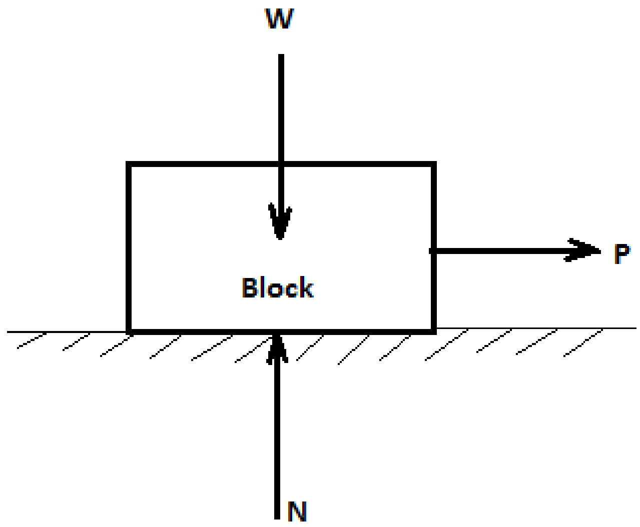


Figure 3.1

I] No friction: (frictional resistance F is also zero)

When P is zero, the block is in equilibrium

Applying conditions of equilibrium,

$\Sigma F_Y = 0$, (↑ +ve)

$N - W = 0$ So, $N = W$

II] Equilibrium:

When P is given increasing values that are insufficient to cause motion, the frictional resistance F increases correspondingly to maintain static equilibrium. Forces acting on the body in equilibrium are as shown in figure 3.2.

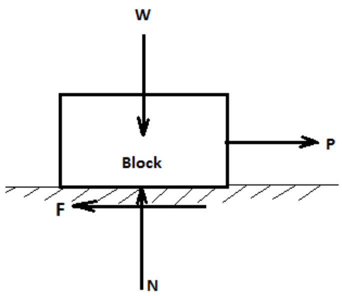


Figure 3.2

$\Sigma F_X = 0$, (→ +ve) $\Sigma F_y = 0$, (↑ +ve)

$P - F = 0$ $N - W = 0$

Additionally, $F < F_{MAX}$ where F_{MAX} is limiting force of friction.

III] Impending Motion:

Eventually, the block is on the verge of motion and at this instant, F attains its maximum available value (F_{MAX}). Any further increase in P then causes motion. The stage when F becomes F_{MAX} when the body is just about to slide, the motion is called impending sliding motion. F_{MAX} is called the limiting or maximum value frictional force. Body is still in static equilibrium. The region up to the point of impending motion is called the range of static friction, and in this stage the value of the friction force is determined by the equations of equilibrium. The FBD of block in impending motion is as shown in figure 3.3.

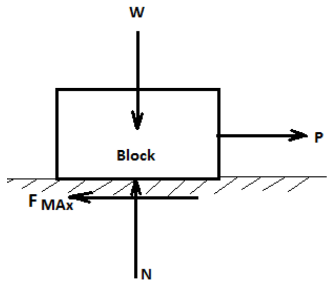


Figure 3.3

For body in static equilibrium,

$\Sigma F_X = 0$, ($\rightarrow$ +ve) $\Sigma F_Y = 0$, ($\uparrow$ +ve)

$P - F_{MAX} = 0$ $N - W = 0$

$P = F_{MAX}$ $N = W$

Additionally, $F = F_{MAX}$ where $F_{MAX} = \mu_{MAX} \times N = \mu_{Limiting} \times N = \mu_S \times N$

where μ_S is coefficient of static friction.

IV] Dynamic Friction:

Any further increase in P then causes motion, but surprisingly, the value of F does not stay at its maximum value but decreases rapidly to a kinetic value which remains fairly constant, as depicted on the graph along with the FBD of the block in figure 3.4.

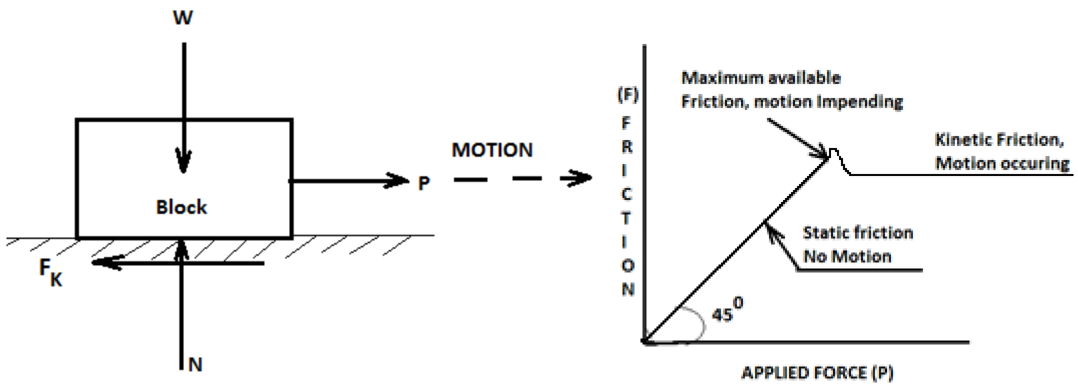


Figure 3.4

One way of understanding these results is to examine a magnified view of the contact surfaces. These are shown in figure 3.5 together with a FBD of the block. The surfaces are assumed to be composed of irregularities (which can look like hills and valleys) which mesh together. Support is necessarily intermittent and exists at the mating humps. The direction of each of the reactions on the block R_1, R_2, R_3 etc. depends not only on the geometric profile of the irregularities but also on the extent of local deformation at each contact point. The total normal force N is the sum of n-components of the R's and the total frictional force F is the sum of tangential components of the R's. When the surfaces are in relative motion, the contacts are more nearly along the tops of the humps, and the tangential components of R's are smaller than when the surfaces are at rest relative to one another. The frictional resistance F is developed by the effort of P to break this meshing or interlocking of irregularities.

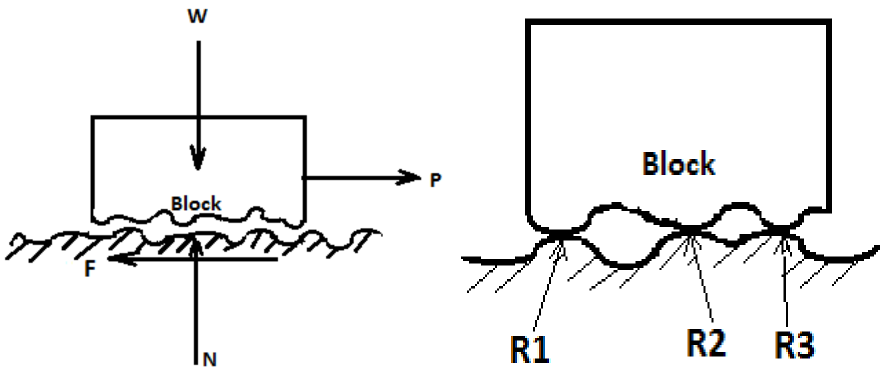


Figure 3.5

It is apparent that frictional resistance depends on the amount of wedging action between hills and valleys of the contact surfaces. The measure of this wedging action depends on the normal pressure N between the surfaces. As a result, the maximum frictional resistance that may exists is proportional to the normal pressure and is expressed as

$$F_{MAX} \propto N$$

This relation may be reduced to an equation by adding a constant of proportionality, say μ, which depends on the roughness of the contact surfaces. This constant is called the **Coefficient of friction**, and above relation may be written as

$$F_{MAX} = \mu N$$

Where F_{MAX} is the maximum available frictional force developed when motion is impending.
In an actual situation, the equations of equilibrium will determine the value of F to maintain the equilibrium. Of course, if F as determined from equilibrium conditions is less than or just equal to the maximum available friction, equilibrium will exist.

- **Angle of Friction and Angle of Repose:**

Angle of Friction:

The angle made by the resultant reaction of normal reaction and limiting frictional force to the normal reaction is known as angle of friction. It is usually denoted by a symbol 'ϕ'.

Explanation: Consider a block of weight W shown in figure 3.6 subjected to a pull 'P'. The Value of applied force 'P' causes impending motion of the block. Let 'N' be the normal reaction and 'F' be the frictional force developed. Normal reaction, N and frictional force, F are mutually perpendicular and can be replaced by a single force 'R' which makes an angle 'ϕ' with normal reaction. This angle is known as angle of friction.

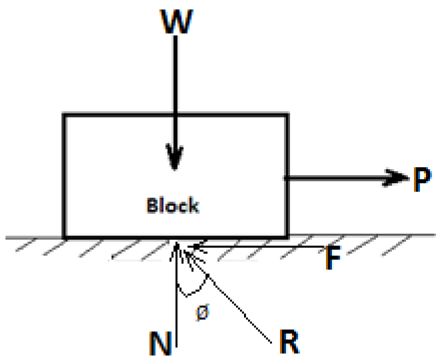


Figure 3.6

$$\tan\phi = \frac{F}{N} = \frac{\mu N}{N} = \mu$$

$$\phi = \tan^{-1}\mu$$

$$R = \sqrt{N^2 + F^2} = \sqrt{N^2 + \mu^2 F^2}$$

$$\therefore R = N\sqrt{1 + \mu^2}$$

Angle of Repose:

It is the minimum angle of inclination of a plane with the horizontal at which the body kept will just slide down on it without the application of any external force but due to self weight.

Explanation: Consider a block of weight 'W' resting on an inclined plane as shown in figure 3.7. Let the inclined plane makes an angle of θ with the horizontal. When θ *is* small, block is will be in equilibrium on inclined plane. The component of weight W sin θ down the plane is balanced by frictional force F. As θ kept on increasing, W sin θ will also increase but being balanced by increase in frictional force F. when θ reaches a certain value say $\theta = \alpha$, block is at the verge of sliding and frictional force reaches the limiting condition. This value $\theta = \alpha$ is known as angle of repose.

Now, consider the equilibrium of the block.

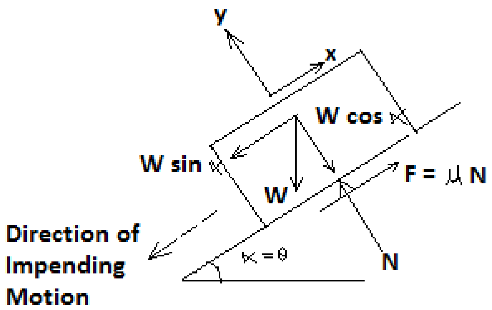


Figure 3.7

Applying conditions of equilibrium,

$$\sum F_Y = 0 \ (\uparrow +ve) \qquad N - W\cos\alpha = 0$$

$$\therefore \ N = W\cos\alpha \ \text{-----------}(1)$$

$$\sum F_X = 0 \ (\rightarrow +ve) \qquad F - W\sin\alpha = 0$$

$$\therefore \ F = W\sin\alpha \qquad \text{But } F = \mu N$$

$$\mu N = W\sin\alpha$$

But from equation (1)

$$N = W\cos\alpha$$

$$\mu W\cos\alpha = W\sin\alpha$$

$$\therefore \mu = \frac{W\sin\alpha}{W\cos\alpha}$$

$$\therefore \mu = \tan\alpha$$

$$\text{But } \theta = \alpha \text{ and } \mu = \tan\phi$$

$$\therefore \tan\phi = \tan\alpha = \tan\theta$$

$$\therefore \ \theta = \alpha = \phi$$

only at the time of impending motion.

