# MECHANICS AND MATERIALS I

1

Ali Javili

Bilkent University

# MECHANICS AND MATERIALS I

## Introduction to Statics i

## Statics of Particles

## Chap. 2

[ Beer Johnston et al. 9th edition ]

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Bilkent University

NOTATION :

NOTATION:

- VECTORS
- VECTOR MAGNITUDES

NOTATION:

- VECTORS → $\mathbb{F}$, $\vec{F}$, $\underline{F}$, $\vec{AB}$
- VECTOR MAGNITUDES → $F$, $|\mathbb{F}|$, $|\vec{F}|$, $|\underline{F}|$, $|\vec{AB}|$, $AB$

NOTATION :

My preferred notation (closer to book)

→ VECTORS → $\mathbf{F}$, $\vec{F}$, $\underline{F}$, $\overrightarrow{AB}$ when needed

→ VECTOR MAGNITUDES → $F$, $|\mathbf{F}|$, $|\vec{F}|$, $|\underline{F}|$, $|\overrightarrow{AB}|$, $AB$

# Statics

# STATICS

↳ EQUILIBRIUM OF FORCES

AND

EQUILIBRIUM OF MOMENTS

# STATICS

- EQUILIBRIUM OF FORCES $\longrightarrow \sum \mathbf{F} = \mathbf{0}$

AND

- EQUILIBRIUM OF MOMENTS $\longrightarrow \sum \mathbf{M}_O = \mathbf{0}$

# STATICS

- EQUILIBRIUM OF FORCES $\rightarrow \sum \mathbf{F} = \mathbf{0}$

  AND

- EQUILIBRIUM OF MOMENTS $\rightarrow \sum \mathbf{M}_O = \mathbf{0}$

ZERO VECTOR ← BOLD ZERO

ABOUT POINT O

SHOULD HOLD FOR ANY POINT!

# STATICS

- EQUILIBRIUM OF FORCES $\Rightarrow \sum \mathbf{F} = \mathbf{0}$

  ZERO VECTOR ← BOLD ZERO

AND

- EQUILIBRIUM OF MOMENTS $\Rightarrow \sum \mathbf{M}_O = \mathbf{0}$

  ABOUT POINT O

  SHOULD HOLD FOR ANY POINT!

- FREE BODY DIAGRAM

  FBD

STATICS

STEP 1: DRAW FBD

STEP 2: EQUILIBRIUM

$\Sigma$ OF FORCES

$\Sigma$ OF MOMENTS

EQUILIBRIUM OF FORCES $\rightarrow \sum \mathbf{F} = \mathbf{0}$

ZERO VECTOR

BOLD ZERO

AND

EQUILIBRIUM OF MOMENTS $\rightarrow \sum \mathbf{M}_O = \mathbf{0}$

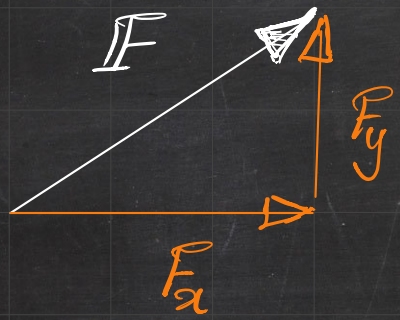
ABOUT POINT O

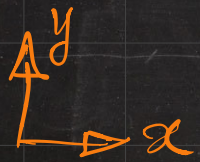
SHOULD HOLD FOR ANY POINT!

