E-Learningcourse on "Engineering Mechanics" –Concurrent coplanar forces - Forces on a plane -Continuation& Concurrent Non-coplanar Forces – Forces in space PPT-3

By

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1. Quick Review of PPT – 1,2

2. Concurrent coplanar forces - Forces on a plane - Equilibrium conditions

3. Concurrent Non-coplanar forces – Forces in space

Review of PPT -1,2

- Overview about Engineering Mechanics

- Resolving of 'n' no. of concurrent coplanar forces – Forces on plane – Straight Quadrant and Inclined Quadrant approaches

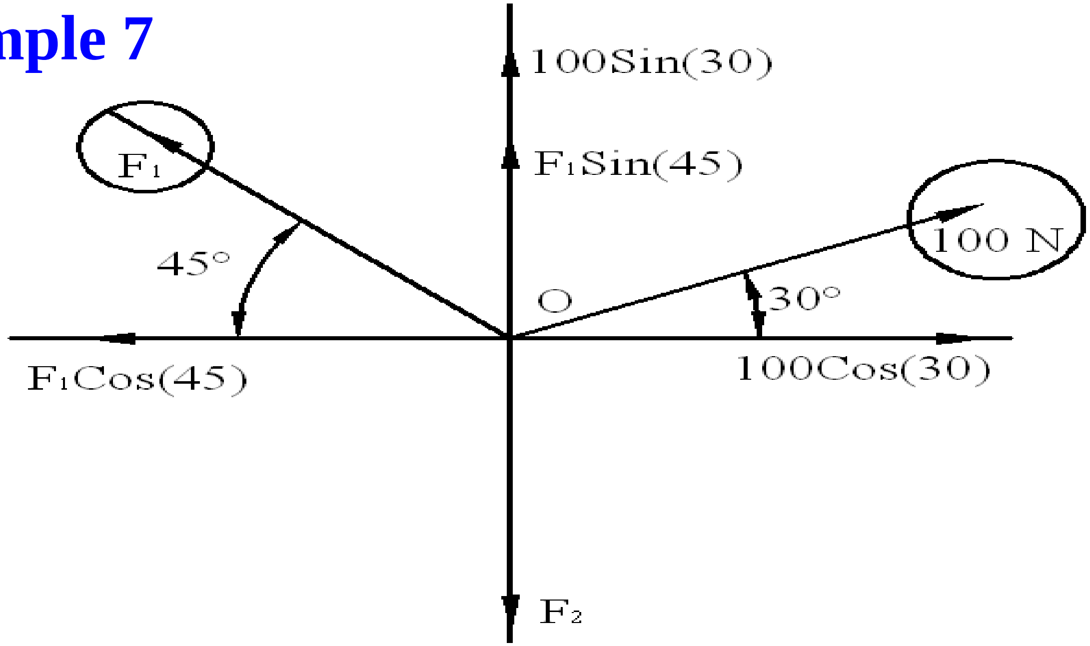
- Example Problems

- Equilibrium of a Particle

$$(\Sigma F_x)\vec{i} + (\Sigma F_y)\vec{j} = 0$$

$$\Sigma F_x = 0 \text{ and } \Sigma F_y = 0$$

Example 7



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$\Sigma F_x = 0$, $(\rightarrow, +ve) \Rightarrow 100 \text{ Cos } (30) - F_1 \text{ Cos } (45) = 0$

$F_1 = 122.7$ N

Applying the second equilibrium condition

$\Sigma F_y = 0$, $(\uparrow, +ve) \Rightarrow 100 \text{ Sin } (30) + F_1 \text{ Sin } (45) - F_2 = 0$

Substituting F_1,

$F_2 = 136.76$ N

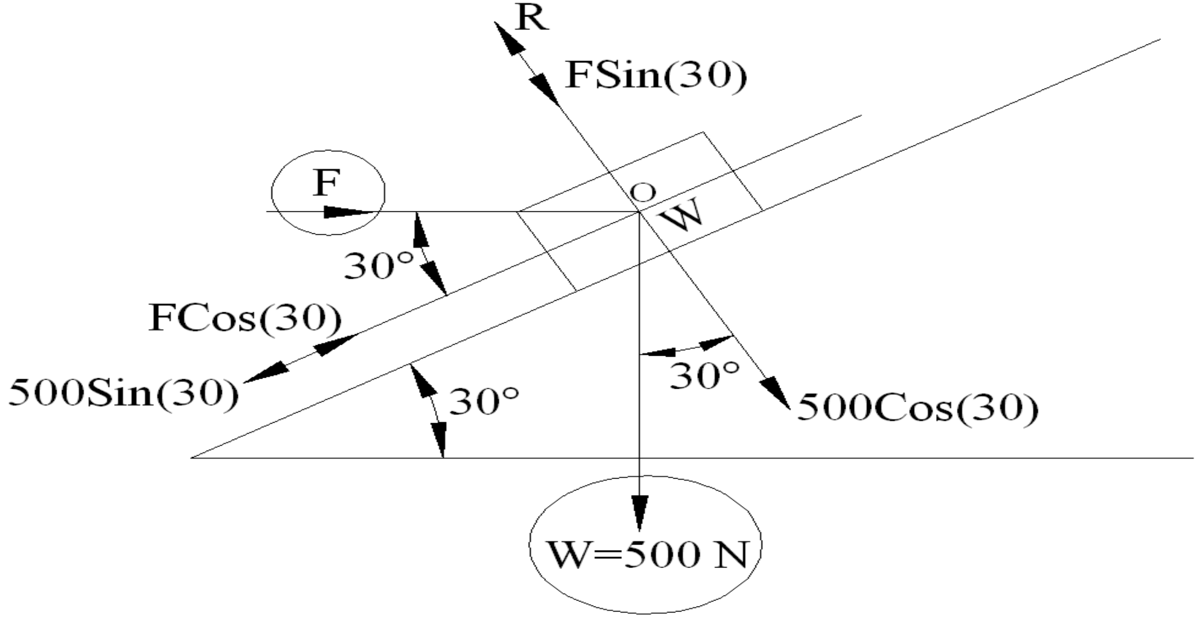
The three forces, 100 N, F_1 and F_2 are applied on the particle such that the particle is under equilibrium.

- Equilibrium of a Particle on an Inclined plane

For equilibrium of a particle on an inclined plane, the resultant R = 0

$$\Sigma F_{\text{along the plane}} = 0 \text{ and } \Sigma F_{\text{Perpendicular to the plane}} = 0$$

Example 8



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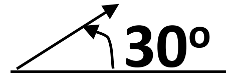
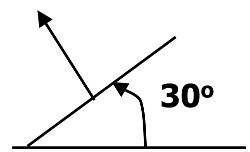
$\Sigma F_{\text{along the plane}} = 0$, (

, +ve)

$F \,\text{Cos}(30) - 500\ \text{Sin}(30) = 0$

$$F = \frac{500\ Sin(30)}{Cos(30)} = 288.7\text{ N}$$

Applying second equilibrium equation

$\Sigma F_{\text{Perpendicular to the plane}} = 0$, (

, +ve)

$R - F\ \text{Sin}(30) - 500\ \text{Cos}(30) = 0$

$R = 577.4\text{ N}$

Equilibrium of a Particle by force polygon

Three or more concurrent coplanar forces, which are acting on the particle, are such that the particle is being under equilibrium.

For this condition the force polygon, which is to be drawn to the scale according to the direction and magnitude of the system of the forces one after the other and is a closed one.

Applicability of Newton's I – law - Equilibrium

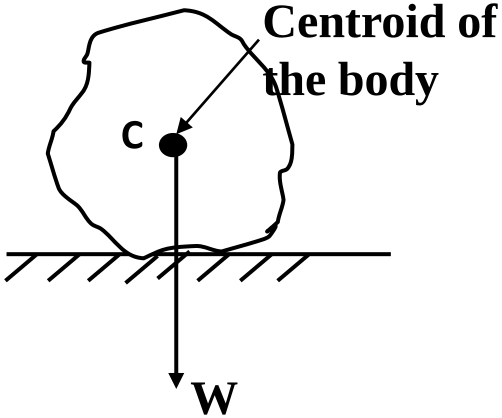
• Applicability of equilibrium of a particle – different engineering problems

• Many of engineering problems are subjected to concurrent coplanar forces and satisfy the conditions of static equilibrium

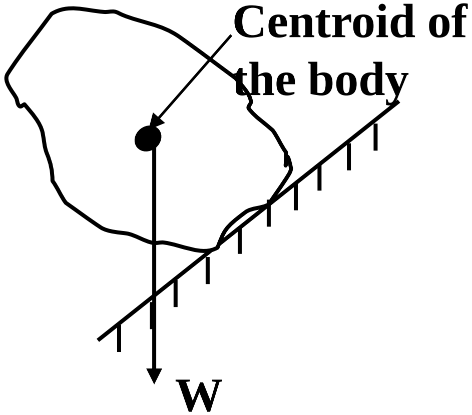
Either they straight plane problems (or) inclined plane problems.

A free body diagram is to be drawn at a point in the body, where the lines of actions of the concurrent forces pass through (called as particle) and representing the direction and magnitude of these forces.

Body weight of 'W'



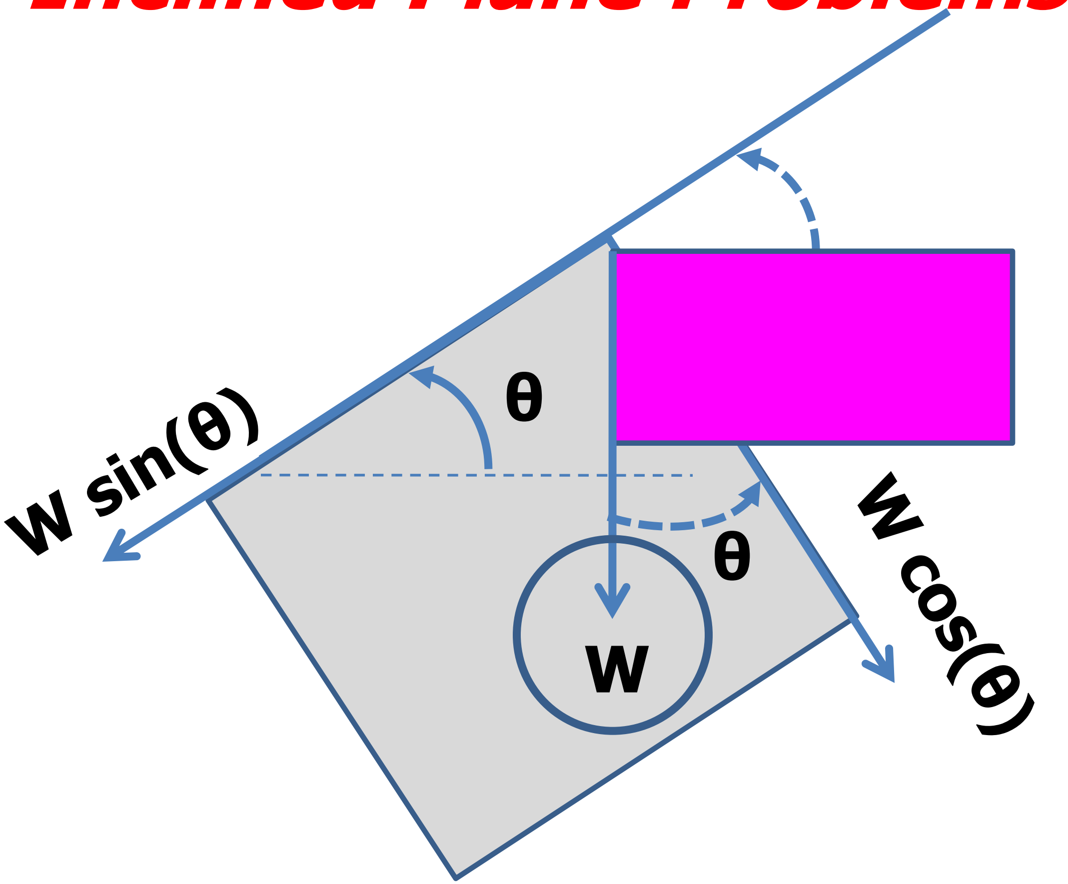
Weight acting on a horizontal plane



Weight acting on an Inclined plane

•**Resolution and components of the force along edges of the Inclined quadrant**

– *Inclined Plane Problems*



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Newton's III law – Reaction force - Equilibrium