When, $\theta < \phi$, Body is in equilibrium

$\therefore \theta = \alpha = \phi$, Body is in impending motion

$\therefore \theta > \phi$, body is in motion

- **Cone of Friction and its significance in the study of friction:**
  When a body is having impending motion in the direction of applied force P, the maximum frictional resistance will cause angle of friction 'ϕ'with the normal reaction to be maximum. If the force P is applied in some other direction, for impending motion again the resultant reaction makes limiting angle of friction with the normal reaction and the direction of frictional resistance will be tangential to the surfaces in contact opposite to, this other direction of applied force P. Thus when the direction of applied force P is gradually changed through 360^0, the resultant R generates an inverted right circular cone whose semi-vertex angle equal to ϕ. This inverted cone with the semi vertex angle ϕ is known as *Cone of friction.* (Refer figure 3.8)

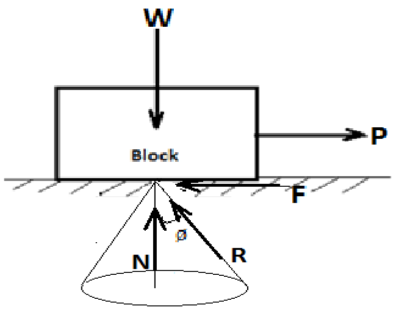


Figure 3.8

Significance: If the resultant reaction is on the surface of this inverted right circular cone whose semi vertex angle is limiting angle of friction ϕ, the motion of the body is impending. If the resultant is within this cone, the body is stationary.

List applications of friction:

Ans: Though we always regard friction for the loss of energy in machines, wear and tear of moving parts, loss of efficiency etc. friction also has its importance and usefulness in human's day to day life.

a) We can walk without slipping because of friction.

b) The tyres of vehicles are especially made rough thereby increasing friction for a better road grip and counter the skidding, making journey safe.

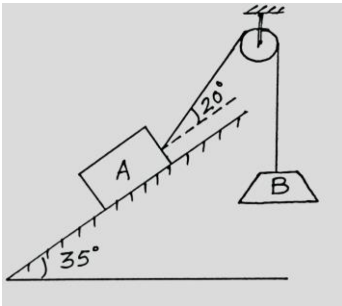
c) Transmission of power by use of belts and ropes is possible due to friction.

d) Screw jack which is able to lift heavy loads works on friction force due to which the load remains in the lifted portion even after the effort is removed.

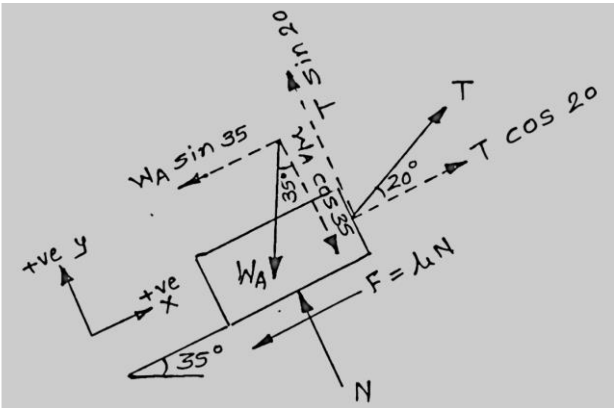
Friction:

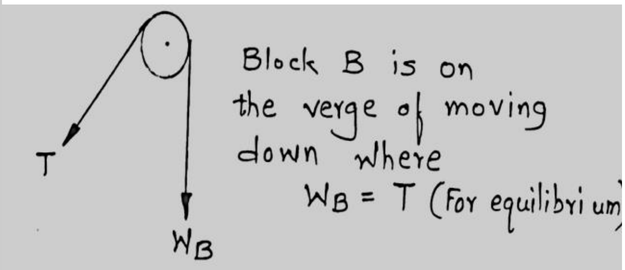
- **Block friction:**

1) Block A of weight 2000 N is kept on a plane inclined at 35^0. It is connected to a weight B by an inextensible string passing over a smooth pulley. Determine weight of B so that it just moves down. Take coefficient of friction is μ =0.2.



Solution: F.B.D of block A **FBD of Pulley**





Applying condition of equilibrium on block A

Σ **F_X = 0 ($\rightarrow$ +ve)**

$- W_A \sin 35 - F + T \cos 20 = 0$

$- 2000 \sin 35 - \mu N + T \cos 20 = 0$

$- 1147.15 – 0.2 N + T (0.94) = 0$

$- 0.2 N + T (0.94) = 1147.150$ ---------------(I)

Σ **F_Y = 0 ($\uparrow$ +ve)**

$N - W_A \cos 35 + T \sin 20 = 0$

$N - 2000 \cos 35 + T (0.342) = 0$

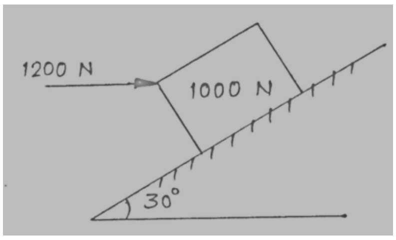
$N + 0.342 T = 1638.3$ ---------------(II)

Solving equation (I) and (II) simultaneously, we get

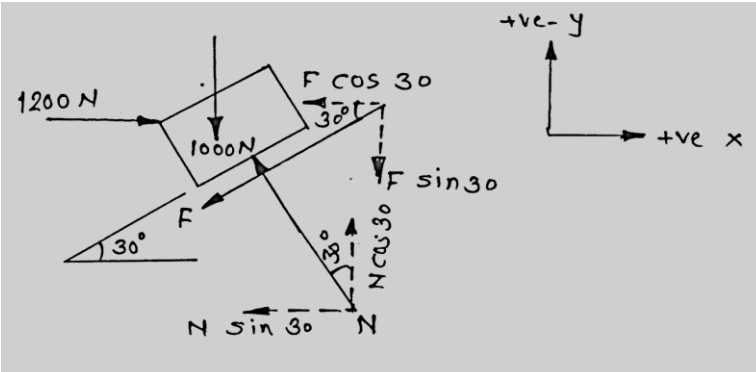
N = 1138.11 N and T = 1462.52 N

Weight of block B = 1462.52 N so that it is on the verge of moving down.

2) If a horizontal force of 1200 N is applied horizontally on a block weighing 1000 N then what will be direction of motion of the block. Take μ = 0.3.



Solution: Draw F.B.D of block



Applying conditions of equilibrium on block

$\sum$ **F_X = 0 ($\rightarrow$ +ve)**

1200 - F cos 30 – N sin 30= 0

1200 – (μ N 0.866) – 0.5 N = 0

0.866 (0.3 N) + 0.5 N = 1200

(0.2598 + 0.5) N = 1200

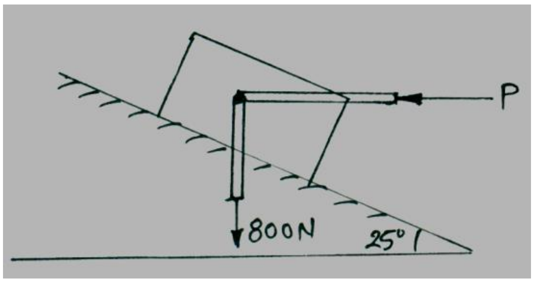
N = 1579.36 N

Frictional Force, F = μ N = 0.3 x 1579.36 = 473.7 N

Since applied force P = 1200N is greater than frictional force F = 473.7 N, hence block will move in upward direction.

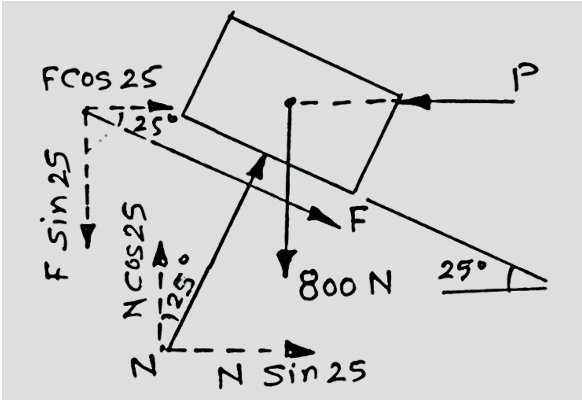
3) **A support block is acted upon by two forces as shown in the figure. Knowing that the coefficients of friction between the block and the incline are μ_S = 0.35 and μ_K = 0.25, determine the force P required,**
   i) To start the block moving up the incline.
   ii) To keep it moving up.
   iii) To prevent it from sliding down.

   Where μ_S= Coefficient of static friction, μ_K = Coefficient of kinetic friction



Solution: i) To start the block moving up the incline.

FBD of block moving in upward direction.



Applying condition of equilibrium on block

$\sum \sum F_X = 0$ (→+ve)

- P + N sin 25 + F cos 25 = 0

- P + (0.422 N) + (0.35 N cos 25) = 0

- P + (0.423 + 0.317) N = 0

P = 0.740 N -------------(I)

$\sum \sum F_Y = 0$ (↑ +ve)

- 800 + N cos 25 - F sin 25 = 0

- 800 + (0.906 N) – (0.35 N sin 25) = 0

-800 + (0.906 – 0.147) N = 0

N = 1054.01 N ---------(II)

Substitute value N in equation (I)

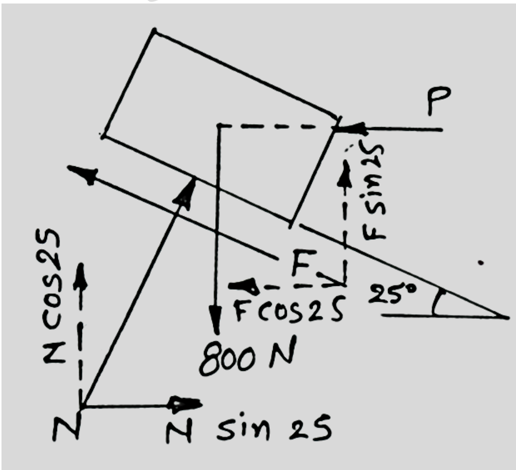
P = 0.74 N

P = 0.74 X 1054.01

P = 779.96 N

(ii) To keep it moving up.