FREE BODY DIAGRAM

FBD

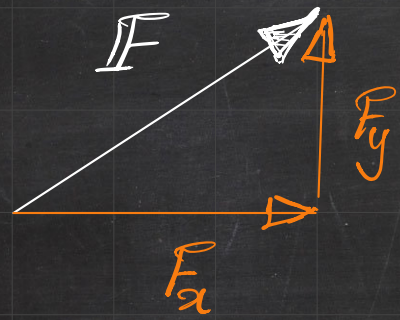
# VECTOR COMPONENTS

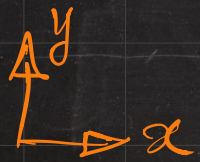


# VECTOR COMPONENTS

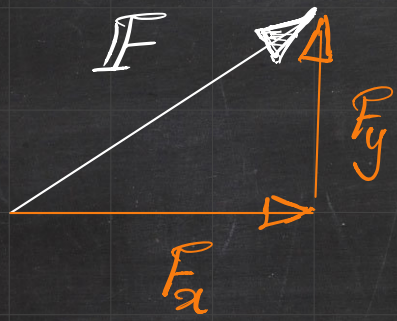
$$\vec{F} = F_x \vec{i} + F_y \vec{j}$$

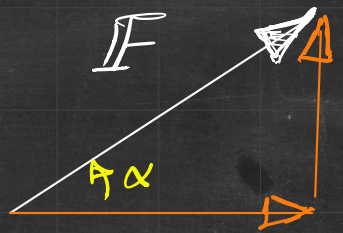


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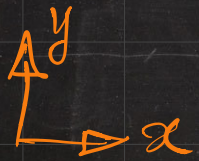
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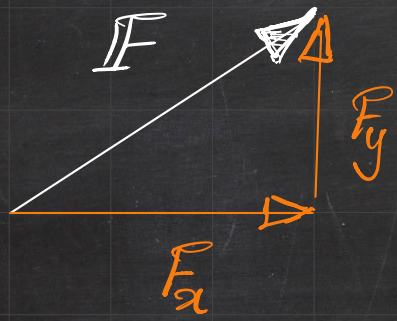

$$F_y = F \sin\alpha$$

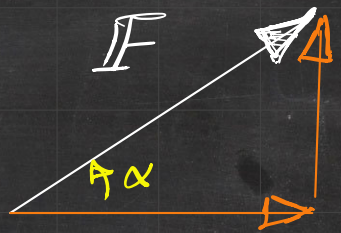
$$F_x = F \cos\alpha$$



# VECTOR COMPONENTS

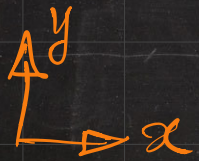
$$\vec{F} = F_x\,\hat{i} + F_y\,\hat{j} \Rightarrow \vec{F} = F\cos\alpha\,\hat{i} + F\sin\alpha\,\hat{j}$$



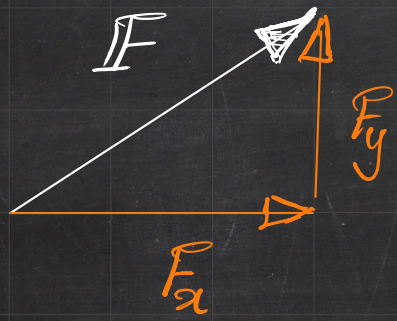

$$F_y = F\sin\alpha$$

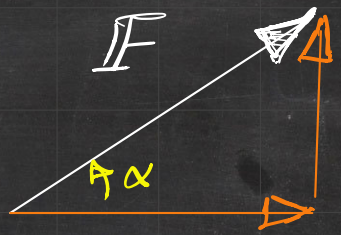
$$F_x = F\cos\alpha$$



# VECTOR COMPONENTS

$$\mathbf{F} = F_x\,\mathbf{i} + F_y\,\mathbf{j} \Rightarrow \mathbf{F} = F\cos\alpha\,\mathbf{i} + F\sin\alpha\,\mathbf{j}$$