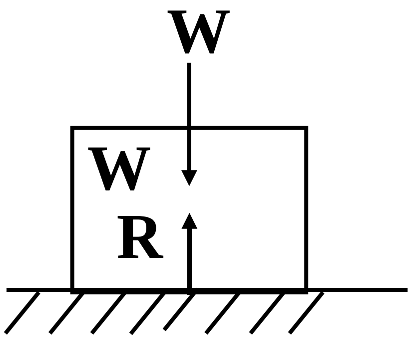


Fig. Reactive force 'R' at the Contact surface

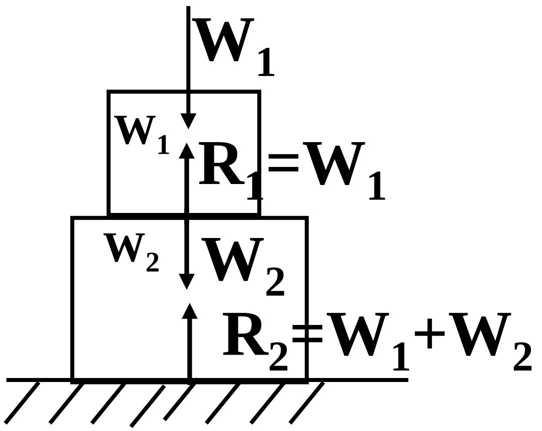
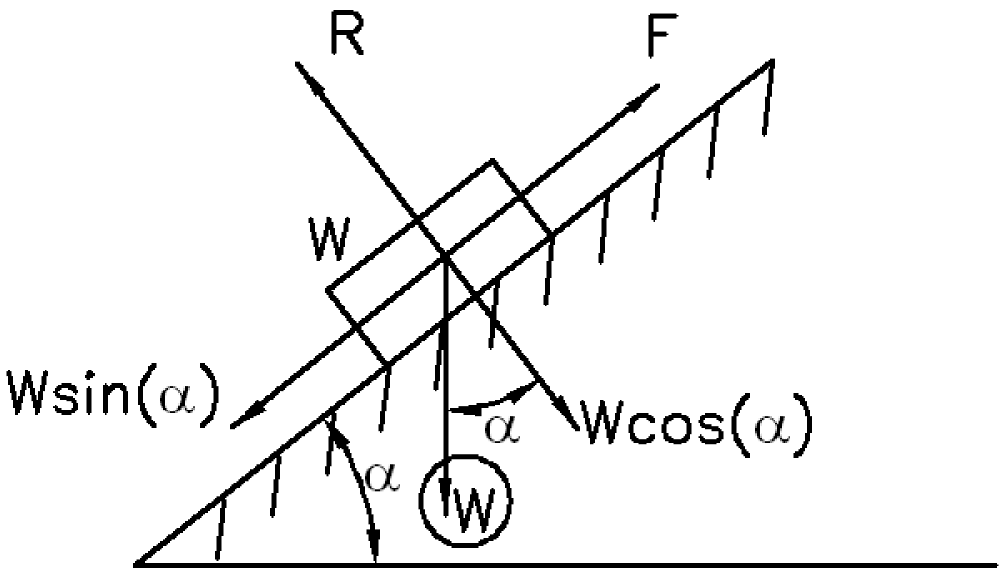
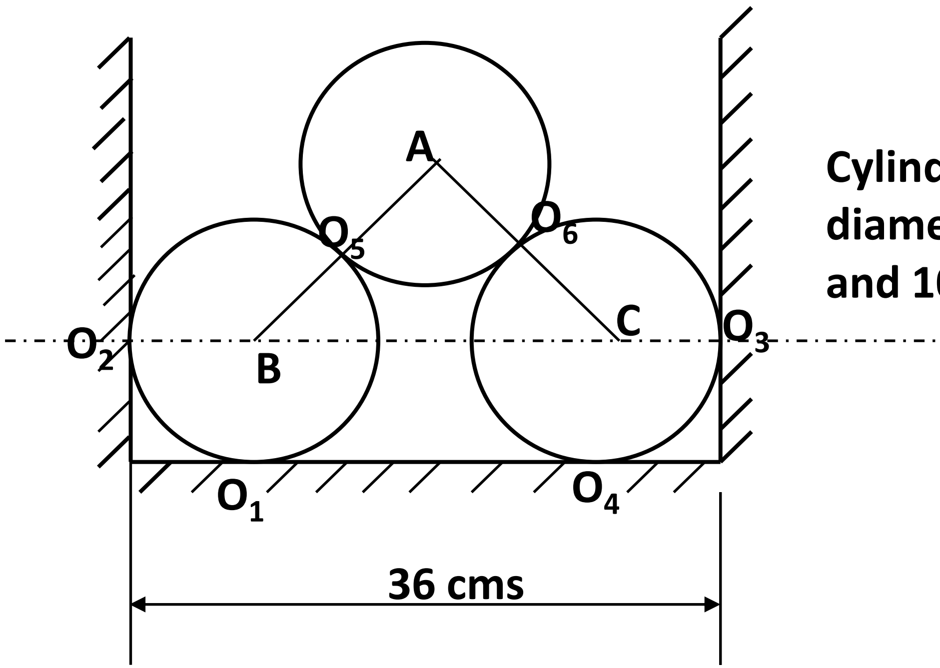


Fig. Reactive forces R_1 & R_2 at two contact surfaces

Reactive force R from an inclined surface due to the body weight

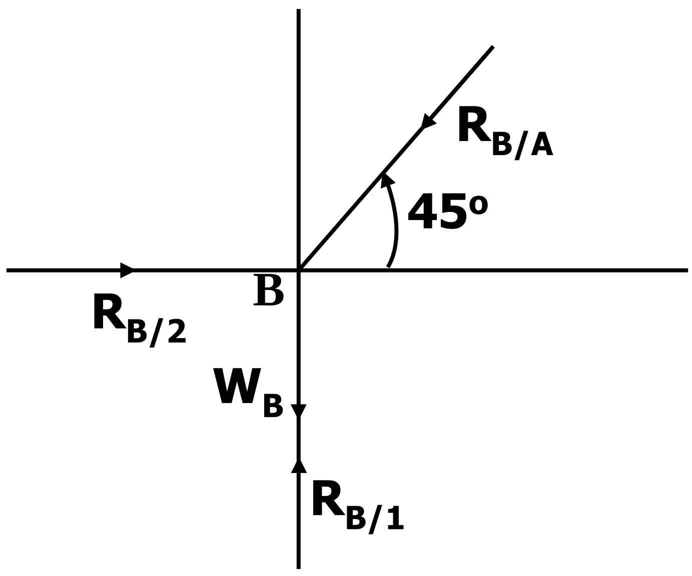


- **Space diagram and Free Body Diagrams (FBD)**

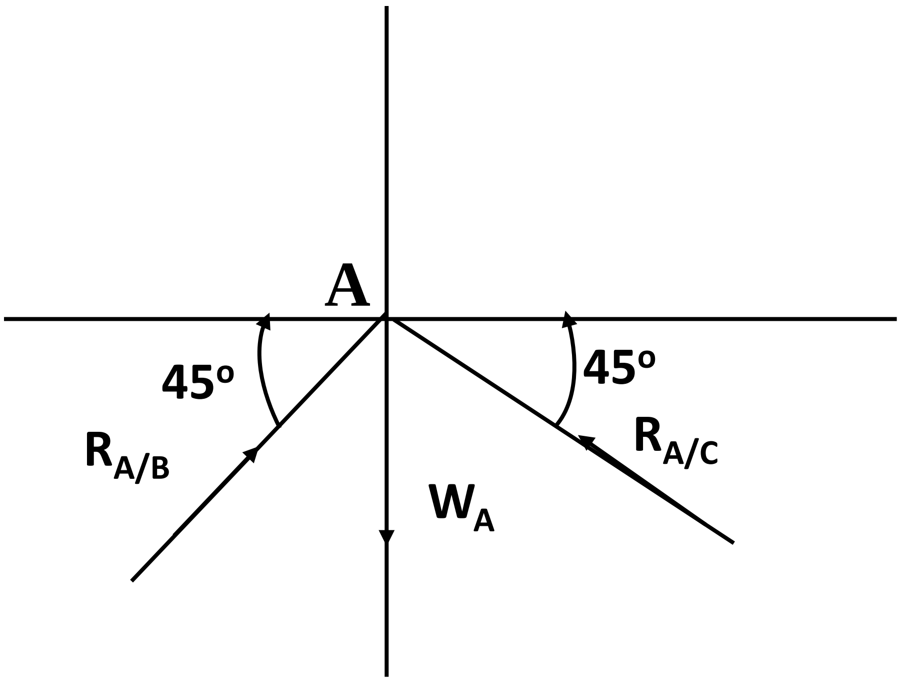


Cylinders A, B and C have equal diameter and weight of 16 cm and 100 N respectively

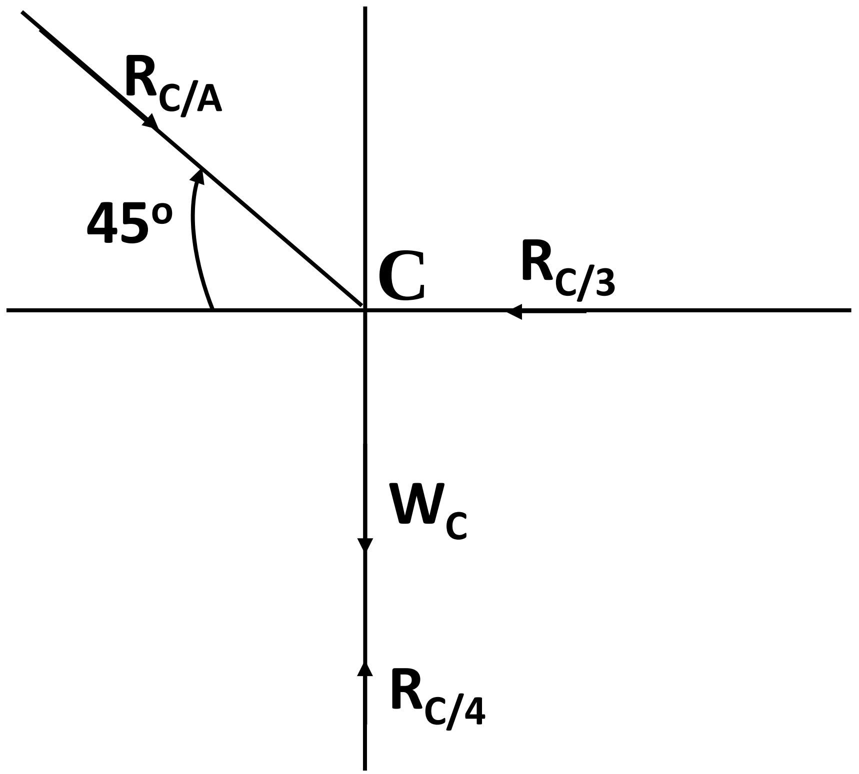
Space diagram showing the physical conditions of the problem



Free Body Diagram (FBD) drawn at point 'B'