Draw F.B.D of block moving up



Applying condition of equilibrium on block

$\sum \sum F_X = 0$ (→+ve)

- P + N sin 25 + F cos 25 = 0

- P + (0.423 N)+ (0.25 N cos 25) = 0

- P + (0.422 + 0.226) N = 0

P = 0.648 N --------------(I)

$\sum \sum F_Y = 0$ (↑ +ve)

- 800 + N cos 25 - F sin 25 = 0

- 800 + (0.906 N) – (0.25 N sin 25) = 0

- 800 + (0.906 – 0.1056) N = 0

N = 999.5 N ---------------(II)

Substitute value N in equation (I)

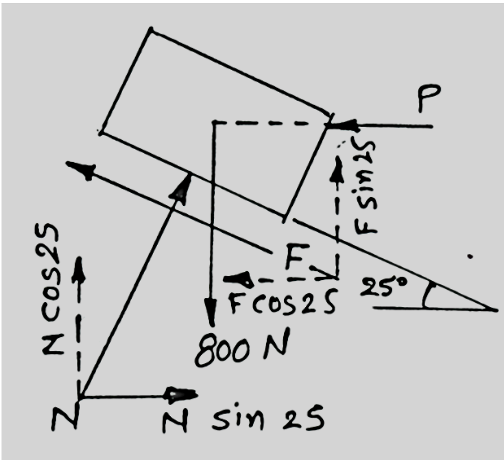
P = 0.649 N

P = 0.649 X 999.5

P = 648.67 N

(iii) To prevent it from sliding down

Draw F.B.D of block sliding down



Applying condition of equilibrium on block

Σ **$\sum F_X = 0$ ($\rightarrow$+ve)**

- P + N sin 25 - F cos 25 = 0

- P + (0.422 N) - (0.35 N cos 25) = 0

- P + (0.423 – 0.317) N = 0

P = 0.105 N --------------(I)

Σ **$\sum F_Y = 0$ ($\uparrow$ +ve)**

- 800 + N cos 25 + F sin 25= 0

- 800 + (0.906 N) + (0.35 N sin 25) = 0

- 800 + (0.906 + 0.147) N = 0

N = 759.7 N --------------(II)

Substitute value N in equation (I)

P = 0. 105 N

P = (0. 105 X 759.7)

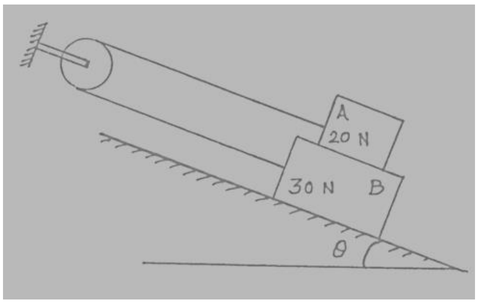
P = 79.76 N

4) 20 N block A and 30 N block B are supported by an inclined plane which is held in position shown in figure. Knowing that the coefficient of friction is 0.15 between the two blocks and zero between block B and incline, determine the value of θ for which motion is impending.

$P = \sigma$

$$\rightarrow \frac{(1316 - 684) \text{ x } 100}{1000} = e^{\mu\theta}\theta\mu\, N_1 \, {}^{11}\!/_{24} \pi\phi = \frac{360 \text{ r}}{1.25 \text{ r}}$$

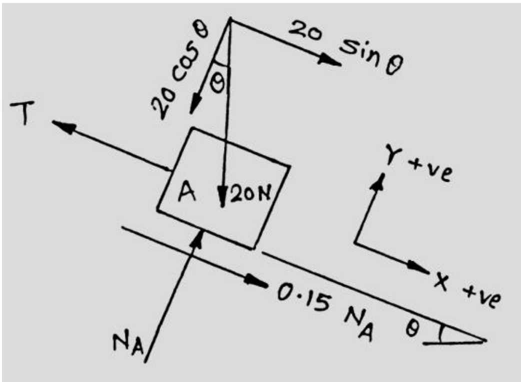
$$\alpha = \tan^{-1} 0.3 \frac{(T_1 - T_2) \text{ x } V}{1000} e^{0.25 \text{ x } 2.618}$$

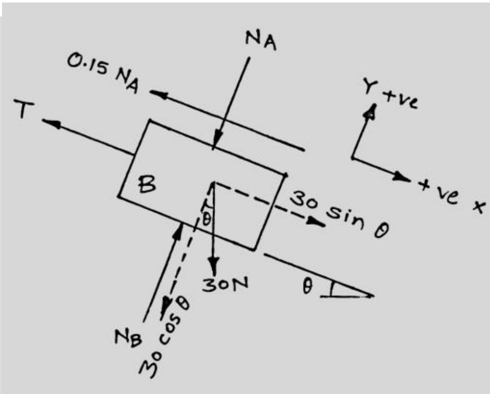


Solution: Assuming pulley to be massless and frictionless, same tension will act on both blocks.

Block B (30 N) being heavier than block A (20 N) will have impending downward motion on the inclined plane

FBD of block A (20 N) **FBD of block B (30 N)**





Applying conditions of equilibrium to block A

$\sum$ **F_y = 0 ($\uparrow$ +ve)**

$N_A - 20 \cos \theta = 0$

$N_A = 20 \cos \theta$ --------------(I)

$\sum$ **F_x = 0 ($\rightarrow$+ve)**

$20 \sin \theta + (0.15\ N_A) - T = 0$

Substituting value of N_A from equation (I)

$20 \sin \theta + (0.15 \text{ x } 20 \cos \theta) - T = 0$

$T = 20 \sin \theta + 3 \cos \theta$ -------------(II)

Applying conditions of equilibrium to block B

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$N_B - N_A - 30 \cos \theta = 0$

Put value of N_A from equation (I)

$N_B - 20 \cos \theta - 30 \cos \theta = 0$

$N_B = 50 \cos \theta$ ----------------(III)

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

$30 \sin \theta - 0.15\ N_A - T = 0$

Put value of N_A and T from equations (I) and (II)

$30 \sin \theta - (0.15 \text{ x } 20 \cos \theta) - (20 \sin \theta + 3 \cos \theta) = 0$

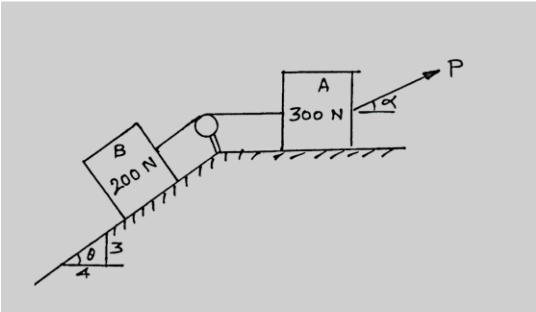
$30 \sin\theta - 3\cos\theta - 20\sin\theta - 3\cos\theta = 0$

$10 \sin\theta = 6\cos\theta$

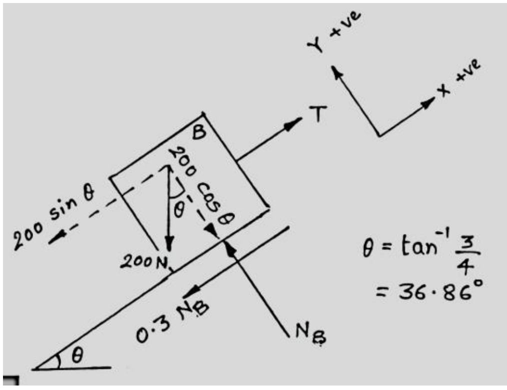
$\tan\theta = 0.6$

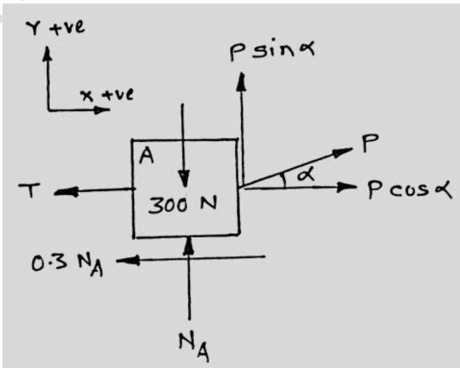
$\therefore$ **θ = 30. 96^0**

5) Find the least force P that will just start the system of blocks moving to the right. Take μ = 0.3. Assume smooth pulley.



Solution: FBD OF 200 N block **FBD of 300 N block**





Applying Conditions of equilibrium to 200 N block

$\Sigma F_X = 0$ ($\rightarrow$+ve)

$T - (200 \sin 36.86) - 0.3\, N_B = 0$

$T - 0.3\, N_B = 119.07$ --------------(I)

$\Sigma F_Y = 0$ ($\uparrow$ +ve)

$N_B - (200 \cos 36.86) = 0$

$N_B = 160.02$ N

Putting this value in equation (I)

$T - (0.3 \times 160.02) = 119.07$

$\therefore T = 167.07$ N

Applying Conditions of equilibrium to 300 N block

$\Sigma F_X = 0$ ($\rightarrow$+ve)

$P \cos\alpha - T - 0.3\, N_A = 0$

$P \cos\alpha - 167.07 - 0.3\, N_A = 0$

$\therefore P \cos\alpha = 167.07 + 0.3$ NA ----------------(II)

$\sum F_Y = 0$ ($\uparrow$ +ve) $N_A = 300 - P \sin \alpha$

$P \sin \alpha + N_A - 300 = 0$

Putting this value in equation (II)

$\therefore P \cos \alpha = 167.07 + 0.3\,(300 - P \sin \alpha)$

$P (\cos \alpha + 0.3 \sin \alpha) = 257.07$

$$P = \frac{257.07}{\cos \alpha + 0.3 \sin \alpha} \text{-------------------(III)}$$

P = f (α), for P to be minimum, $\frac{dp}{d\alpha} = 0$

$$\frac{d_p}{d_\alpha} = \frac{0-257.07(-sinsin\,\alpha+0.3coscos\,\alpha)}{\alpha+0.3sinsin\,\alpha)^{\,2}} = 0$$

$-\sin \alpha + 0.3 \cos \alpha = 0$

$\sin \alpha = 0.3 \cos \alpha$

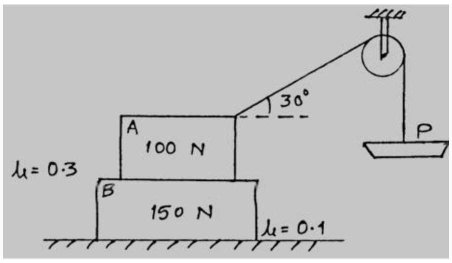
$\tan \alpha = 0.3$

$\alpha = \tan^{-1} 0.3 = 16.7^0$

Putting value of α in equation (III)

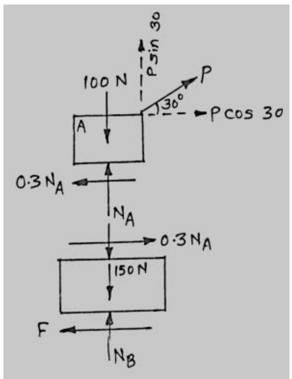
$$P_{Least} = \frac{257.07}{\cos 16.7 + 0.3 \sin 16.7} = 247.12 \text{ N}$$

6) **Two blocks A = 100 N and B = 150 N are resting on the ground as shown in figure. Coefficient of friction between ground and block B is 0.10 and between blocks B and A is 0.30. Find the minimum weight W in the pan so that motion starts. Find whether B is stationary w.r.t. ground and A moves or B is stationary w.r.t. A. Assume pulley to be massless and frictionless.**



Solution: 100 N block A and weight in the pan P are connected by same string passing over a smooth pulley. Hence tension in the string T = Weight in the pan P will act on 100 N block. Two impending motions are possible in this case. 1) Either 100 N block slips and 150 N block remains stationary or 2) the 100 N and 150 N blocks move together with slipping between 150 N block and the ground.