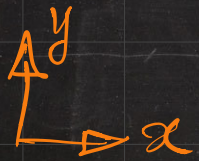



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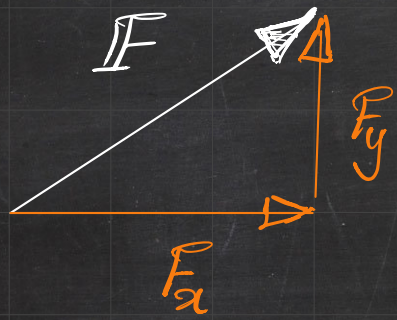
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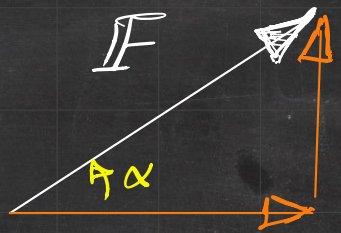
$$|\mathbf{F}| = \sqrt{F_x^2 + F_y^2} = \sqrt{F^2\cos^2\alpha + F^2\sin^2\alpha} = F$$



# VECTOR COMPONENTS

$$\vec{F} = F_x \hat{i} + F_y \hat{j} \Rightarrow \vec{F} = F\cos\alpha\,\hat{i} + F\sin\alpha\,\hat{j}$$

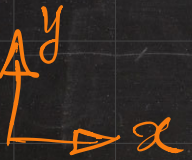



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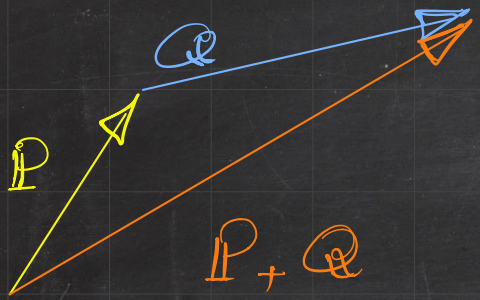
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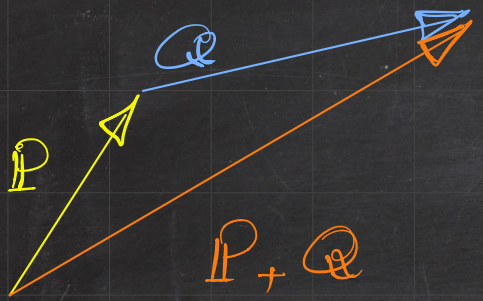

$$\tan\alpha = \frac{\sin\alpha}{\cos\alpha} = \frac{F\sin\alpha}{F\cos\alpha} \Rightarrow \tan\alpha = \frac{F_y}{F_x}$$

# ADDITION OF VECTORS

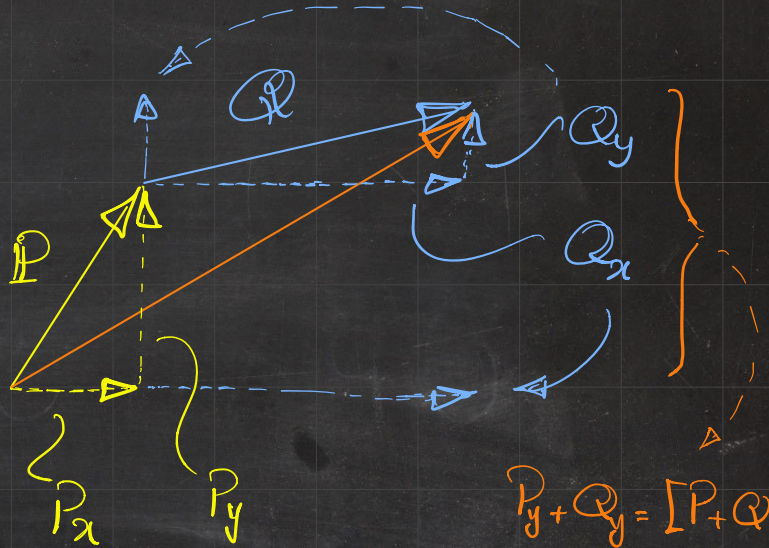



Parallelogram rule (Graphical)