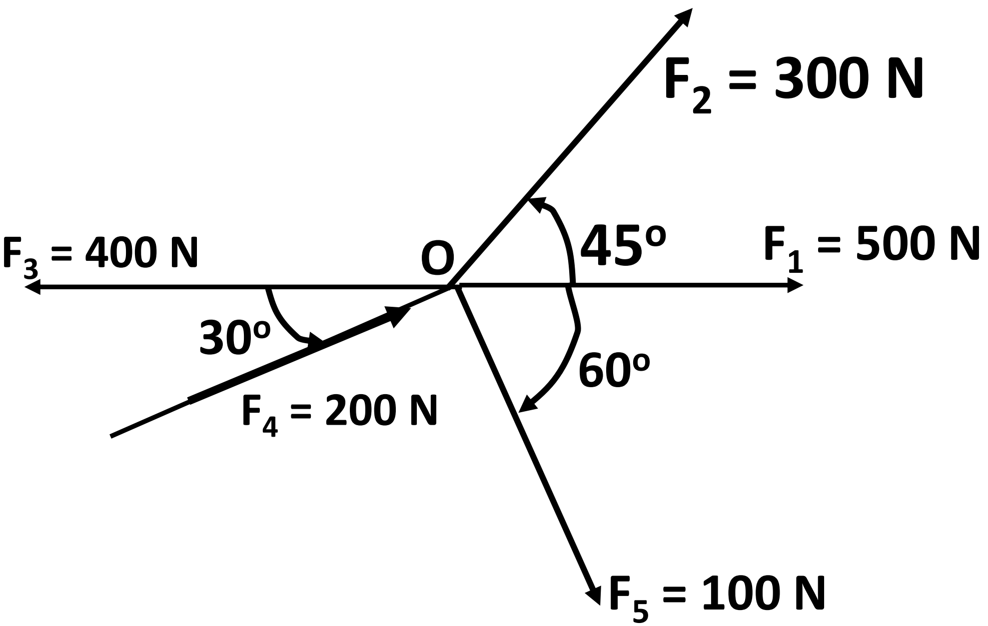
Free body diagram drawn at point 'A'

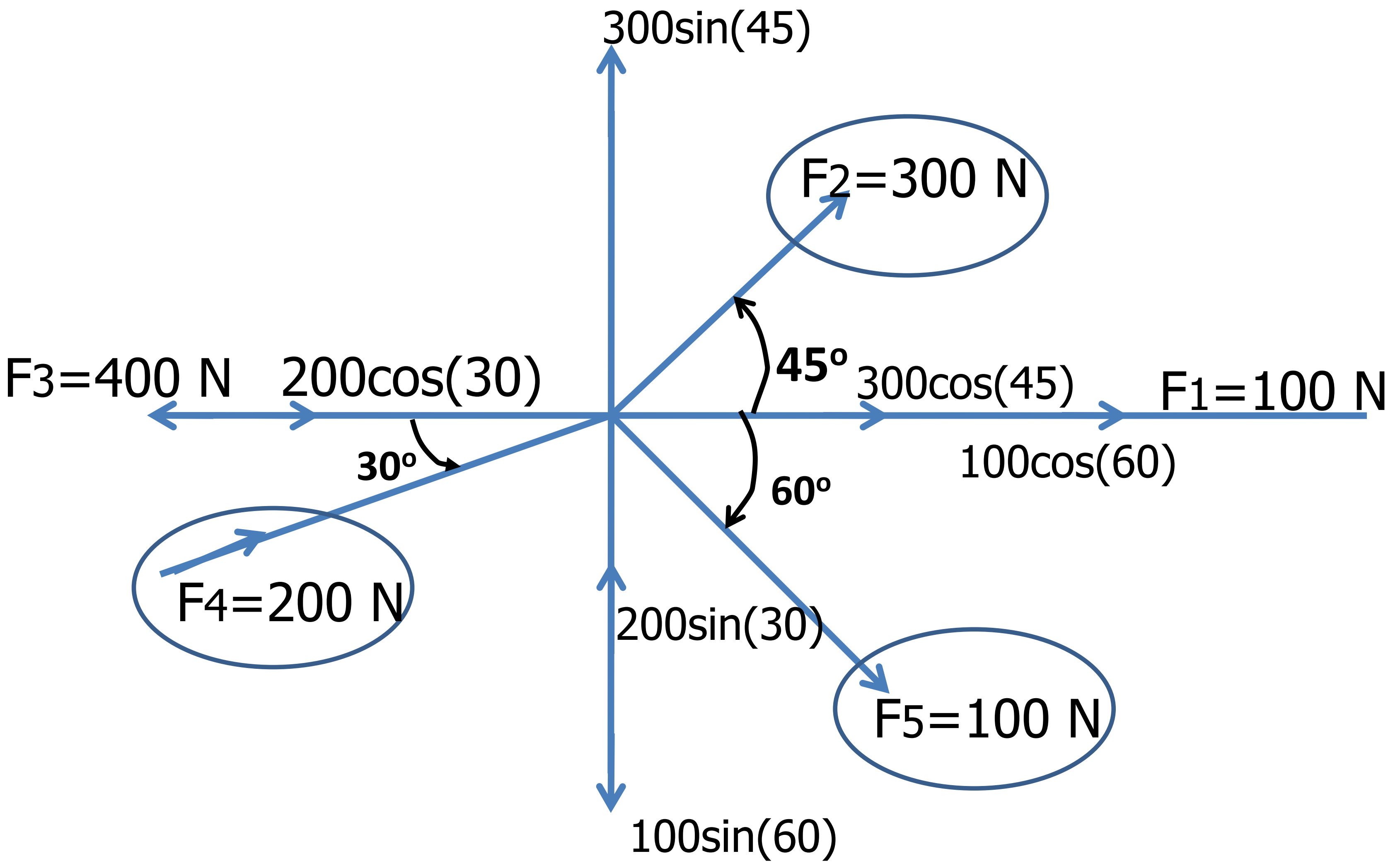


Free Body Diagram drawn at point ‘A’

Problem 9

Find the resultant of the a system of concurrent coplanar forces shown in Fig. 2.32 by using polygon law of graphical approach.



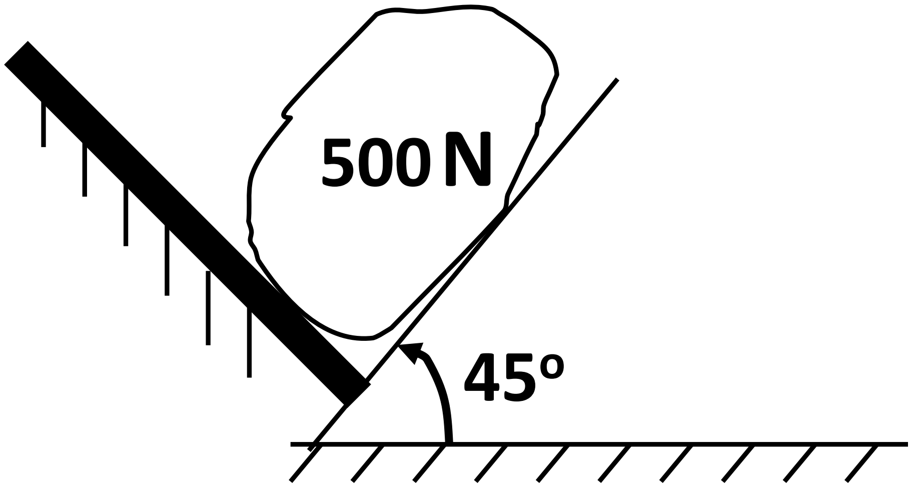

300sin(45)
F2=300 N
F3=400 N
200cos(30)
45°
300cos(45)
F1=100 N
30°
100cos(60)
60°
F4=200 N
200sin(30)
F5=100 N
100sin(60)

For solution refer the Book on "Engineering Mechanics" By Vela Murali
Published by Oxford University Press (2010)

Practice your self from the free body diagram

Problem 10

A stone of weight 500 N as shown is supported against to plane surface which is perpendicular to the 45^{o} inclined surface. What is the magnitude of the force that is supporting the stone in the direction of the inclined plane and the reaction force from the surface.



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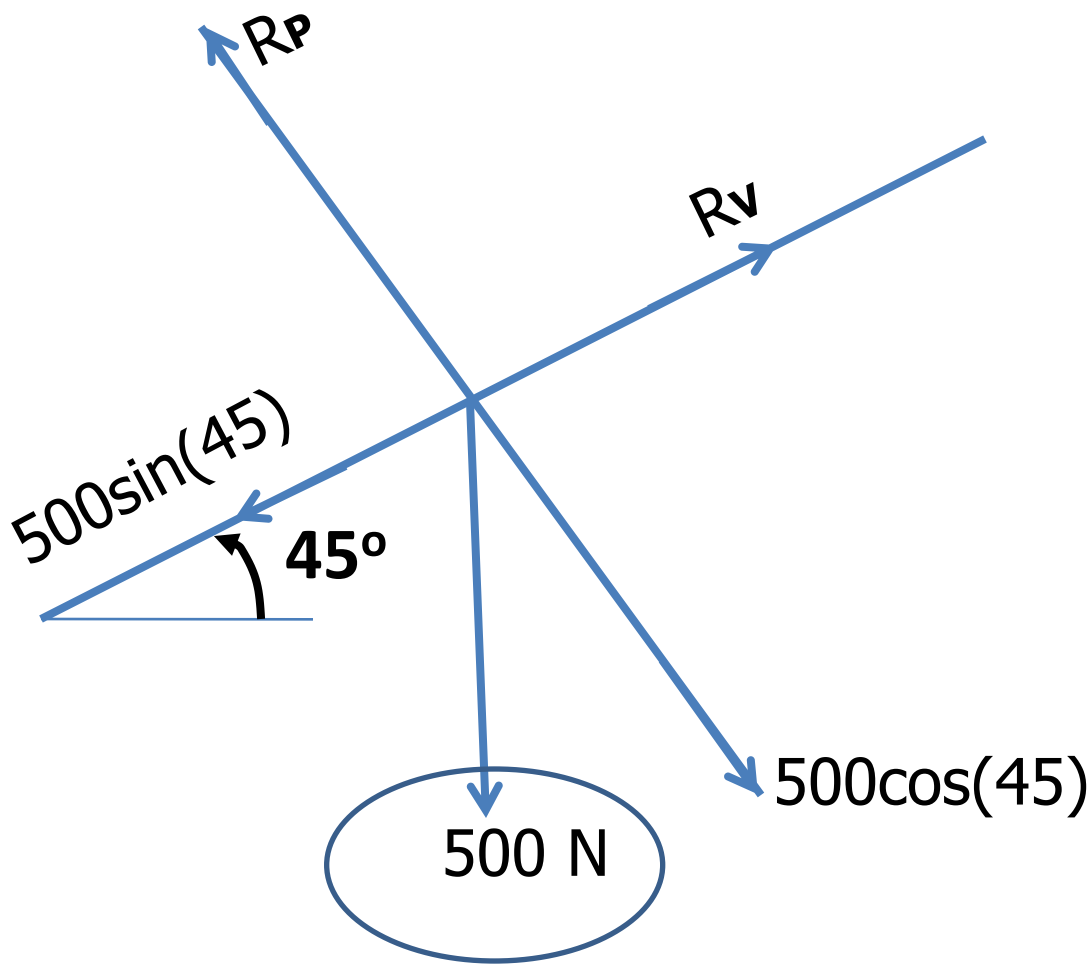

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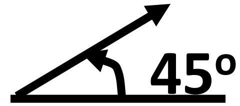
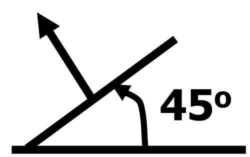
$\Sigma F_{\text{along the plane}} = 0$, (

, +ve)

$R_V - 500 \, Sin(45) = 0$

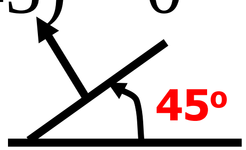
$R_V = 500 \, Sin(45) =$ **353.55 N**

Applying second equilibrium equation

$\Sigma F_{\text{Perpendicular to the plane}} = 0$, (

, +ve)

$R_P - 500 \, Cos(45) = 0$

R_P = 353.5 N, 

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Problem 11

Determine the magnitudes of F_1 and F_2 which are holding the body of weight 6 kN suspended from the string at point ‘O’ as shown. Assume the pulley over which the string passes is smooth.