Case 1) : 100 N block slips and 150 N block remains stationary



Applying conditions of equilibrium,

$\Sigma F_X = 0$ ($\rightarrow$+ve)

$P \cos 30 - 0.3 N_A = 0$

$N_A = 2.886 P$ -----------------(I)

$\Sigma F_Y = 0$ ($\uparrow$ +ve)

$N_A + P \sin 30 - 100 = 0$

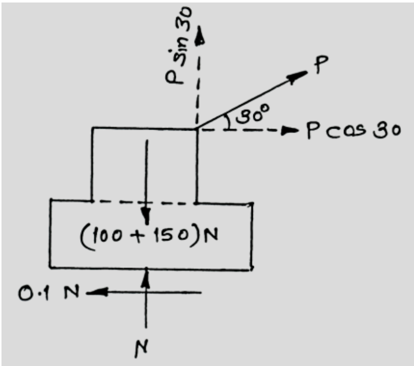
Put value of $N_A = 2.886 P$ in above equation

$2.886 P + 0.5 P - 100 = 0$

$P = 29.533$ N ----------------(II)

Case 2) : 100 N and 150 N blocks slip together

FBD of (100 N + 150 N) blocks together



Applying conditions of equilibrium,

$\Sigma F_X = 0$ ($\rightarrow$+ve)

$P \cos 30 - 0.1 N = 0$

$P = 0.116 N$ -----------------(III)

$\Sigma F_Y = 0$ ($\uparrow$ +ve)

$N + P \sin 30 - 250 = 0$

$N = 250 - 0.5 P$

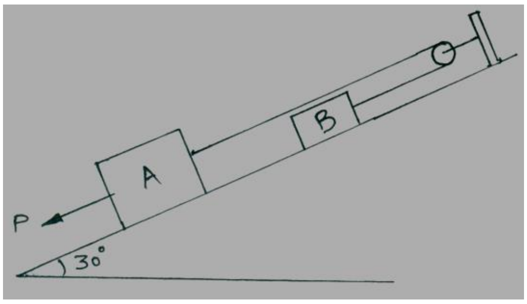
Substituting above equation in equation (III)

$P = 0.116 (250 - 0.5 P)$

$P = 27.41$ N -----------------(IV)

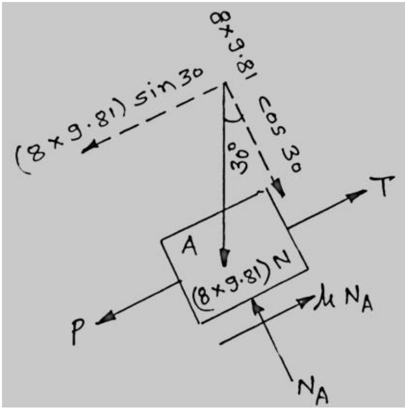
From (II) and (IV) it can be said that when P > 27.41 N, both the blocks start moving together as a single body i.e. block A is stationary w.r.t. block B and both the blocks are moving w.r.t. ground. When P > 29.533 N, blocks A and B will move relative to each other i.e. they will slip over each other.

7) Determine the force ‘P’ to cause motion to impend. Take masses of blocks A and B as 8 kg and 4 kg respectively and the coefficient of sliding friction as 0.3. The force ‘P’ and rope are parallel to the inclined plane. Assume frictionless pulley. **(Dec 2010) [08 Marks]**

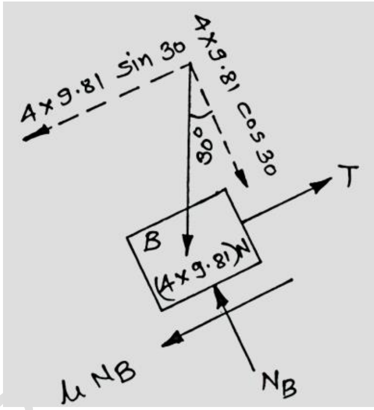


Solution: Under the action of force P, block A has downward impending motion and block B has upward impending motion. Draw FBD of block A and B and apply conditions of equilibrium.

FBD of 4 kg block A



FBD of 8 kg block B



Applying conditions of equilibrium to 4 kg block,

$\sum$ **F_Y = 0 ($\uparrow$ + ve)**

N_B – (4 x 9.81 x cos 30) = 0

N_B = 33.983 N

$\sum$ **F_X = 0 ($\rightarrow$+ ve)**

T – 0.3 N_B – (4 x 9.81 x sin 30) = 0

T – (0.3 x 33.983) – 19.62 = 0

T = 29.81 N

Applying conditions of equilibrium to 4 kg block,

$\sum$ **F_Y = 0 ($\uparrow$ + ve)**

N_A – (8 x 9.81 x cos 30) = 0

N_A = 67.96 N

$\sum$ **F_X = 0 ($\rightarrow$+ ve)**

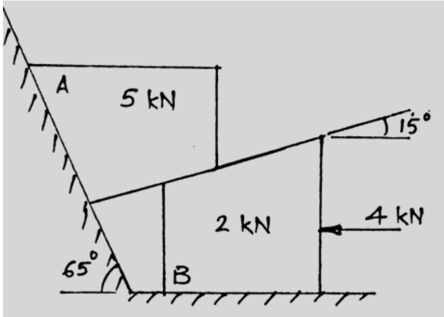
- P + 0.3 N_A + T – (8 x 9.81 x sin 30) = 0

P = 10.96 N

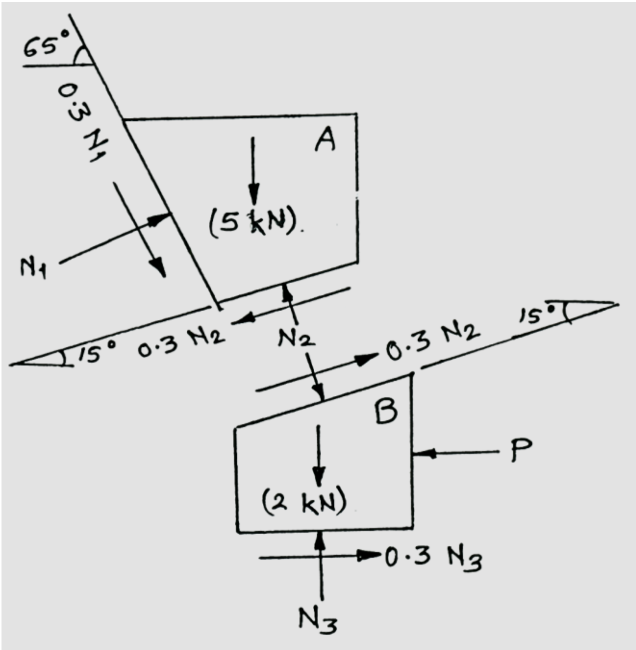
- **Wedge and Block friction:**

  1) If coefficient of friction at all sliding surfaces is 0.3, find whether the 4 KN force is enough to move 5

KN load of inclined surfaces.



Solution: F.B.D of block A and B



Applying condition of equilibrium to block A,

Σ **F_X = 0 ($\rightarrow$+ve)**

$- N_2 \sin 15 – F_2 \cos 15 + F_1 \cos 65 + N_1 \sin 65 = 0$

$- 0.258 N_2 - (0.3 N_2) 0.965 + (0.3 N_1) 0.422 + 0.906 N_1 = 0$

$- 0. 548 N_2 + 1.0326 N_1 = 0$ ----------------(I)

Σ **F_Y = 0 ($\uparrow$ +ve)**

$- 5 + N_2 \cos 15 - F_2 \sin 15 + N_1 \cos 65 - F_1 \sin 65 = 0$

$- 5 + 0.965 N_2 – (0.3 N_2) 0.258 + 0.422 N_1 – (0.3 N_1) 0.906 = 0$

$0.8876 N_2 + 0.1502 N_1 = 5$ -----------------(II)

Solving equations (I) and (II) simultaneously

N_1= 2.74 kN and N_2 = 5.16 kN

Applying condition of equilibrium to wedge B,

Σ **F_X = 0 ($\rightarrow$+ve)**

$F_3 - P + F_2 \cos 15 + N_2 \sin 15 = 0$

$(0.3\ N_3) - P + (0.3\ N_2)\ 0.965 + 0.258\ N_2 = 2.86$

$0.3\ N_3 + 0.5475\ N_2 = P$

Substituting value of N_2 in above equation

So $P = 0.3\ N_3 + 2.8251$ ------------------(III)

$\sum F_Y = 0$ ($\uparrow$ +ve)

$-2 + N_3 + F_2 \sin 15 - N_2 \cos 15 = 0$

$-2 - N_3 + (0.3\ N_2)\ 0.258 - 0.965\ N_2 = 0$

Substituting value of N_2 in above equation

$N_3 = -6.58$ kN

$N_3 = 6.58$ kN (-ve sign indicates assumed direction is wrong hence direction is to be reverse)

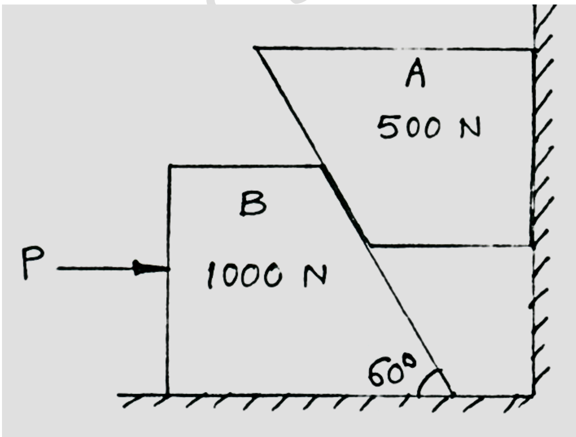
Substituting value of N_3 in equation (III)

$P = 0.3\ N_3 + 2.8251$

$P = 4.8$ kN

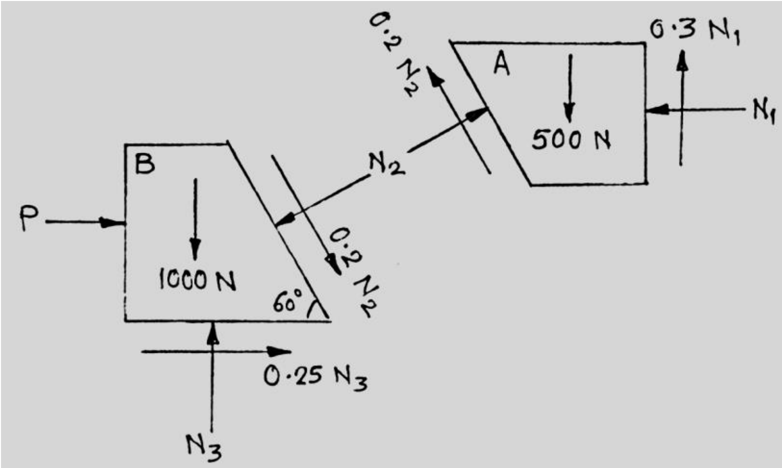
As P (4.8 kN) is more than the given applied force of 4 kN, it is not sufficient to move the block of 5 kN.