# ADDITION OF VECTORS



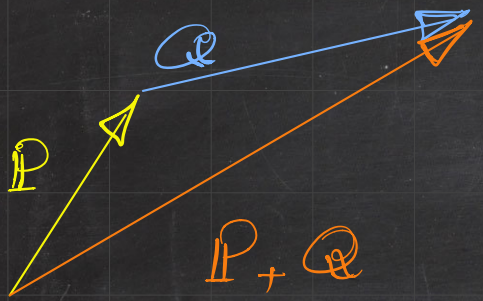

Parallelogram rule (Graphical)



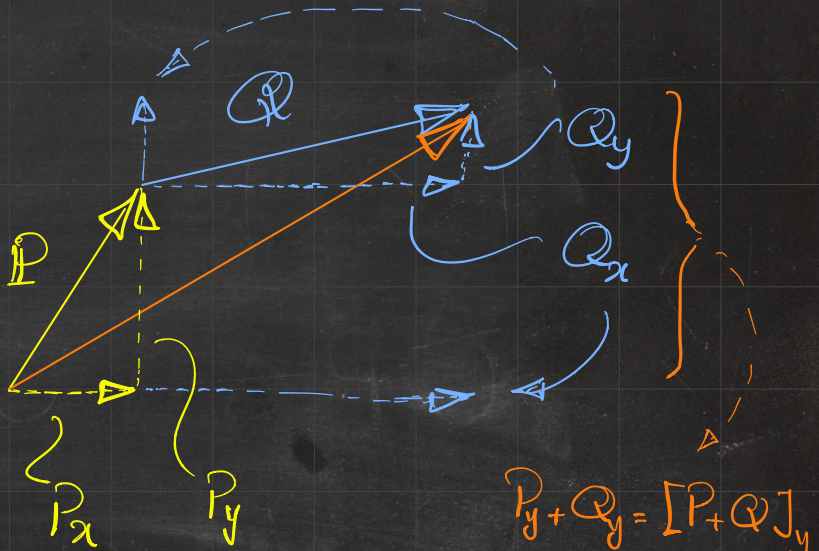

$$P_y + Q_y = [P+Q]_y$$

$$P_x + Q_x = [P+Q]_x$$

# ADDITION OF VECTORS

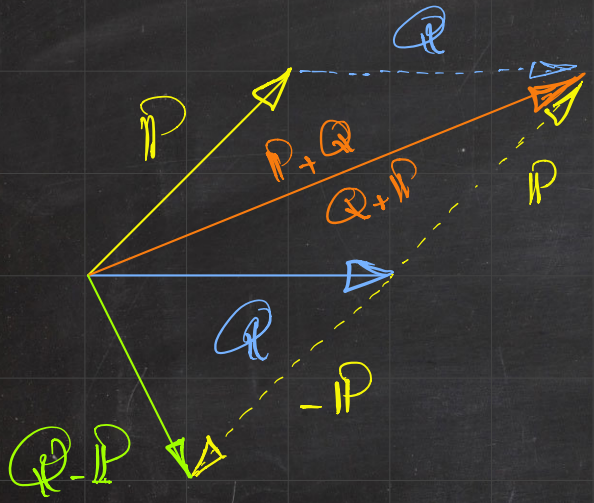



Parallelogram rule (Graphical)




$$\mathbf{P}+\mathbf{Q} = P_x\hat{i} + P_y\hat{j} + Q_x\hat{i} + Q_y\hat{j} = [P_x+Q_x]\hat{i} + [P_y+Q_y]\hat{j}$$