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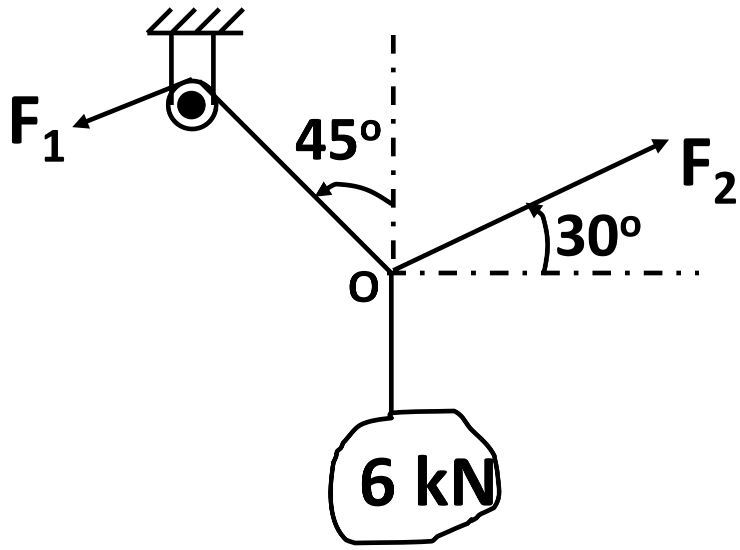

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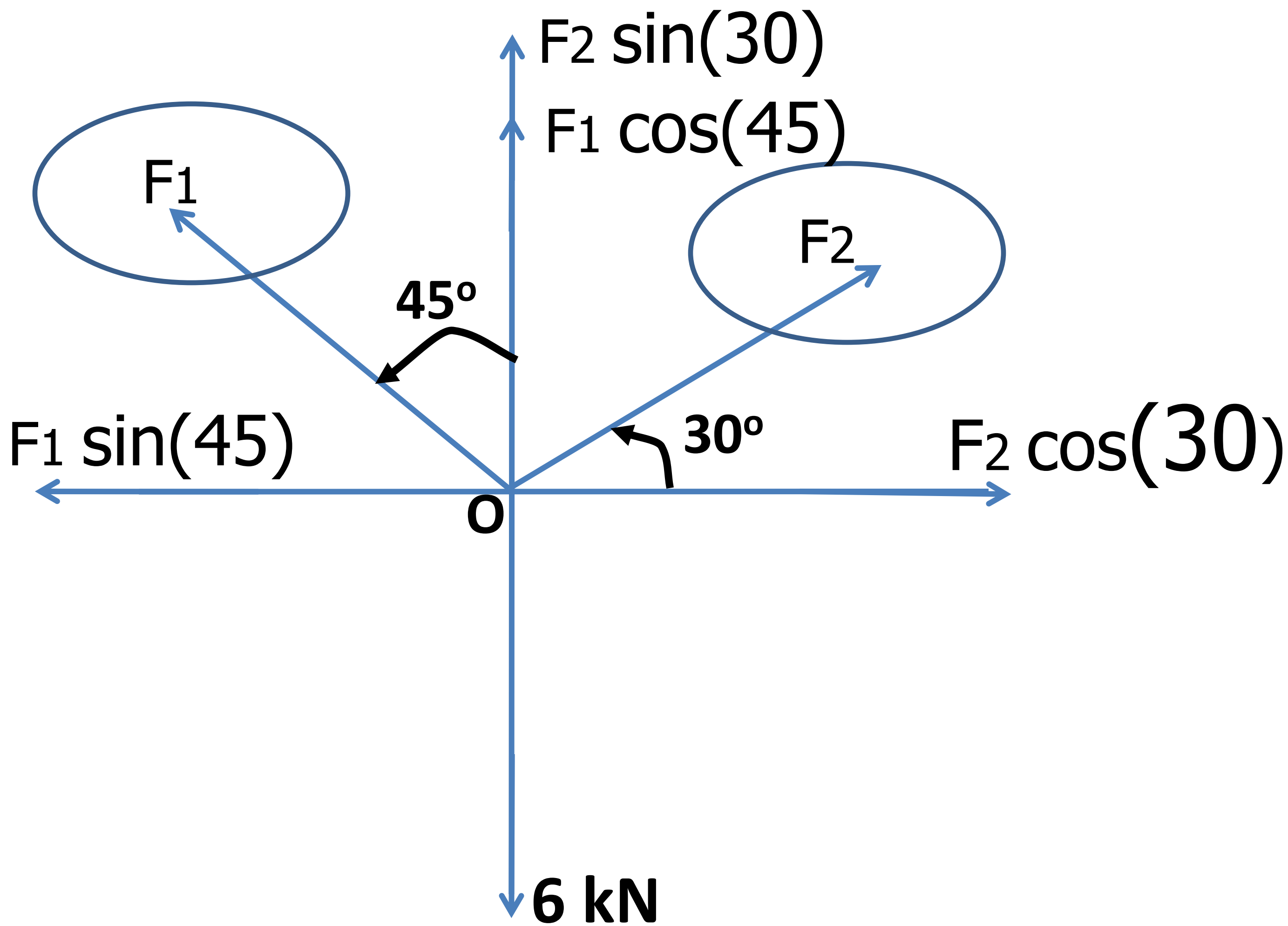

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ΣF_x ($\rightarrow$, +ve) = 0, $F_2 \cos(30) - F_1 \sin(45) = 0$

$$F_2 = F_1 \frac{Sin(45)}{Cos(30)}$$

$F_2 = 0.816\ F_1$ (1)

ΣF_y ($\uparrow$, +ve) = 0, $F_2 \sin(30) + F_1 \cos(45) - 6 = 0$

Substituting (1)

$(0.816 F_1)\sin(30) + F_1 \cos(45) = 6$

$F_1 =$ 5.379 kN (2)

Substituting (2) in (1)

$F_2 = 0.816\ (5.379) =$ 4.39 kN

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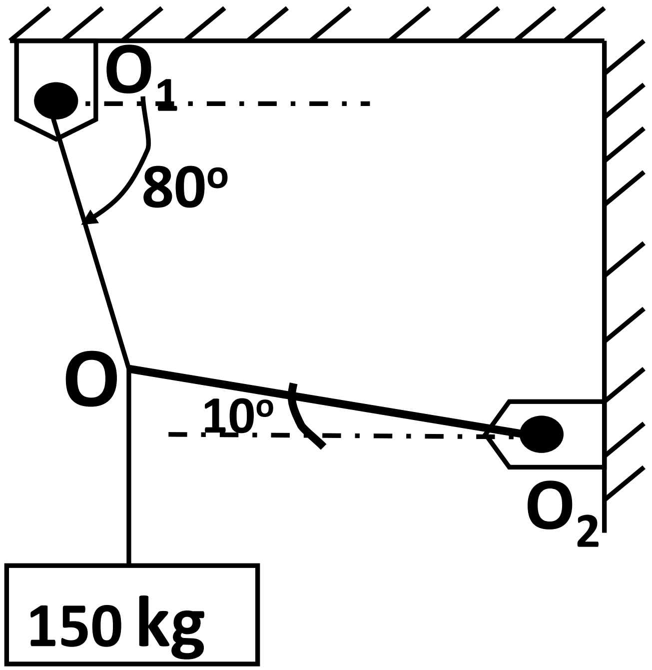
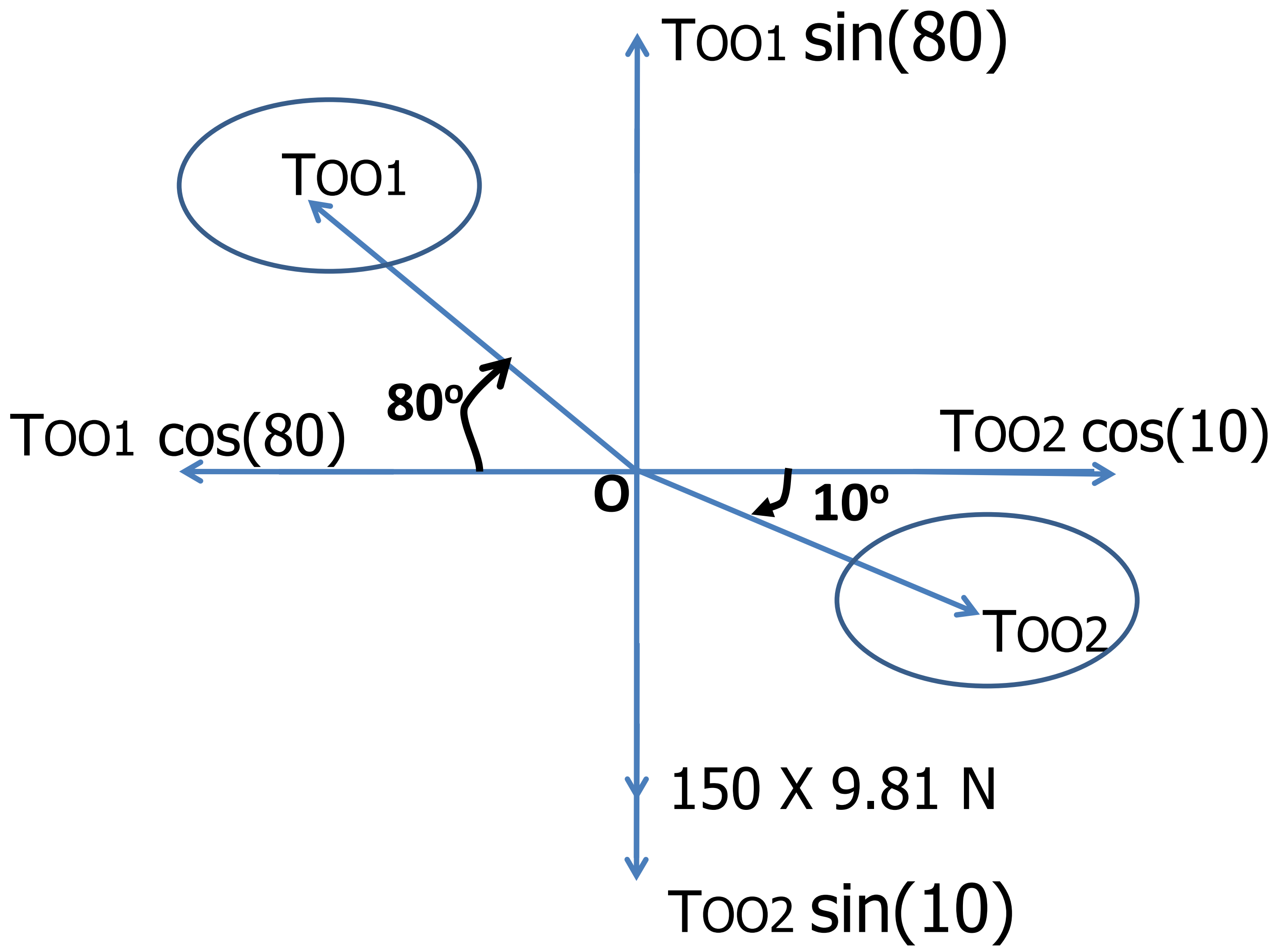
Problem 12

Two cables are tied together at point 'O' and loaded as shown. Determine the tension in OO_1 and OO_2.