2) Assuming the values for μ = 0.25 at the floor and 0.3 at the wall and 0.2 between the blocks, find the minimum value of a horizontal force P applied to the lower block that will hold the system in equilibrium. [May'12]



Solution: In the absence of applied load P, body A will be moving down and body B will be sliding to the left. When force P is applied gradually, motion of block B gets retarded and at some minimum value of P, the blocks A and B will be in static equilibrium.

FBD of blocks A and B:



Applying conditions of equilibrium to 500 N block,

$\sum F_X = 0$ **(→+ve)**

$-0.2 N_2 \cos 60 + N_2 \sin 60 - N_1 = 0$

$N_1 = 0.766 N_1$ --------------- (I)

$\sum F_Y = 0$ **(↑ +ve)**

$0.2 N_2 \sin 60 + N_2 \cos 60 - 500 + 0.3 N_1 = 0$

Substituting value of N_1 from equation (I)

$0.673 N_2 - 500 + (0.3 \times 0.766 \times N_2) = 0$

$N_2 = 553.70$ N ---------------(II)

Applying conditions of equilibrium to 1000 N block,

$\sum F_X = 0$ **(→+ve)**

$P + 0.25 N_3 + 0.2 N_2 \cos 60 - N_2 \sin 60 = 0$

Substituting value of N_2 from equation (II)

$P + 0.25 N_3 + (0.2 \times 553.70 \cos 60) - 553.7 \sin 60 = 0$

$P + 0.25 N_3 - 424.15 = 0$ ----------------(III)

$\sum F_Y = 0$ **(↑ +ve)**

$N_3 - 0.2 N_2 \sin 60 - N_2 \cos 60 - 1000 = 0$

Substituting value of N_2 from equation (I)

$N_3 - (0.2 \times 553.70 \sin 60) - 553.70 \cos 60 - 1000 = 0$

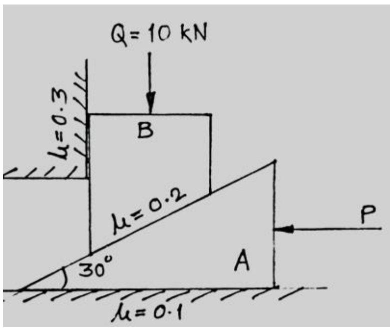
$N_3 = 1372.76$ N ---------------(IV)

Substituting value of N_3 in equation (III)

$P = 424.15 - (0.25 \times 1372.76)$

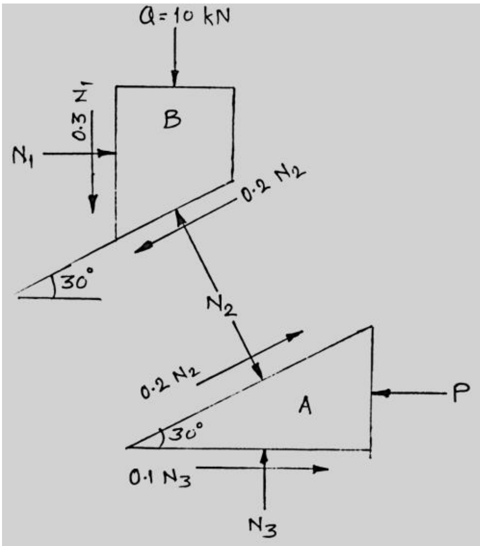
$P = 80.96$ N

3) A wedge A and block B are subjected to known weight Q = 10 kN and force P as shown in figure. Determine the range of force P for which there is no motion.



Solution: Case I: Block B has impending motion in upward direction

FBD of blocks A and B



For equilibrium of block B,

$\sum F_X = 0$ **(→+ve)**

$N_1 - 0.2\ N_2 \cos 30 - N_2 \sin 30 = 0$

$N_1 - 0.67\ N_2 = 0$ -----------------(I)

$\sum F_Y = 0$ **(↑ +ve)**

$-\ 0.3\ N_1 - 10 - 0.2\ N_2 \sin 30 + N_2 \cos 30 = 0$

$-\ 0.3\ N_1 + 0.77\ N_2 = 10$ ------------------(II)

$N_1 = 11.77$ kN and $N_2 = 17.57$ kN

For equilibrium of block A,

$\sum F_X = 0$ **(→ +ve)**

$0.1\ N_3 - P + N_2 \sin 30 - 0.2\ N_2 \cos 30 = 0$

$0.1\ N_3 + 0.673\ N_2 = P$ ---------------(III)

$\sum F_Y = 0$ **(↑ +ve)**

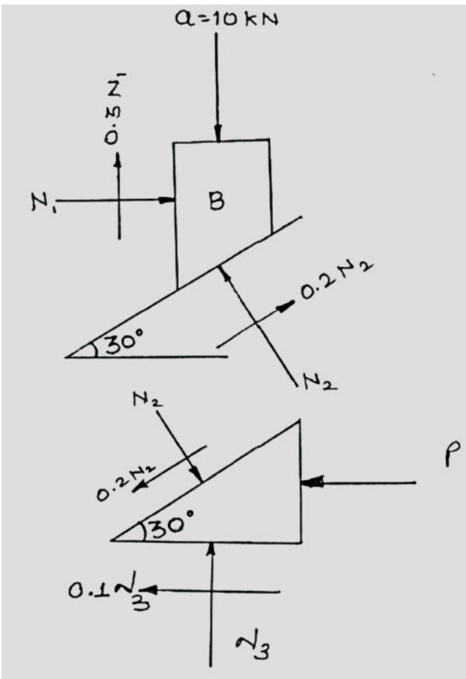
$-\ N_2 \cos 30 + 0.2\ N_2 \sin 30 + N_3 = 0$

$N_3 - 0.766\ N_2 = 0$

$N_3 = 13.63$ kN and $P = 13.3$ kN

Case II: Block B has impending motion in downward direction

FBD of blocks A and B



For equilibrium of block B,

$\sum F_X = 0$ **(→+ve)**

$N_1 + 0.2\ N_2 \cos 30 - N_2 \sin 30 = 0$

$N_1 - 0.326\ N_2 = 0$ -----------------(III)

$\sum F_Y = 0$ **(↑ +ve)**

$0.3\ N_1 - 10 + 0.2\ N_2 \sin 30 + N_2 \cos 30 = 0$

$0.3\ N_1 + 0.966\ N_2 = 10$

$N_1 = 3.064$ kN and $N_2 = 9.40$ kN

$-0.1\ N_3 - P + N_2 \sin 30 - 0.2\ N_2 \cos 30 = 0$

$P = -0.1\ N_3 + 0.326\ N_2$

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$N_3 - N_2 \cos 30 - 0.2\ N_2 \sin 30 = 0$

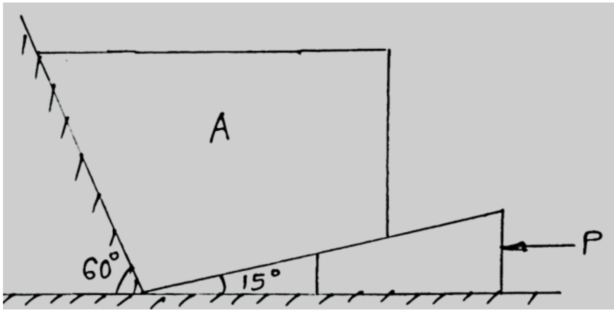
$N_3 - 0.966\ N_2 = 0$

$N_3 = 9.08$ kN and $P = 2.156$ kN

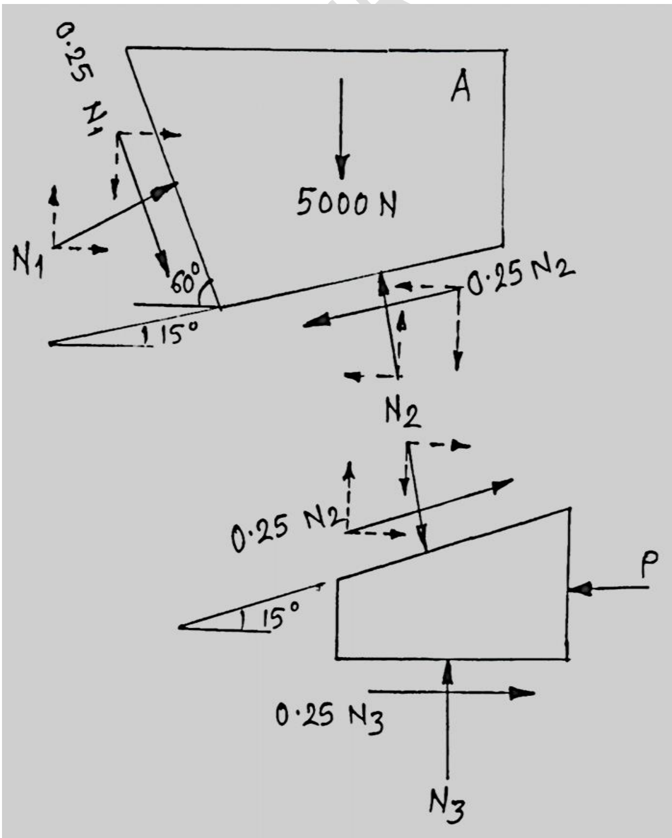
For equilibrium of block A,

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

4) Determine the force P required to move the block A of weight 5000 N up the inclined plane. Coefficient of friction between all contact surfaces is 0.25. Neglect the weight of the wedge and the wedge angle is 15^0. (May' 11) [10 M]



Solution: FBD of block A and B:



Applying conditions of equilibrium to block A,

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

$N_1 \sin 60 + (0.25\ N_1 \cos 60) – N_2 \sin 15 – (0.25\ N_2 \cos 15) = 0$

$0.991\ N_1 – 0.5\ N_2 = 0$ -------------------(I)

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$N_1 \cos 60 – (0.25\ N_1 \sin 60) + N_2 \cos 15 – (0.25\ N_2 \sin 15) – 5000 = 0$

$0.283\ N_1 + 0.9012\ N_2 = 5000$ ---------------------(II)

Solving equations (I) and (II), we get

N_1 = 2416.4 N and N_2 = 4789.34 N

Applying conditions of equilibrium to block B,

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$N_3 + (0.25\ N_2 \sin 15) – N_2 \cos 15 = 0$

N_3 = 4316.25 N ------------------(III)

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

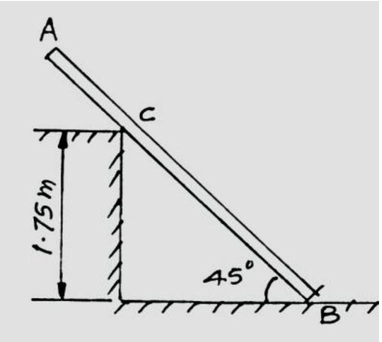
$0.25\ N_3 + (0.25\ N_2 \sin 15) + N_2 \sin 15 – P = 0$

Substituting values of N_2 and N_3 from equations (II) and (III)

P = 3475.17 N

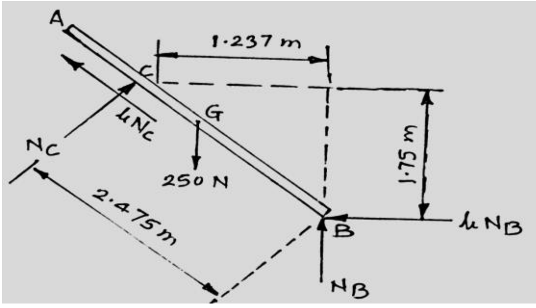
- **Ladder Friction:**

1) Determine minimum value of coefficient of friction so as to maintain the position shown in figure. Length of rod AB is 3.5 m and it weighs 250 N.