$$P_x + Q_x = [P+Q]_x$$



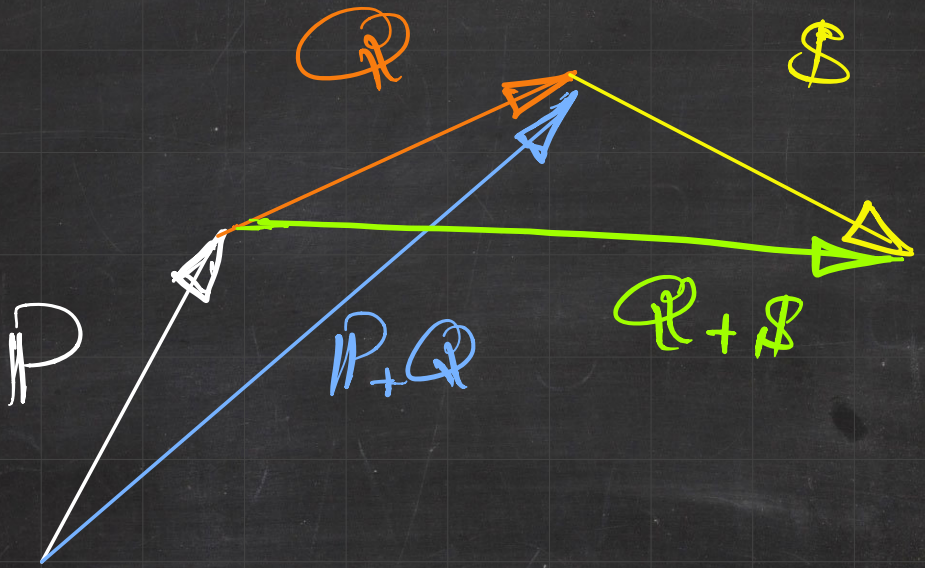

$$\mathbf{P} + \mathbf{Q} = \mathbf{Q} + \mathbf{P}$$

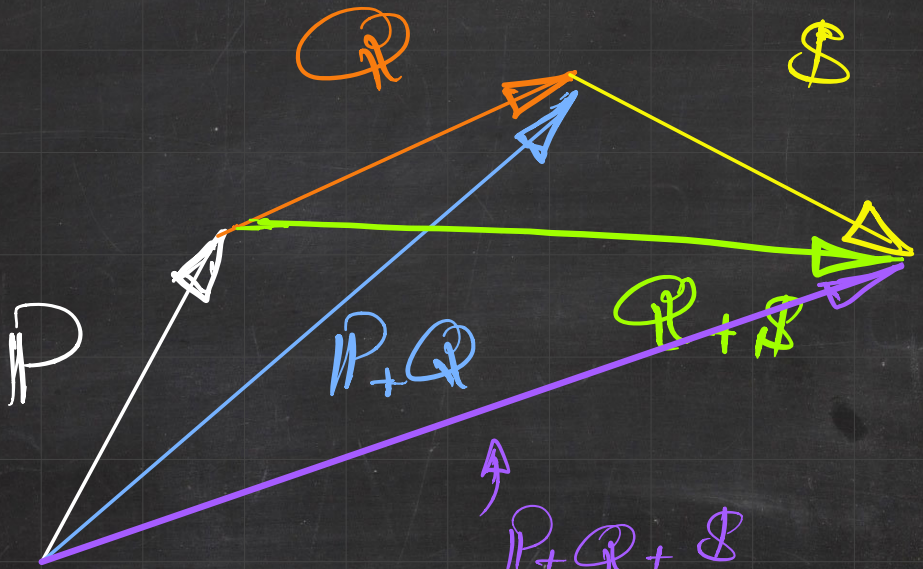
The vector addition is commutative

$$\mathbf{Q} - \mathbf{P} = \mathbf{Q} + [-\mathbf{P}]$$

$$\mathbf{R} = \mathbf{P} + \mathbf{Q}$$

$\mathbf{R}$ → resultant force


Q
S
P
P+Q
Q+S


P
Q
S
P+Q
Q+S
P+Q+S
[P+Q]+S
P+[Q+S]