O1
80°
O
10°
O2
150 kg



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ΣF_x (→, +ve) = 0, $T_{OO2}\cos(10) - T_{OO1}\cos(80) = 0$

$$T_{OO2} = T_{OO1}\frac{Cos(80)}{Cos(10)}$$

$T_{OO2} = 0.176\, T_{OO1}$ (1)

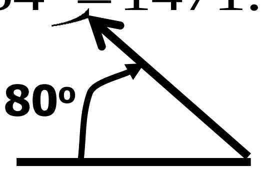
ΣF_y (↑, +ve) = 0,

$T_{OO1}\sin(80) - 150\,(9.81) - T_{OO2}\sin(10) = 0$

Substituting (1)

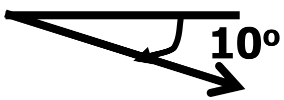
$$T_{OO1}(0.954) = 1471.5$$

T_{OO1}= 1542.45 N, (2)



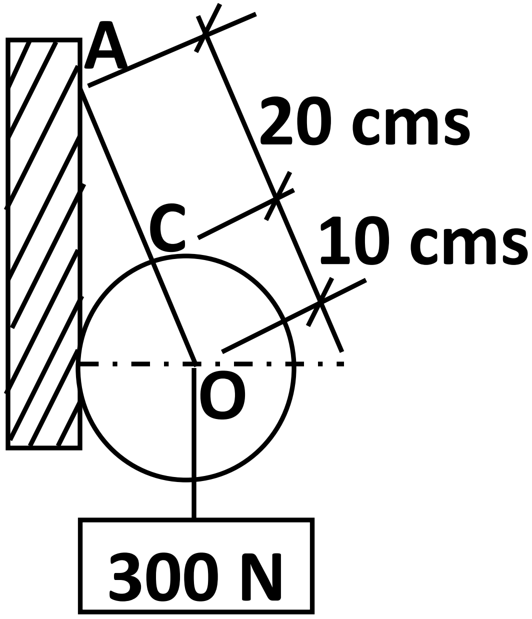
Substituting (2) in (1)

T_{OO2}= (0.176) (1542.45) = 271.47 N,



Problem 12

A string of length 20 cms is attached to a point A on a smooth vertical wall and to a point C on the surface of the sphere of radius 10 cms. The sphere whose weight is 300 N hangs in equilibrium against the wall. Find the tension in the string and the reaction of the wall.



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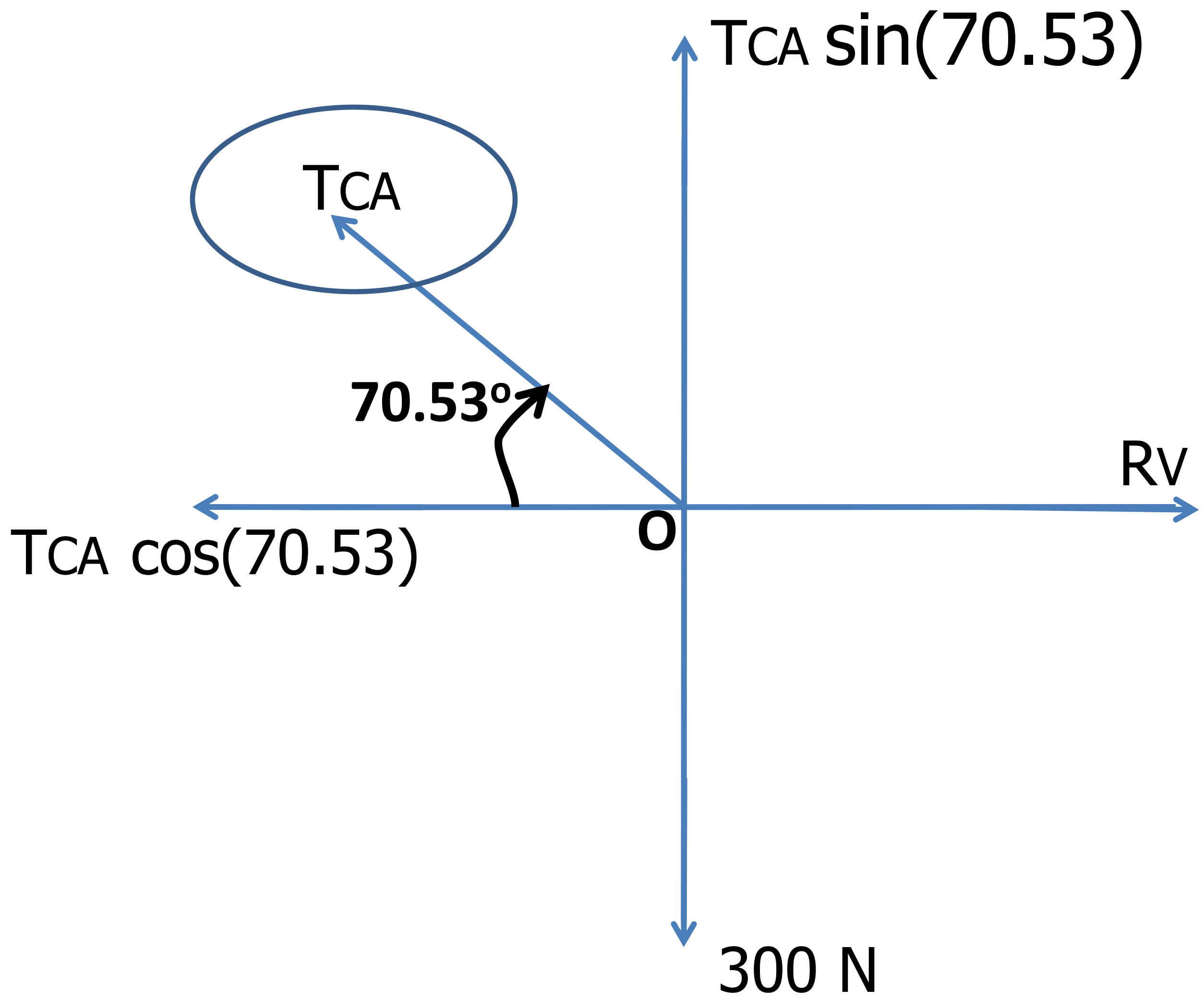

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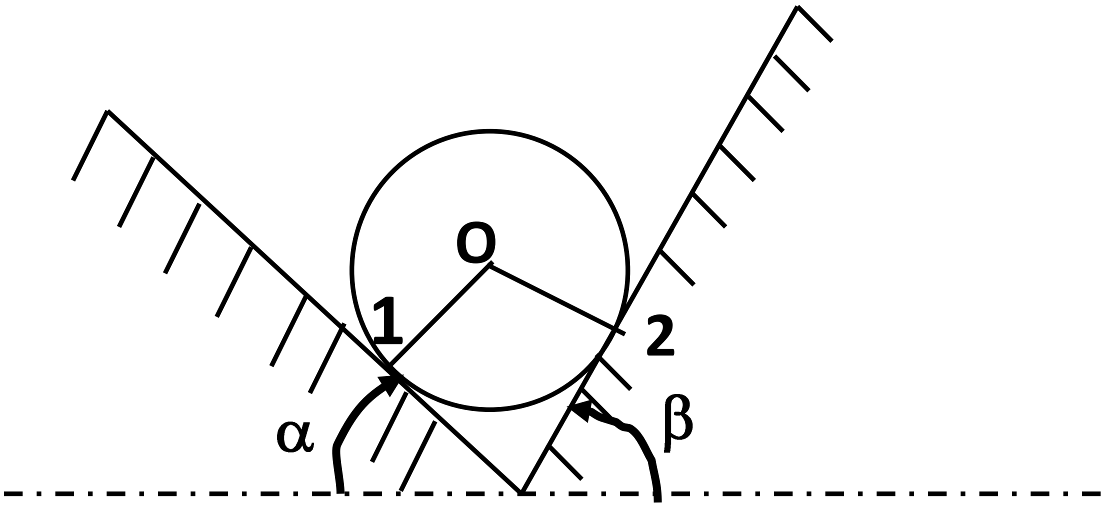
For solution refer the Book on "Engineering Mechanics" By Vela Murali
Published by Oxford University Press (2010)

Practice your self

Problem 13

A spherical ball of weight 'W' rest in 'V' shaped surface whose sides are inclined at angles α and β to the horizontal. Find the pressure on each side of the 'V' shaped surface



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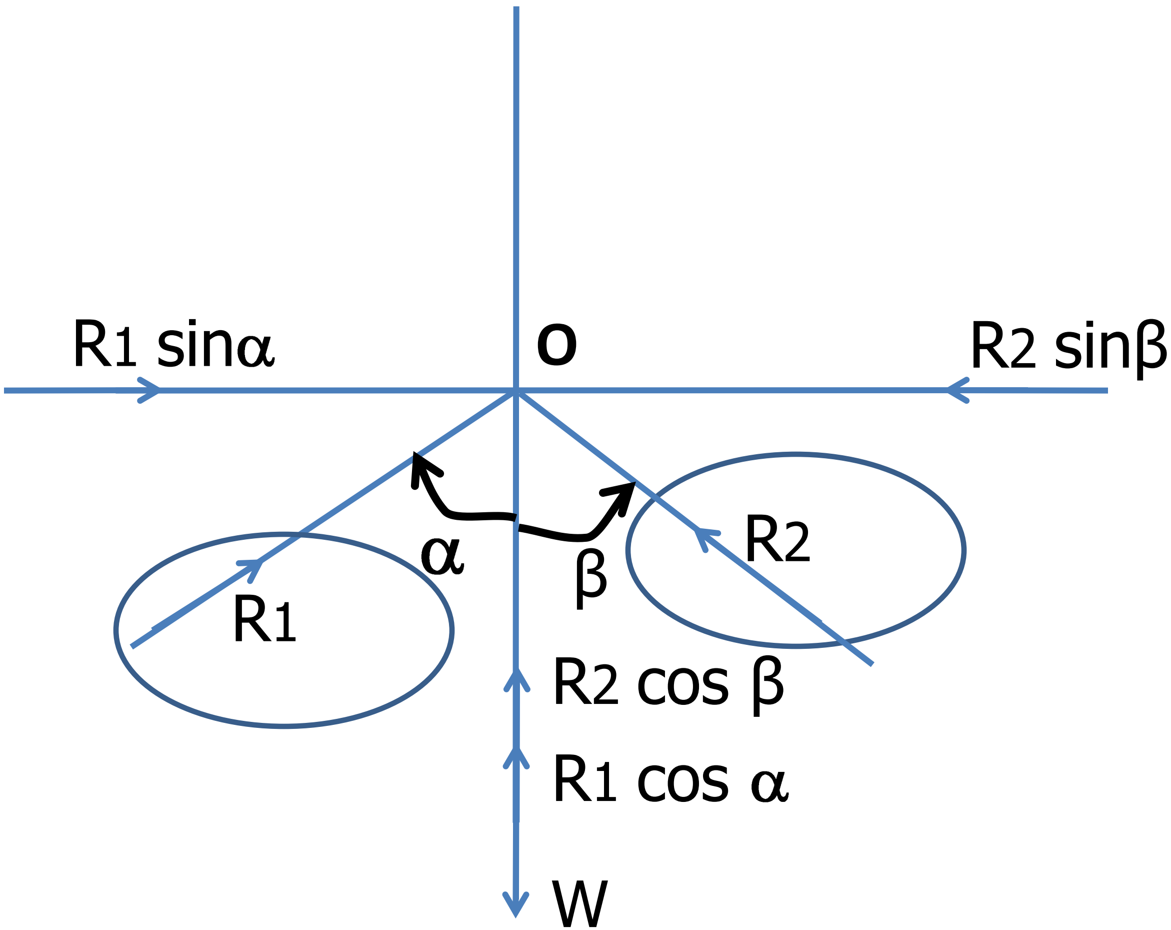
Drawing FBD @ Point ‘O’



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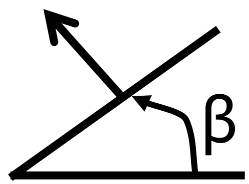
ΣF_x ($\rightarrow$, +ve) = 0, $R_1 \sin(\alpha) - R_2 \sin(\beta) = 0$

$$R_1 = R_2 \frac{Sin(\beta)}{Sin(\alpha)} \qquad (1)$$

ΣF_y ($\uparrow$, +ve) = 0, $R_1 \cos(\alpha) - W + R_2 \cos(\beta) = 0$

Substituting (1)

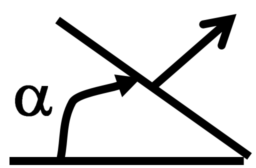
$$R_2 = \frac{W Sin(\alpha)}{Sin(\beta + \alpha)} \,,$$



(2)

Substituting (2) in (1)

$$R_1 = \frac{W Sin(\beta)}{Sin(\alpha + \beta)} \,,$$



Problem 14

Determine the mass that must be supported at ‘P’ and the angle ‘α’ of the cord in order to hold the system in equilibrium.