Solution: The rod AB is supported by a rough surface at B and a rough edge at C. The ladder looses its equilibrium position by slipping to the right.

FBD of the ladder



Applying COE to rod AC

$\sum$ **M_B = 0 (Anticlockwise +ve)**

$250 \times 1.237 - (N_C \times 2.475) = 0$

$N_C = 125$ N

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

$N_C \cos 45 - \mu N_C \sin 45 - \mu N_B = 0$

$125 \cos 45 - \mu \times 125 \sin 45 - \mu N_B = 0$

$\mu (N_B + 88.39) = 88.39$ ----------------(I)

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$N_C \sin 45 + \mu N_C \cos 45 + N_B - 250 = 0$

$125 \sin 45 + \mu \times 125 \cos 45 + N_B - 250 = 0$

$N_B = 161.61 - 88.39\,\mu$ ----------------(II)

Substituting above value of N_B in equation (I)

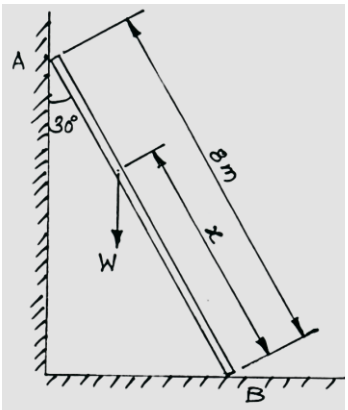
$\mu [(161.61 - 88.39\mu) + 88.39] = 88.39$

$88.39\,\mu^2 - 250\,\mu + 88.39 = 0$

Solving above quadratic equation, $\mu = 0.414$ or $\mu = 2.414$

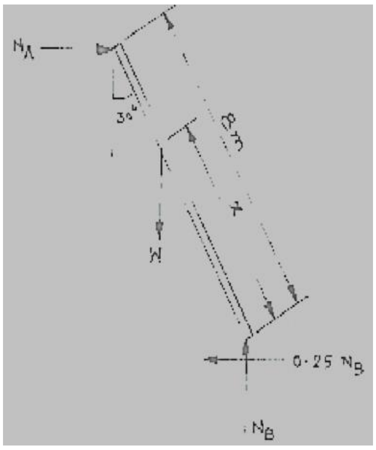
Since μ cannot be more than 1, the feasible value of $\mu = 0.414$.

2) **A weightless ladder of length 8 m is resting against a smooth vertical wall and rough horizontal ground as shown in figure. The coefficient of friction between ground and ladder is 0.25. A man of weight 500 N wants to climb up the ladder. Find how much distance along the ladder the man can climb without slip. A second person weighing 800 N wants to climb less than the earlier person. Would he climb less than the earlier person? Find the distance covered by him.**



Solution: Let W be the weight of man and X be the distance along the ladder the man can climb without slip occurring.

FBD of ladder



Applying condition of equilibrium

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

$N_A - 0.25\ N_B = 0$

$N_A = 0.25\ N_B$ ---------------(I)

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$-W + N_B = 0$

$W = N_B$ ---------------(II)

$\sum$ **M_B = 0 (Anticlockwise +ve)**

$-N_A\ (8 \cos 30) + W\ (X \sin 30) = 0$

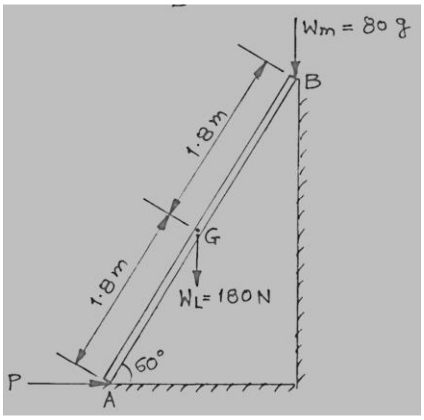
Using equations (I) and (II)

$W \left(\frac{X}{2}\right) - 0.25\ W\ (8 \times 0.866) = 0$

$X = 3.464$ m

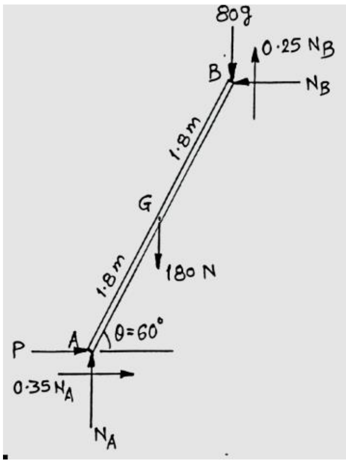
Since X is independent of W. Hence man of 500 N and 800 N can climb same distance or for that matter man with any weight can climb the same distance before slip occurs.

3) **A uniform ladder 3.6 m long weighs 180 N. it is held in position as shown in the figure. The coefficient of friction between the wall and the ladder is 0.25 and that between the floor and ladder is 0.35. The ladder in addition to its weight supports a man of 80 kg at its top end. Calculate the horizontal force P to be applied to the ladder at the floor level to prevent slipping. if the force P is not applied what should be the minimum inclination of the ladder with horizontal so that there is no slipping?**



Solution: In the absence of force P, ladder slips with end B coming down the wall and end A moving to the left. When external force P is applied, it prevents slipping and bring the ladder into static equilibrium with end B having impending downward motion and end A having impending leftward motion.

FBD of ladder



Applying conditions of equilibrium to the ladder,

$\sum$ **F_Y = 0 ($\uparrow$ +ve)**

$N_A + 0.25\ N_B + 180 - (80 \times 9.81) = 0$

$N_A + 0.25\ N_B = 964.8$ ---------------(I)

$\sum$ **F_X = 0 ($\rightarrow$+ve)**

$0.35\ N_A + P - N_B = 0$

Substituting value of N_A from equation (I)

$0.35\ (964.8 - 0.25\ N_B) + P = 0$

$P = 1.087\ N_B - 337.68$ ---------------(II)

$\sum$ **M_A = 0 (Anticlockwise +ve)**

$(0.25\ N_B - (80 \times 9.81)) \times 3.6 \cos\theta + N_B \times 3.6 \sin\theta - (180 \times 1.8 \cos\theta) = 0$

$N_B\ (0.9 \cos\theta + 3.6 \sin\theta) - (288 \times 9.81 \cos\theta) - 324 \cos\theta = 0$

$N_B = \dfrac{3149.28 \cos\theta}{3.6 \sin\theta + 0.9 \cos\theta}$ -----------------(III)

Substituting above value of N_B in equation (II)

$P = 1.087 \left[\dfrac{3149.28 \cos\theta}{3.6 \sin\theta + 0.9 \cos\theta}\right] - 337.68$ -----------------(IV)

Case I: To find P when θ = 60^0

Substituting $\theta = 60^0$ in equation (IV)

$P = 1.087 \left[\dfrac{3149.28 \cos 60}{3.6 \sin 60 + 0.9 \cos 60}\right] - 337.68$

P = 142.3 N

Case II: To find θ when P = 0

Substituting P = 0 in equation (IV)

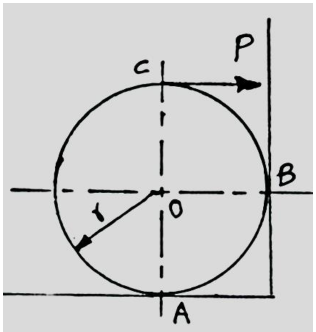
$$1.087 \left[\frac{3149.28 \cos \theta}{3.6 \sin \theta + 0.9 \cos \theta} \right] - 337.68 = 0$$

$1117.83 \sin \theta = 2869.82 \cos \theta$

$\tan \theta = 2.567$

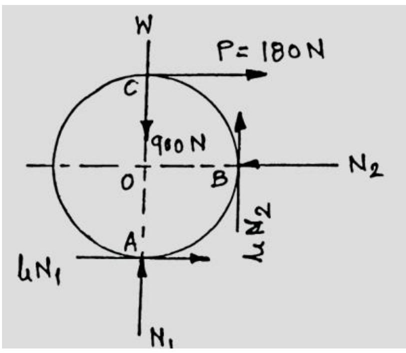
$\theta = 68.72^0$

3) For the system given in figure (i) if applied force P is 180 N will the cylinder rotate? Take weight of the cylinder W = 900 N and coefficient of friction as 0.25.

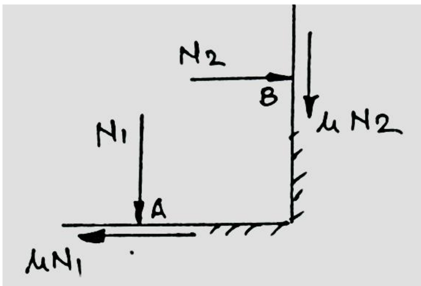


Solution: Now because of force P whether the cylinder will rotate or not is not known. Hence frictional forces F_1 and F_2 may or may not have reached its maximum limiting values μN_1 and μN_2 respectively. Therefore to begin with frictional forces F_1 and F_2 and not as μN_1 and μN_2.

FBD of cylinder



FBD of floor and wall



As cylinder is in equilibrium,

Σ **F_X = 0 ($\rightarrow$+ve)**

$180 + F_1 = N_2$--------------------(I)

Σ **F_Y = 0 ($\uparrow$ +ve)**

$900 = N_1 + F_2$--------------------(II)

$\sum$ **M_C = 0 (Anticlockwise +ve)**

$(- 180 \times 2r) + (N_2 \times r) + (F_2 \times r) = 0$ --------------------(III)

Now let us assume that F_2 has reached its limiting value μN_2 i.e. 0.25 N_2 and find the values of N_2, N_1 and F_1 solving above equations.

From equation (III), $180 \times 2r = (N_2 \times r) + (0.25\ N_2 \times r)$

$N_2 = \frac{360\ r}{1.25\ r} = 288$ N

From equation (II), $900 = N_1 + F_2 = N_1 + (0.25 \times 288)$

$N_1 = 828$ N

From equation (I), $180 + F_1 = 288$

$F_1 = 108$ N

Now from the Free body diagram, it is seen that the forces F_1, F_2 and P create moments about O.