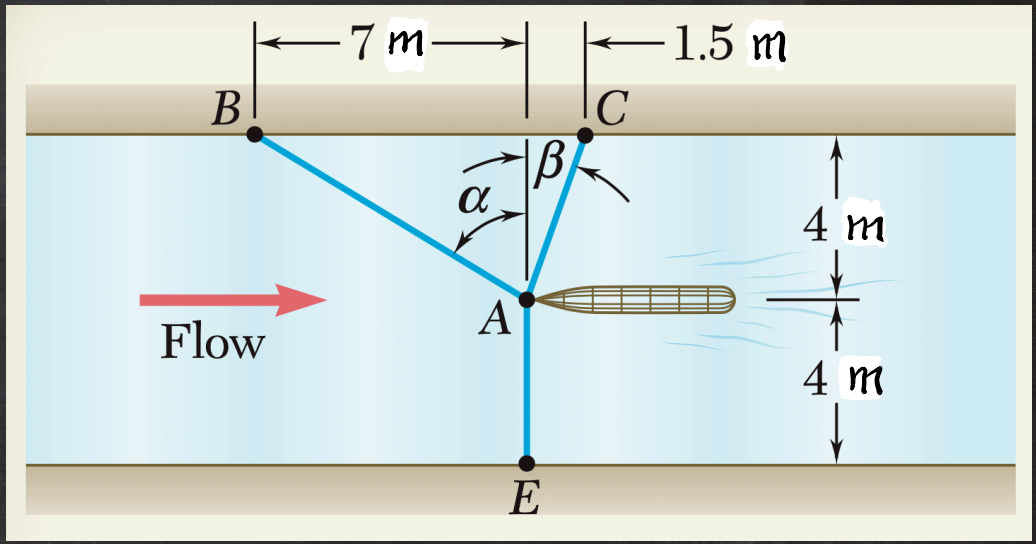
# Exercise 1 . [ similar to ... P. 39 ... 2.6 ]

THE BOAT IN THE TEST CHANNEL REMAINS IN EQUILIBRIUM BY THE THREE CABLES ATTACHED TO IT. FOR A GIVEN SPEED, THE TENSION IN THE CABLES AB, AE READ TO

$T_{AB} = 200N$

$T_{AE} = 300N$

... DETERMINE ...




DRAG FORCE : $F_D$

TENSION IN CABLE AC : $T_{AC}$

- Cables / Ropes carry tension only!

→ Cables / Ropes carry tension only!

→ FBD

$\Sigma F = 0$, $\Sigma M_o = \emptyset$

2D

$\Sigma F_x = 0$

$\Sigma F_y = 0$

not applicable here since all forces applied at a point !

- Cables / Ropes carry tension only!

- FBD
  - $\Sigma F = 0$, $\Sigma M_o = \emptyset$

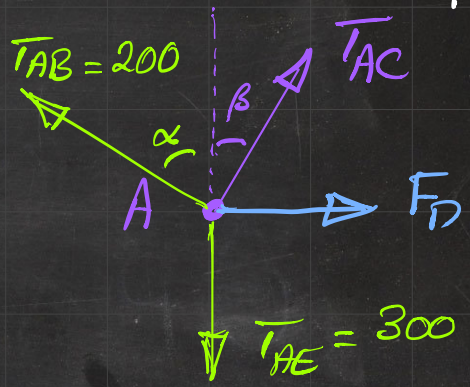
2D

$\Sigma F_x = 0$

$\Sigma F_y = 0$

not applicable here since all forces applied at a point !