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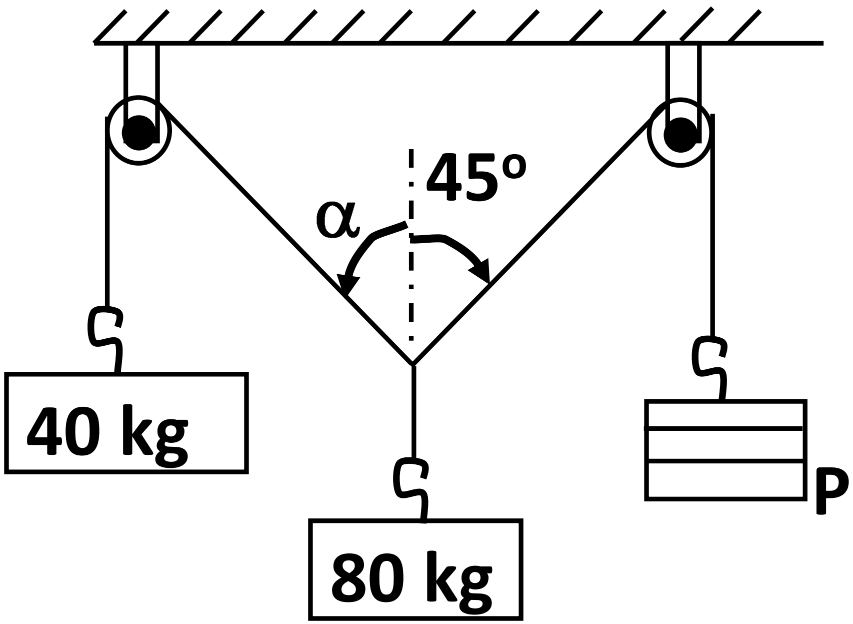
45°
α
40 kg
80 kg
P

For solution refer the Book on "Engineering Mechanics" By Vela Murali
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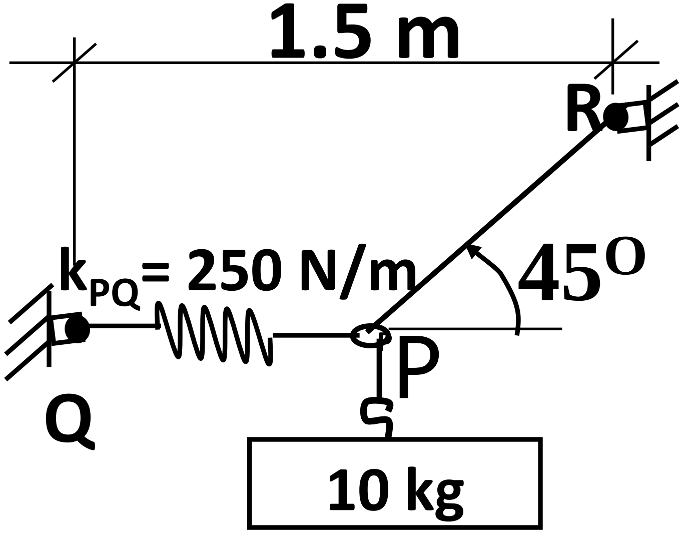
Practice your self

Problem 15

Determine the required length of cord PR in Fig. so that the10 kg block suspended in the position shown. The un-deformed length of the spring PQ is 0.5 m, and the has the stiffness 250 N/m.



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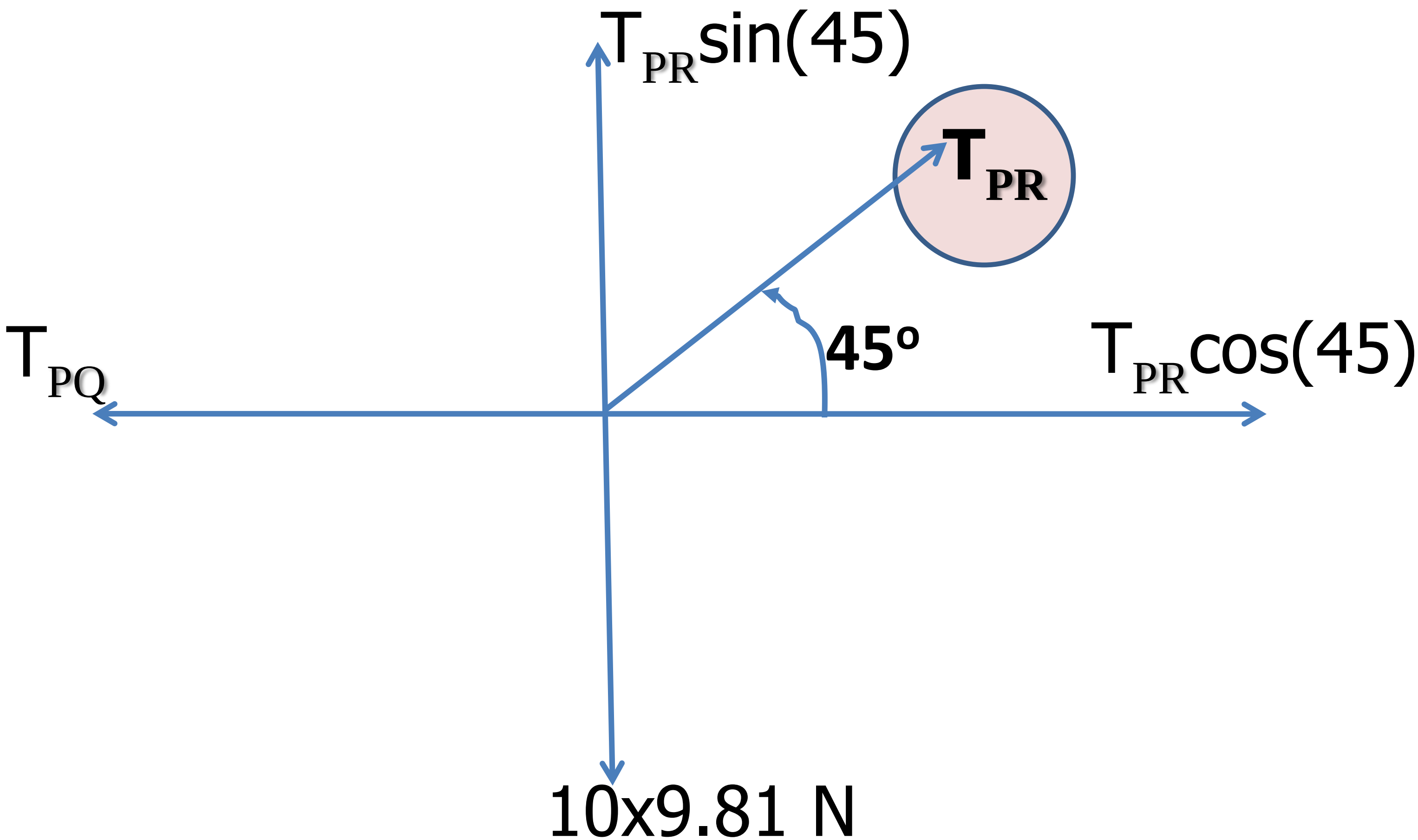
Drawing FBD at point 'P'



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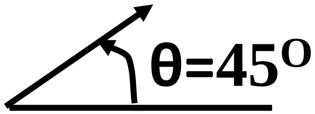
Applying equilibrium conditions

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

$$T_{PR}\sin(45) - 98.1 = 0$$

$$T_{PR} = 138.7\,N, \qquad (1)$$



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

$$T_{PR}\cos(45) - T_{PQ} = 0$$

Substituting (1)

$$T_{PQ} = 98.1 \ N, \leftarrow$$

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$$Deformation\ in\ PQ = \frac{Tension\ force,\ T_{PQ}}{Stiffness\ K_{PQ}}$$

$$\Delta_{PQ} = \frac{98.1}{250} = 0.3924m$$

$$Deformed\ length = Undeformed\ length + Deformation$$

$$= 0.5 + 0.3924 = 0.8924\text{m}$$

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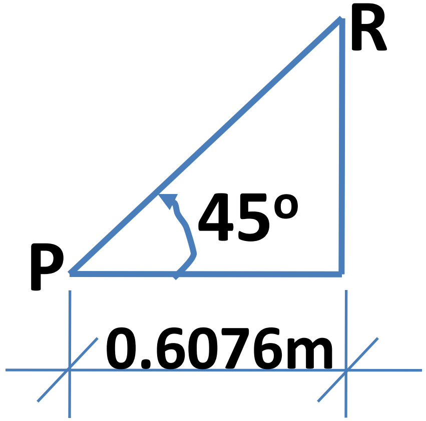

$$\cos 45 = \frac{1.5 - 0.8924}{PR} = \frac{0.6076}{PR}$$

$$PR = 0.8593\text{m}$$

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Particle Mechanics -Concurrent Non-coplanar forces - Forces in space

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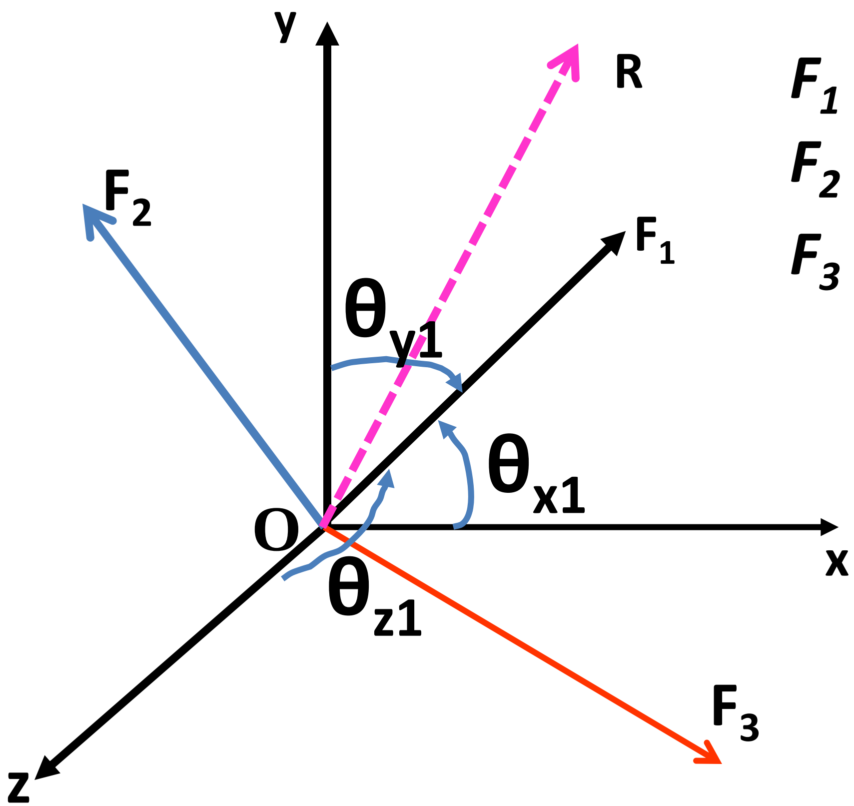
- **Concurrent Non-coplanar forces**



$F_1 = F_{x1}i + F_{y1}j + F_{z1}k$

$F_2 = F_{x2}i + F_{y2}j + F_{z2}k$

$F_3 = F_{x3}i + F_{y3}j + F_{z3}k$

$F_{x1} = F_1 \cos(\theta_{x1})$, $F_{y1} = F_1 \cos(\theta_{y1})$, $F_{z1} = F_1 \cos(\theta_{z1})$ etc……

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$$\sum F_x = F_{x1} + F_{x2} + F_{x3}$$

$$\sum F_y = F_{y1} + F_{y2} + F_{y3}$$

$$\sum F_z = F_{z1} + F_{z2} + F_{z3}$$

$$R = \sqrt{\left(\sum F_x\right)^2 + \left(\sum F_y\right)^2 + \left(\sum F_z\right)^2}$$

$$\theta_x = \cos^{-1}\left(\frac{\sum F_x}{R}\right), \quad \theta_y = \cos^{-1}\left(\frac{\sum F_y}{R}\right) \quad \theta_z = \cos^{-1}\left(\frac{\sum F_z}{R}\right)$$

$$Cos^2(\theta_x) + Cos^2(\theta_y) + Cos^2(\theta_z) = 1$$

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- ***Problem 16***

A force of 200 kN is acting at a point making an angle of 120^o and 60^o with x- and y- axes respectively. Find the components of the force and express the force as a vector.