Moments of F_1 and F_2 about O is anticlockwise $= (F_1 \times r) + (F_2 \times r)$

$= (108 \times r) + (0.25 \times 288 \times r)$

$= 180\ r$

Moment of P about O is clockwise $= P \times r = 180\ r$

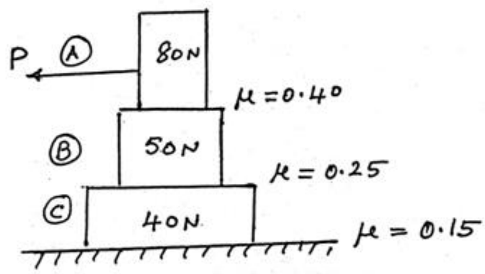
Both clockwise and anticlockwise moments are equal and hence the cylinder will not rotate. Now maximum possible limiting value of $F_1 = \mu N_1 = 0.25 \times 828 = 207$ N

But here it has reached only 108 N , there is a scope for F_1 to increase from 108 N to 207 N before the cylinder start rotating.

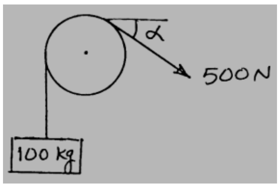
University Problems:

Friction:

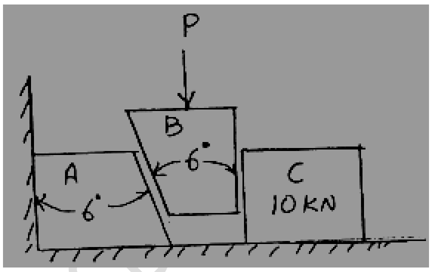
1. A car of 1000 kg mass is to be parked on the same 10^0 incline year round. The static coefficient of friction between the tires and the road varies between the extremes of 0.05 and 0.9. Is it always possible to park the car at this place? Assume that the car can be modeled as a particle. **(May' 08) [05 M]**
2. Find the power transmitted by the belt running over a pulley of 600 mm diameter at 200 rpm. The coefficient of friction between the pulley and the belt is 0.25 and the angle of lap is 160^0 and maximum tension in the belt is 2.5 kN. Neglect centrifugal tension. **(May' 08) [05 M]**
3. Three blocks are placed on the surface one above the other as shown in figure. The static coefficient of friction between the blocks and block C and surface is also shown. Find the maximum value of P that can be applied before any slipping takes place. **(May' 08) [10 M]**



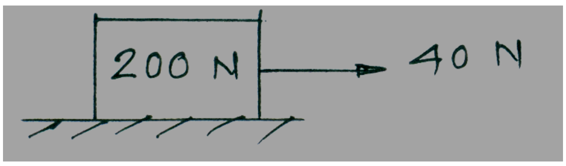
4. For the given arrangement, find the angle α for which load begins to slip. Take μ = 0.3 between fixed drum and rope. **(Dec' 08) [05 M]**



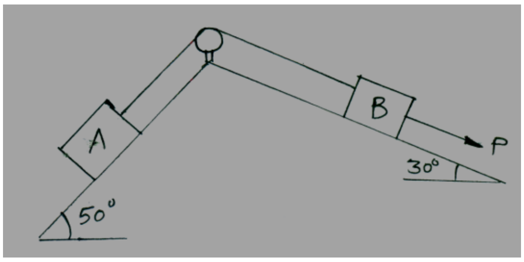
5. Two 6^0 wedges are used to push a block horizontally as shown. Calculate the minimum force required to push the block of weight 10 kN. Take μ = 0.25 for all contact surfaces. **(Dec' 08) [10 M]**



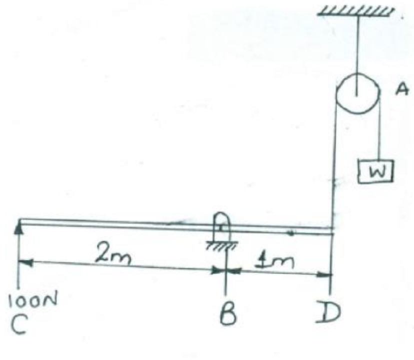
6. A belt 100 mm wide and 8 mm thick is transmitting power at a belt of speed 1600 m/min .The angle of lap of a smaller pulley is 165^0 and coefficient of friction is 0.3.The maximum permissible stress is the belt is 2 N/mm^2 and the mass of belt is 0.9 kg/m. Find the power transmitted and the initial tension in the belt also find the maximum power that can be transmitted and the corresponding belt speed. **(May' 09) [10 M]**
7. Explain centrifugal tension in the belt. **(May' 09) [04 M]**
8. A block of weight 200 N rests on a horizontal surface. The coefficient of friction between the block and the horizontal surface is 0.4. Find the frictional force acting on the block if a horizontal force of 40 N is applied to the block. **(Dec' 09) [05 M]**



9. Two blocks A and B of weight 500 N and 750 N respectively are connected by a cord passes over a frictionless pulley as shown in the figure. The coefficient of friction between the block A and the inclined plane is 0.4 and that between the block B and the inclined plane is 0.3. Determine the force P to be applied to block B to produce the impending motion of block B down the plane. **(Dec' 09) [10 M]**

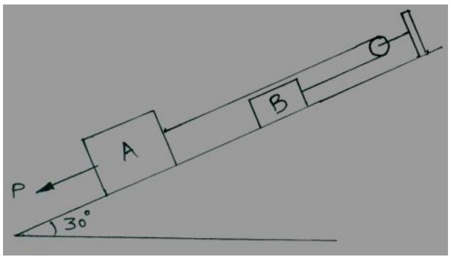


10. A lever CD is connected to cylindrical drum A through a belt as shown in figure such that the drum does not rotate. The coefficient of friction between the belt and the drum is 0.3. A boy exert a 100 N upward push on the lever at C. Determine: (i) the maximum weight W that the boy can lift (ii) the maximum weight W that the boy can hold. **(Dec'09) [05 M]**

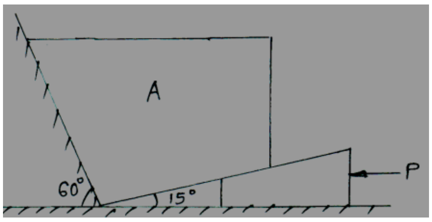


11. A belt 120 mm wide and 8 mm thick is transmitting power at a belt speed of 1400 m/min. The angle of lap of the smaller pulley is 160^0 and coefficient of friction is 0.3. The maximum permissible stress in the belt is 2 N/mm^2 and the mass of the belt is 0.8 kg/m. Find the power transmitted and the initial Tension in the belt. Also find the maximum power that can be transmitted and the corresponding belt speed. **(May' 10) [12 M]**

12. Determine the force 'P' to cause motion to impend. Take masses of blocks A and B as 8 kg and 4 kg respectively and the coefficient of sliding friction as 0.3. The force 'P' and rope are parallel to the inclined plane. Assume frictionless pulley. **(Dec' 10) [08 M]**



13. Determine the force P required to move the block A of weight 5000 N up the inclined plane. Coefficient of friction between all contact surfaces is 0.25. Neglect the weight of the wedge and the wedge angle is 15^0. **(May' 11) [10 M]**



14. Derive an equation to find the centrifugal tension in a belt drive. **(May' 11) [04 M]**

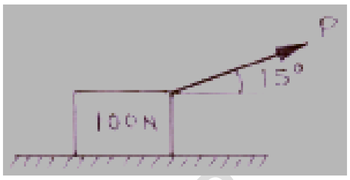
15. A leather belt of width 200 mm and thickness 10 mm has a maximum permissible tension as 2×10^6 N/m^2.

If the ratio of tension is 1.8, determine at what velocity should it be run so as to transmit maximum power? Also determine maximum value of power. Take mass of the belt material as 2.2 kg/m. **(May' 11) [08 M]**

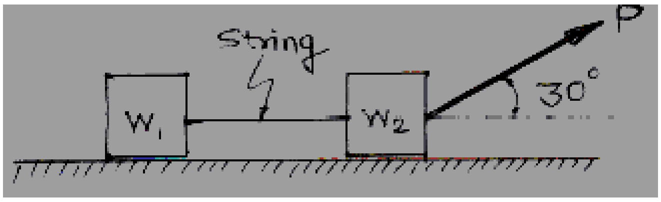
3.11 Practice Problems: (Based on University Patterns)

- **Block Friction**

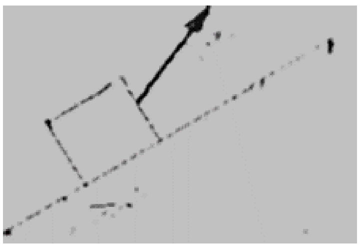
1. A wooden block rests on a horizontal plane as shown in figure. Determine the force 'P' required to (a) pull it (b) push it. Assume the weight of block as 100 N and the coefficient of friction μ = 0.4.



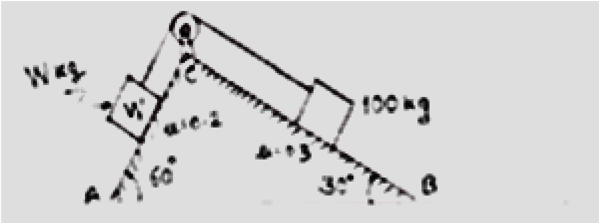
2. In the figure below, the two blocks (W_1 = 30 N and W_2= 50 N) are placed on rough horizontal plane. Coefficient of friction between the block of weight W_1 and plane is 0.3 that between block of weight W_2 and plane is 0.2. Find the minimum value of the force 'P' to just move the system. Also find the tension in the string.



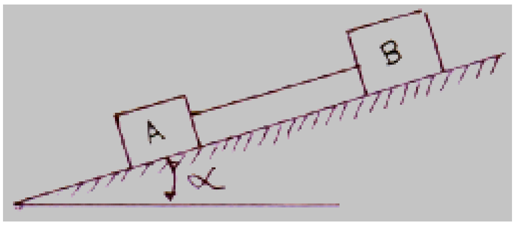
3. Determine the minimum value and the direction of a force P required to cause motion of a 100 kg block to impend upon 30^0 plane. The coefficient of friction is 0.20.



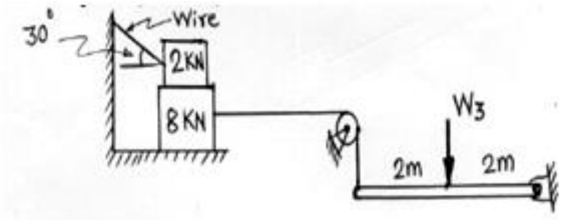
4. Two inclined planes AC and BC inclined at 60°and 30° to the horizontal meet at a ridge C. A mass of 100 kg rests on the inclined plane BC and is tied to a rope which passes over a smooth pulley at the ridge, the other end of the rope being connected to a block of W kg mass resting on the plane AC. Determine the least and greatest value of W for the equilibrium of the whole system.