FBD




$\alpha = \tan^{-1}(3/4) = 60.26^\circ$

$\beta = \tan^{-1}(1.5/4) = 20.56^\circ$

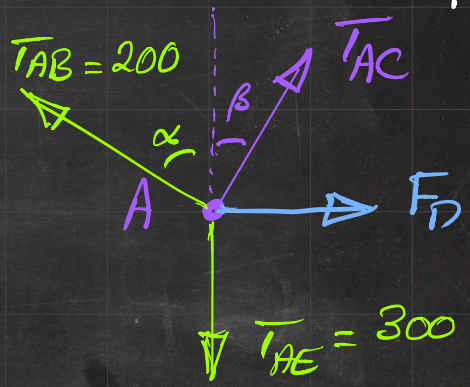
$$\Sigma F_x = 0$$

$$F_D + T_{AC}\sin\beta - T_{AB}\sin\alpha = 0$$

$$\Sigma F_y = 0$$

$$T_{AC}\cos\beta + T_{AB}\cos\alpha - T_{AE} = 0$$

FBD




$$\alpha = \tan^{-1}(7/4) = 60.26^\circ$$

$$\beta = \tan^{-1}(1.5/4) = 20.56^\circ$$

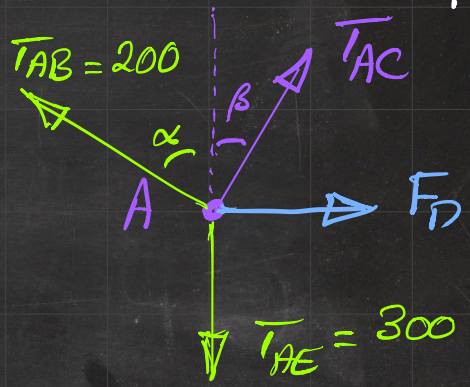
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FBD




$$\alpha = \tan^{-1}\left(\tfrac{7}{4}\right) = 60.26^\circ$$

$$\beta = \tan^{-1}\left(\tfrac{1.5}{4}\right) = 20.56^\circ$$

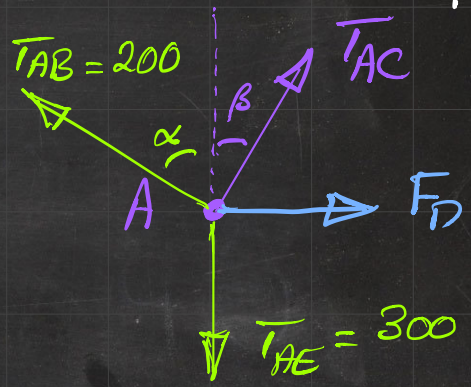
$\Sigma F_x = 0$

$F_D + T_{AC}\sin\beta - T_{AB}\sin\alpha = 0$ ✓ ✓ ✓

$\Sigma F_y = 0$

$T_{AC}\cos\beta + T_{AB}\cos\alpha - T_{AE} = 0$ ✓ ✓ ✓ ✓

FBD




$\alpha = \tan^{-1}(7/4) = 60.26^\circ$

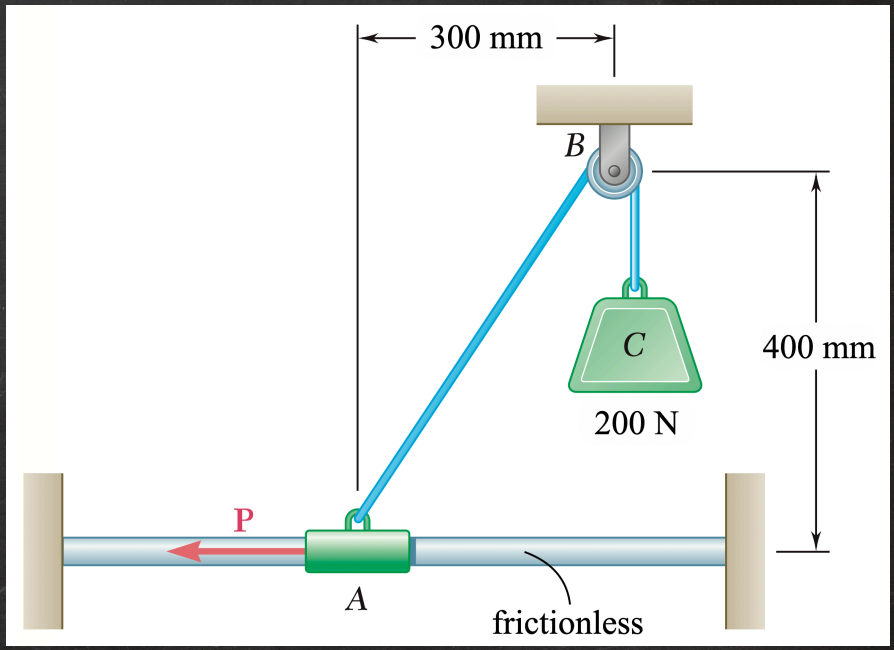
$\beta = \tan^{-1}(1.5/4) = 20.56^\circ$