Solution

$$Cos^2(\theta_x) + Cos^2(\theta_y) + Cos^2(\theta_z) = 1$$

$$Cos^2(120) + Cos^2(60) + Cos^2(\theta_z) = 1$$

$$Cos^2(\theta_z) = 0.5$$

$$Cos(\theta_z) = \pm 0.7071$$

$$Taking\ \ positive\ value,\ \ \theta_z = 45^o$$

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$$F_x = FCos\theta_x = 200Cos(120) = -100 \ \ N$$

$$F_y = FCos\theta_y = 200Cos(60) = 100 \ \ N$$

$$F_z = FCos\theta_z = 200Cos(45) = 141.4 \ \ N$$

$$\vec{F} = -100 \ \vec{i} + 100 \ \vec{j} + 141.4 \ \vec{k}$$

- ***Problem 17***

A force $\vec{F} = 200\ \vec{i} + 100\ \vec{j} - 50\ \vec{k}$ **acts at a point ‘O. Find the magnitude and the direction of the force.**

- **Solution**

F_x = 200 units, F_y = -100 units

F_z = -50 units

Magnitude of the force =

$$\sqrt{\left(\sum F_x\right)^2 + \left(\sum F_y\right)^2 + \left(\sum F_z\right)^2} = 229.13\,Units$$

$$\theta_x = \cos^{-1}\left(\frac{\sum F_x}{R}\right),\ \theta_y = \cos^{-1}\left(\frac{\sum F_y}{R}\right)\ \theta_z = \cos^{-1}\left(\frac{\sum F_z}{R}\right)$$

$$\theta_x = 29.2^o, \theta_y = 115.87^o, \theta_z = 102.6^o$$

- ***Problem 18***

A force of 300 kN acts along a line joining two points A (1,2,3) and B (2, 4,-5). Determine its components and express it as vector.

For solution refer the Book on "Engineering Mechanics" By Vela Murali
Published by Oxford University Press (2010)

Practice your self

Problem 19

A force of 250 kN acts along a line joining two points P (-3,4,6) and Q(5,-5,8). Determine the component of the force along the line joining two points A (3,2,1) and B (4,3,5).

- **Solution**

To find out the inclination of the line 'AB' with respect to x, y& z axis

$$dx_{PQ} = x_Q - x_P = 8$$

$$dy_{PQ} = y_Q - y_P = -9$$

$$dz_{PQ} = z_Q - z_P = 2$$

$$r_{PQ} = \sqrt{dx_{PQ}^2 + dy_{PQ}^2 + dz_{PQ}^2} = 12.2$$

$$\theta_{x-PQ} = \cos^{-1}\left(\frac{dx_{PQ}}{r_{PQ}}\right) = 49.02^o$$

$$\theta_{y-PQ} = \cos^{-1}\left(\frac{dy_{PQ}}{r_{PQ}}\right) = 137.5^o$$

$$\theta_{z-PQ} = \cos^{-1}\left(\frac{dz_{PQ}}{r_{PQ}}\right) = 80.56^o$$

To find out the inclination of the line ‘AB’ Whose coordinates are A(3,2,1)& B(4,3,5) with respect to x, y& z axis

$$dx_{AB} = x_B - x_A = 1$$

$$dy_{AB} = y_B - y_A = 1$$

$$dz_{AB} = z_B - z_A = 4$$

$$r_{AB} = \sqrt{dx_{AB}^2 + dy_{AB}^2 + dz_{AB}^2} = 4.24$$

$$\theta_{x-AB} = \cos^{-1}\left(\frac{dx_{AB}}{r_{AB}}\right) = 76.36^o$$

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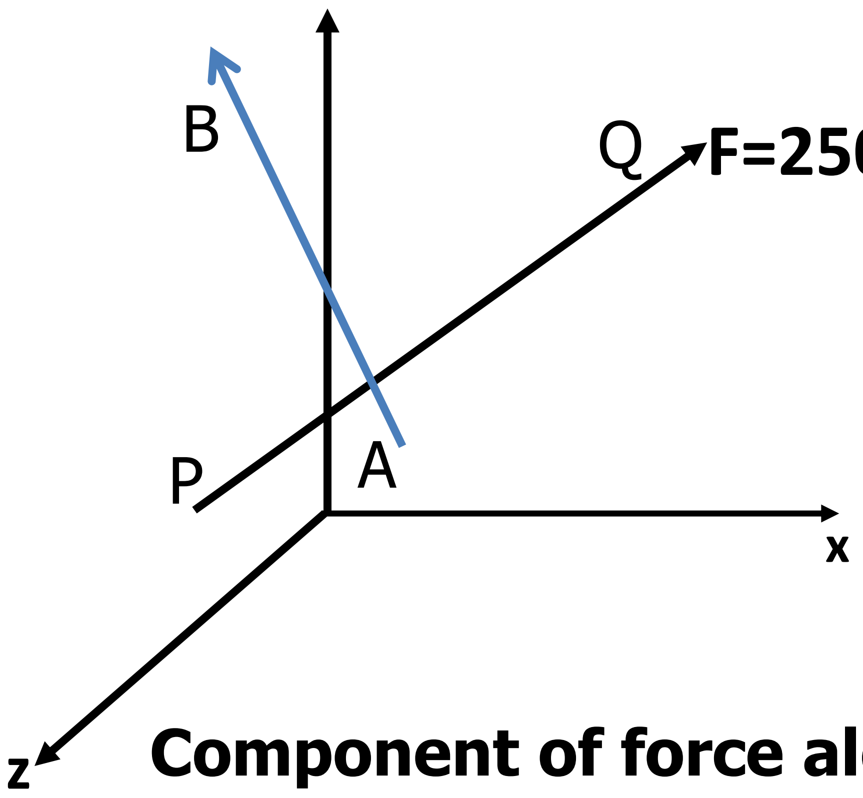

Component of force along the line 'AB'

$$F_{AB} = (F\cos(\theta_{x-PQ})\cos(\theta_{x-AB}))$$

$$+(F\cos(\theta_{y-PQ})\cos(\theta_{y-AB})) + (F\cos(\theta_{z-PQ})\cos(\theta_{z-AB})) = 33.85kN$$

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Problem 20

The following forces act at a point.

$$\vec{F}_1 = 60\vec{i} - 20\vec{j} + 30\vec{k}\ kN$$

$$\vec{F}_2 = 20\vec{i} + 40\vec{j} + 10\vec{k}\ kN$$

$$\vec{F}_3 = -15\vec{i} + 25\vec{j}\ kN$$

Find the resultant and its direction.

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For solution refer the Book on "Engineering Mechanics" By Vela Murali
Published by Oxford University Press (2010)

Practice your self

Problem 21

F_1 = 400 N is acting along the line joining the two points of (0,0,0) & (x_1, y_1, z_1) = (4,-1,5) units;
F_2 = 300 N is acting along the line joining the two points of (0,0,0) & (x_2, y_2, z_2) = (5,-3,-5) units;
F_3 = 500 N is acting along the line joining the two points of (0,0,0) & (x_3, y_3, z_3) = (-6, -6, -5) units.
Find the resultant and its direction.

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Practice your self

Problem 22

A force F acts at the origin of a coordinate system in a direction defined by the angles $\theta_y = 70^o$ and $\theta_z = 60^o$. If the component of the force F along 'x' direction equals to – 180 N.

Determine (i) the angle θ_x (ii) the magnitude of the force 'F' (iii) the components of the force 'F' along 'y' and 'z' directions (iv) The components of the force 'F' along a line through the origin and the point (2,2,2).

•**Solution**

$\theta_y = 70^o$, $\theta_z = 60^o$

$$Cos^2(\theta_x) + Cos^2(\theta_y) + Cos^2(\theta_z) = 1$$

$$Cos^2(\theta_x) + Cos^2(70) + Cos^2(60) = 1$$

$$\theta_x = 142.7^o$$

X- component of the force = -180 N

$$F_x = FCos(\theta_x) = -180$$

$$F = 226.23N$$

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$$F_y = FCos(\theta_y) = 77.37N$$

$$F_z = FCos(\theta_z) = 113.12N$$

To find out the inclination of the line 'OP' Whose coordinates are O(0,0,0)& P(2,2,2) with respect to x, y& z axis

$$dx_{OP} = x_P - x_O = 2$$

$$dy_{OP} = y_P - y_O = 2$$

$$dz_{OP} = z_P - z_O = 2$$

$$r_{OP} = \sqrt{dx_{OP}^2 + dy_{OP}^2 + dz_{OP}^2} = 3.46 \ units$$

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$$\theta_{x-OP} = \cos^{-1}\left(\frac{dx_{OP}}{r_{OP}}\right) = 54.7^o$$

$$\theta_{y-OP} = \cos^{-1}\left(\frac{dy_{OP}}{r_{OP}}\right) = 54.7^o$$

$$\theta_{z-OP} = \cos^{-1}\left(\frac{dz_{OP}}{r_{OP}}\right) = 54.7^o$$

Component of force along the line 'OP'

$$F_{OP} = (F\cos(\theta_x)\cos(\theta_{x-OP}))$$

$$+(F\cos(\theta_y)\cos(\theta_{y-OP})) + (F\cos(\theta_z)\cos(\theta_{z-OP})) = 6.11N$$

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Equilibrium of the Particle applied with a system of Concurrent Non-coplanar forces

$$\Sigma F_x = 0 \quad (\rightarrow, +ve)$$

$$\Sigma F_y = 0 \quad (\uparrow, +ve)$$

and

$$\Sigma F_z = 0 \quad (\swarrow, +ve)$$

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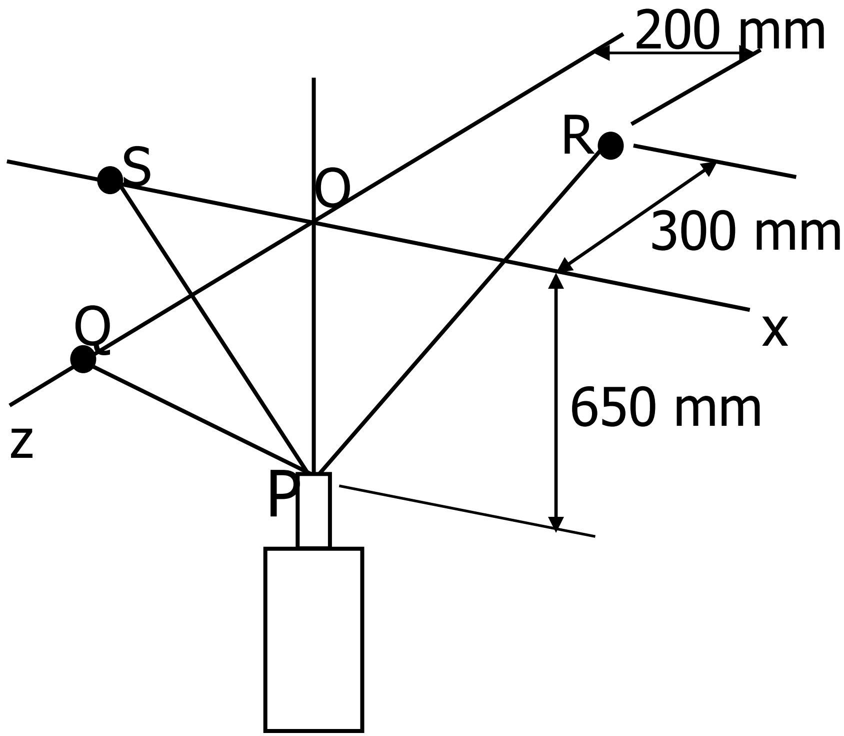
Problem 23

A container of weight W=1500 N is supported by three cables as shown in Fig. Determine the tension in each cable.