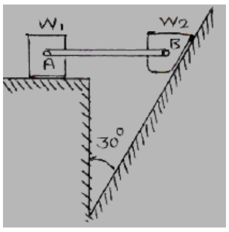
5. A cord connects two bodies A and B of weights 450 N and 900 N. The two bodies are placed on an inclined plane and cord is parallel to inclined plane. The coefficient of friction for body A is 0.16 and that for B is 0.42. Determine the inclination of the plane to the horizontal and tension in the cord when the motion is about to take place down the plane. The body A is below the body B on the inclined plane.



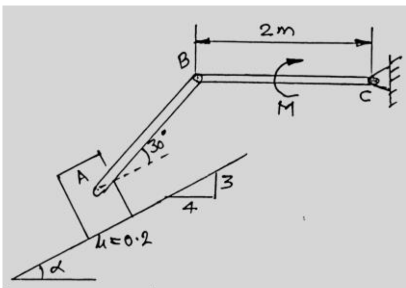
6. Find the minimum weight W_3 for the limiting equilibrium. Take $\mu = 0.20$ for all the rubbing surfaces.



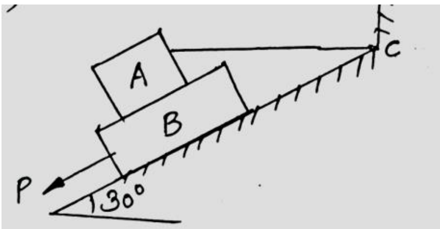
7. Two blocks W_1 and W_2, which are connected by a horizontal link AB, are supported on rough planes as shown in figure. The coefficient of friction for block A = 0.4. The angle of friction for the block B is 200. Find the smallest weight W_1 of the block A for which equilibrium can exist if W_2 = 2250 N.



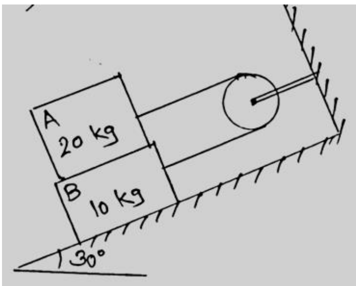
8. The figure shows a block 'A' held in equilibrium on an inclined plane by a moment 'M' applied to link 'BC'. Link 'AB' and link 'BC' are hinged at 'B'. The weight of the block is 10 kN. The rod 'BC' is 2 m long. Assume the links to be weightless and hinges to be ideally smooth. Calculate 'M' to just start the motion of the block upwards. Take coefficient of friction between block and the plane to be 0.2.



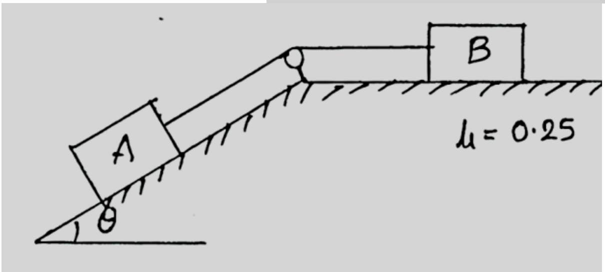
9. Block A of mass 30 kg, rests on block B of mass 40 kg. Block A is restrained from moving by a horizontal rope tied at point C, what force P applied parallel to the plane inclined at 300 with horizontal is necessary to start block B down the plane. Take coefficient of friction for all the surfaces as 0.35.



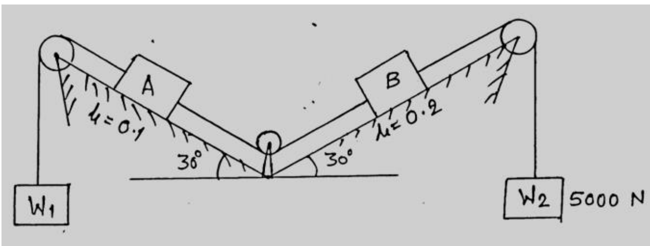
10. Block A has a mass of 20 kg and block B has a mass of 10 kg. Knowing that the coefficient of static friction is 0.15, between the two blocks and zero between block B and the slope, find the magnitude of the frictional force between the two masses. What is the force in the string tying the blocks?



11. Find the value of θ if the blocks A and B shown in figure have impending motion. Given block A = 20 kg, block B = 20 kg, $\mu_A = \mu_B = 0.25$.

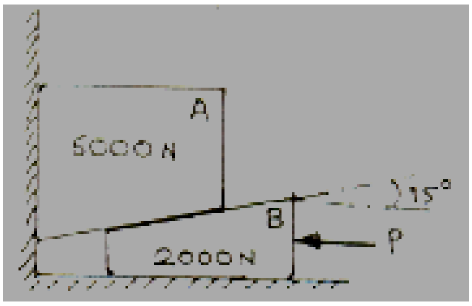


12. Two blocks A and B weighing 800 N and 1000 N respectively rest on two inclined planes each inclined at 300 to the horizontal. They are connected by a rope passing through a smooth pulley as shown. Ropes carrying loads of W_1 and 5000 N (W_2) and passing over pulleys at the tops of the planes are also connected to the two blocks as shown in figure. Coefficient of friction may be taken as 0.1 and 0.2 for blocks A and B respectively. Determine the least and greatest value of W_1 for the equilibrium of the whole system.

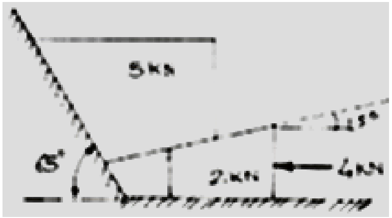


- **Wedge and Block friction:**

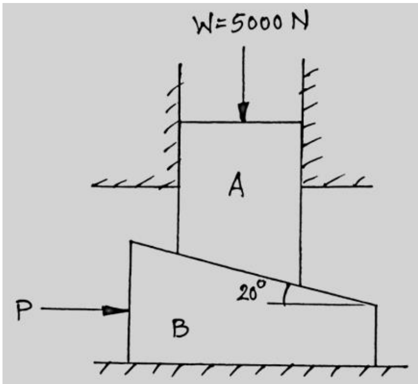
1. Find force P required to lift 6000 N block A. Take μ at surfaces in contact as 0.3.



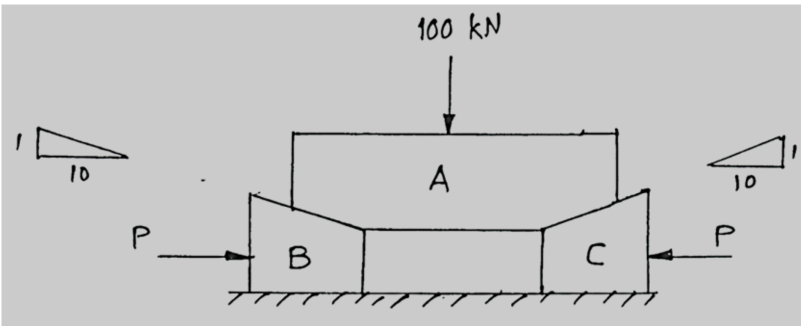
2. If co-efficient of friction at all sliding surfaces is 0.3, find whether the 4 kN force is enough to move the 5 kN load of inclined surface.



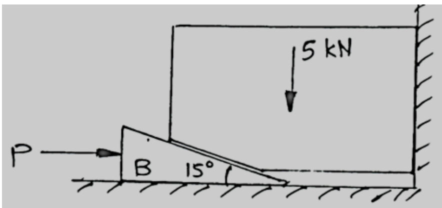
3. The block A as shown in the figure, supports a load W = 5000 N and is to be raised by forcing the wedge B under it. The angle of friction for all surfaces in contact is ϕ = 15^0. Determine the force P which is necessary to start the wedge under the block. The block and wedge have negligible weight.



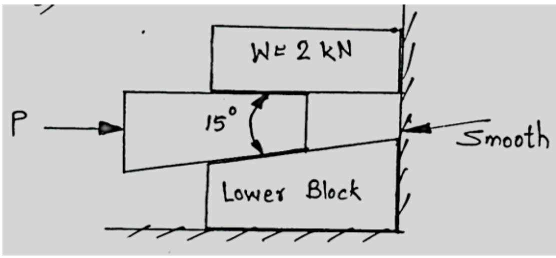
4. Calculate the magnitude of the horizontal force P acting on the wedges B and C to raise a load of 100 kN resting on A. Assume μ between the wedges and the ground as 0.25 and between the wedges and A as 0.2. Also assume symmetry of loading and neglect the weight of A, B and C. Wedges are resting on horizontal surface and their slope is 1:10.



5. The wedge B is used to raise the weight of 5 kN resting on a block A. what horizontal force P, is required to do this, if the coefficient of friction for all the surfaces in contact is 0.2?



6. Determine the horizontal force P to be applied to the wedge so as to raise the weight W of 2 kN. Assume the wedge to be of negligible weight and the contact surfaces between weight W and vertical wall are smooth. The coefficient of friction between weight W and wedge is 0.25 and that between wedge and lower block is also 0.25. Is the system self locking one?



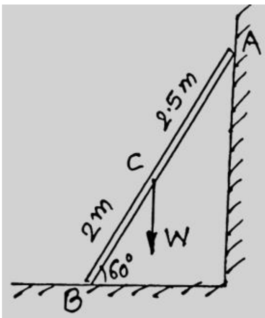
Hint: If $\theta > \alpha$ (block is Self locking)

If $\theta < \alpha$ (block is revesible)

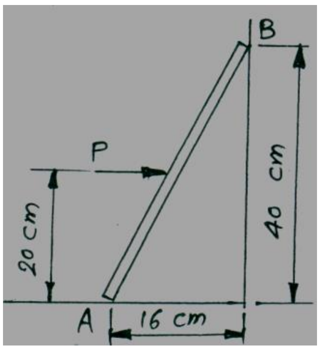
If $\theta = \alpha$ (block is on verge of motion)

- **Ladder friction:**

1. The ladder shown is non homogeneous. Its mass of 40 kg may be considered concentrated 2 m from bottom. It rests against a smooth wall at A and on a rough floor at B. the coefficient of static friction between the ladder and the floor is $\frac{1}{3}$. Will the ladder stand in the 60^0 position?



2. A 100 N uniform rod AB is held in the position shown in the figure. If coefficient of friction is 0.15 at A and B. Calculate range of values of P for which equilibrium is maintained.



3. A uniform ladder of length 4 m rests against a rough vertical wall with its lower end on a rough horizontal floor, the ladder being inclined at 50^0 to the horizontal. The coefficient of friction between the ladder and the wall is 0.3 and that between the ladder and the floor is 0.5. A man of weight 500 N ascends up the ladder. What is maximum length up along to ladder the man will be able to ascend before the ladder commences to slip. The weight of the ladder is 1000 N.

4. Determine the minimum value of the co-efficient of friction so as to maintain the position shown in figure. Length of Rod AB is 3.5 m and it weighs 250 N. **(Dec' 07) [10 M]**