OS=500 mm
OQ=600mm

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- **Solution**

To find out the inclination of the line 'PR' whose coordinates are P(0,-650,0)& R(200,0,-300) with respect to x, y& z axis

$$dx_{PR} = x_R - x_P = 200mm$$

$$dy_{PR} = y_R - y_P = 650mm$$

$$dz_{PR} = z_R - z_P = -300mm$$

$$r_{PR} = \sqrt{dx_{PR}^2 + dy_{PR}^2 + dz_{PR}^2} = 743.3 \ mm$$

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$$\theta_{x-PR} = \cos^{-1}\left(\frac{dx_{PR}}{r_{PR}}\right) = 74.39^{o}$$

$$\theta_{y-PR} = \cos^{-1}\left(\frac{dy_{PR}}{r_{PR}}\right) = 29.02^{o}$$

$$\theta_{z-PR} = \cos^{-1}\left(\frac{dz_{PR}}{r_{PR}}\right) = 113.8^{o}$$

$$\left.\begin{aligned} F_{x-PR} &= T_{PR}\cos\left(\theta_{x-PR}\right) = 0.27T_{PR} \\ F_{y-PR} &= T_{PR}\cos\left(\theta_{y-PR}\right) = 0.87T_{PR} \\ F_{z-PR} &= T_{PR}\cos\left(\theta_{z-PR}\right) = -0.403T_{PR} \end{aligned}\right\} \qquad (1)$$

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To find out the inclination of the line ‘PS’ whose coordinates are P(0,-650,0)& S(-500,0,0) with respect to x, y& z axis

$$dx_{PS} = x_S - x_P = -500mm$$

$$dy_{PS} = y_S - y_P = 650mm$$

$$dz_{PS} = z_S - z_P = 0mm$$

$$r_{PS} = \sqrt{dx_{PS}^2 + dy_{PS}^2 + dz_{PS}^2} = 820.1\ mm$$

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$$\theta_{x-PS} = \cos^{-1}\left(\frac{dx_{PS}}{r_{PS}}\right) = 127.6^{o}$$

$$\theta_{y-PS} = \cos^{-1}\left(\frac{dy_{PS}}{r_{PS}}\right) = 37.56^{o}$$

$$\theta_{z-PS} = \cos^{-1}\left(\frac{dz_{PS}}{r_{PS}}\right) = 90^{o}$$

$$\left.\begin{aligned} F_{x-PS} &= T_{PS}\cos(\theta_{x-PS}) = -0.61T_{PS} \\ F_{y-PS} &= T_{PS}\cos(\theta_{y-PS}) = 0.79T_{PS} \\ F_{z-PS} &= T_{PS}\cos(\theta_{z-PS}) = 0 \end{aligned}\right\} \qquad (2)$$

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To find out the inclination of the line 'PQ' whose coordinates are P(0,-650,0)& Q(0,0,600) with respect to x, y& z axis

$$dx_{PQ} = x_Q - x_P = 0mm$$

$$dy_{PQ} = y_Q - y_P = -650mm$$

$$dz_{PQ} = z_Q - z_P = 600mm$$

$$r_{PQ} = \sqrt{dx_{PQ}^2 + dy_{PQ}^2 + dz_{PQ}^2} = 884.59 \ mm$$

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$$\theta_{x-PQ} = \cos^{-1}\left(\frac{dx_{PQ}}{r_{PQ}}\right) = 90^o$$

$$\theta_{y-PQ} = \cos^{-1}\left(\frac{dy_{PQ}}{r_{PQ}}\right) = 137.3^o$$

$$\theta_{z-PQ} = \cos^{-1}\left(\frac{dz_{PQ}}{r_{PQ}}\right) = 47.3^o$$

$$\left.\begin{aligned} F_{x-PQ} &= T_{PQ}\cos(\theta_{x-PQ}) = 0 \\ F_{y-PQ} &= T_{PQ}\cos(\theta_{y-PQ}) = 0.735T_{PQ} \\ F_{z-PQ} &= T_{PQ}\cos(\theta_{z-PQ}) = 0.678T_{PQ} \end{aligned}\right\} \qquad (3)$$

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Components of force acting along the line PO

$$\left.\begin{aligned} F_{x-PO} &= 0 \\ F_{y-PO} &= -1500N \\ F_{z-PO} &= 0 \end{aligned}\right\} \qquad (4)$$

For equilibrium it must satisfy the following Equations,

i) $\Sigma F_x = 0$, (→, +ve) ii) $\Sigma F_y = 0$, (↑, +ve)
iii) $\Sigma F_z = 0$, (↙, +ve)

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From equations (1), (2), (3) and (4)

$$\sum F_x = 0 \quad \Rightarrow 0.27T_{PR} - 0.61T_{PS} + 0 + 0 = 0 \quad (5)$$

$$\sum F_y = 0 \quad \Rightarrow 0.87T_{PR} + 0.79T_{PS} + 0.735T_{PQ} - 1500 = 0$$

$$Substituting \;\; Eq.(5)$$

$$T_{PQ} = 2040.8 - 2.756T_{PS} \quad (6)$$

$$\sum F_z = 0 \quad \Rightarrow -0.403T_{PR} + 0 + 0.678T_{PQ} + 0 = 0$$

$$Substituting \;\; Eq.(5) \,\&\, Eq.(6)$$

$$T_{PS} = 497N \quad (7)$$

$$Substituting \;\; Eq.(7) \;\; in \;\; Eq.(5)$$

$$T_{PR} = 1125.11N \quad (8)$$

$$Substituting \;\; Eq.(7) \;\; in \;\; Eq.(6)$$

$$T_{PQ} = 668.75N \quad (9)$$

Tensions are

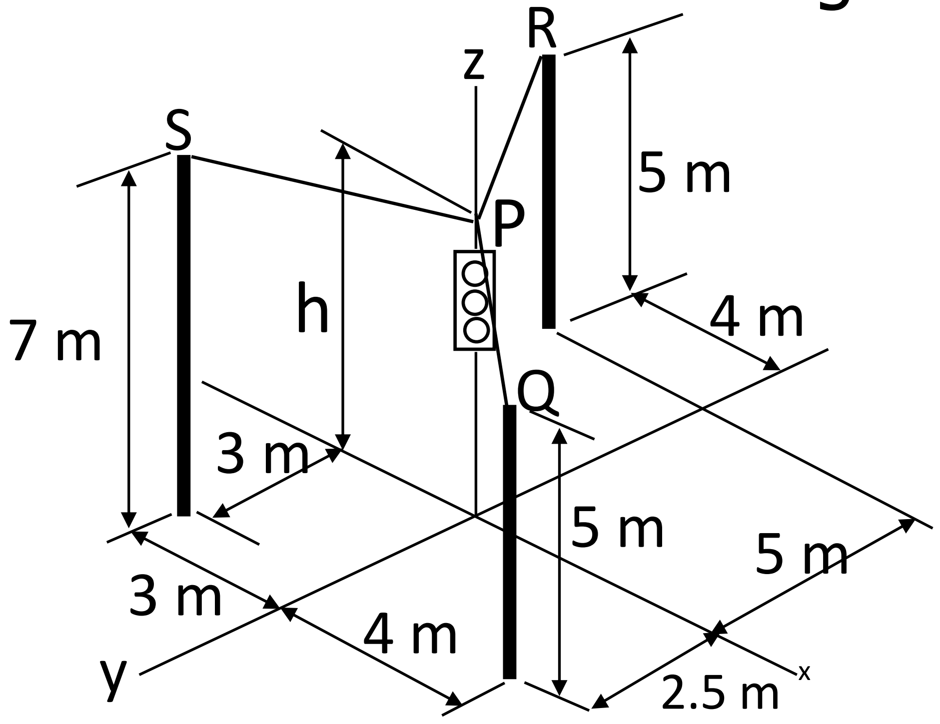
$$T_{PS} = 497.84\ N, (\theta_x, \theta_y, \theta_z) = (127.6^o, 37.56^o, 90^o)$$

$$T_{PR} = 1125.11\ N, (\theta_x, \theta_y, \theta_z) = (74.39^o, 29.02^o, 113.8^o)$$

$$T_{PQ} = 668.75\ N, (\theta_x, \theta_y, \theta_z) = (90^o, 137.3^o, 47.3^o)$$

Problem 24

Determine the tension developed in the three cables required to support the traffic light, which has a mass of 30 kg. Take h = 4 m



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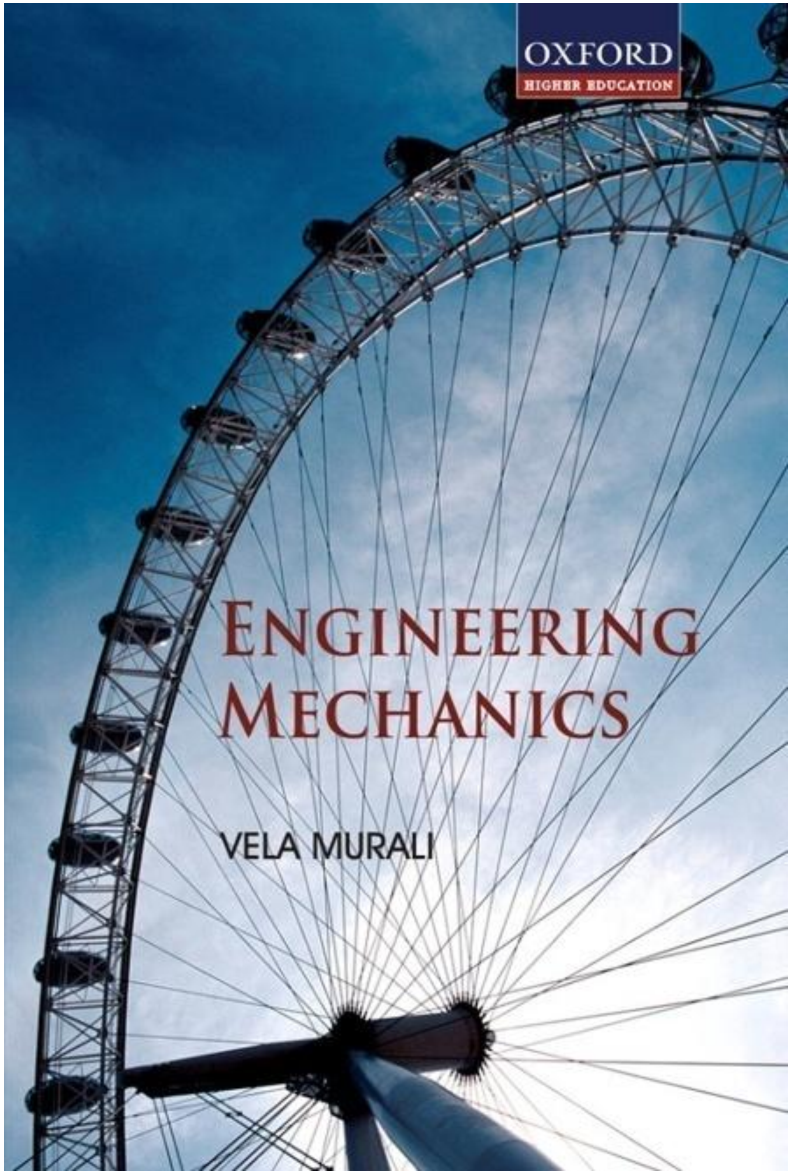

Reference:
"Engineering Mechanics"
by
Vela Murali
Published by Oxford University Press (2010)