$\Rightarrow$ 2 EQNs., 2 UNKNOWNS $\Rightarrow$ $T_{AC} = 214.5\,N$, $F_D = 98.3\,N$

# Exercise 2 . [ similar to ... P. 44 ... 2.63 ]

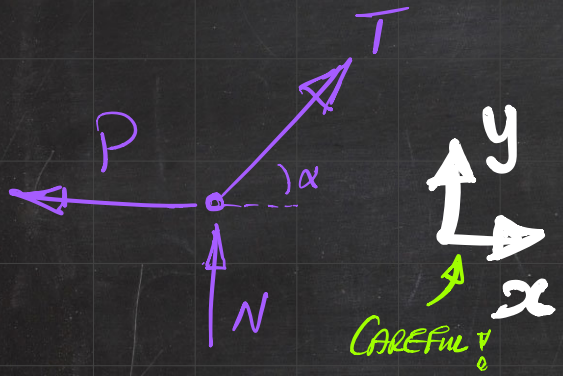
COLLAR A IS CONNECTED TO A 200N LOAD AND CAN SLIDE ON A FRICTIONLESS HORIZONTAL ROD.

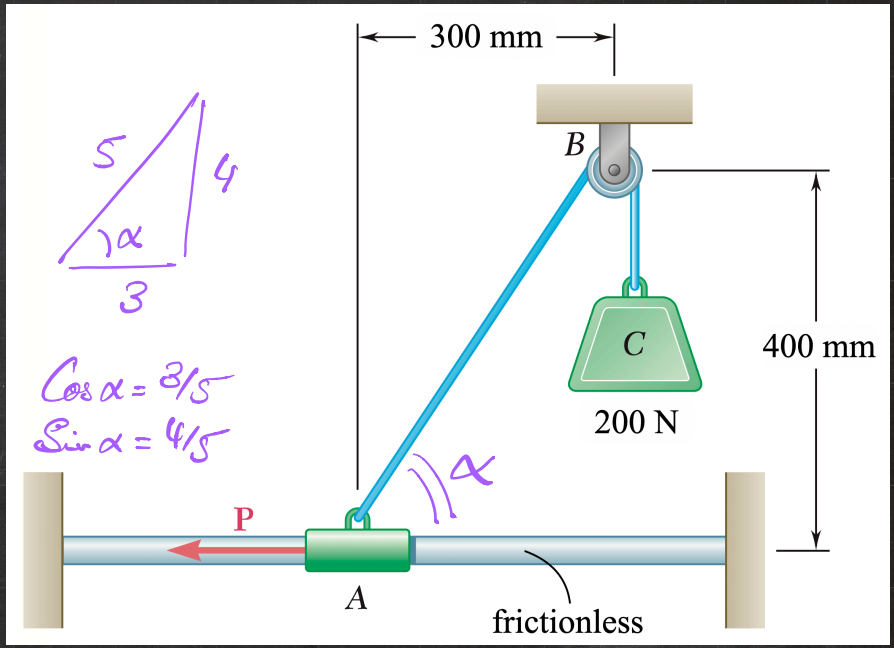
DETERMINE THE MAGNITUDE OF FORCE P REQUIRED FOR EQUILIBRIUM.



* FBD

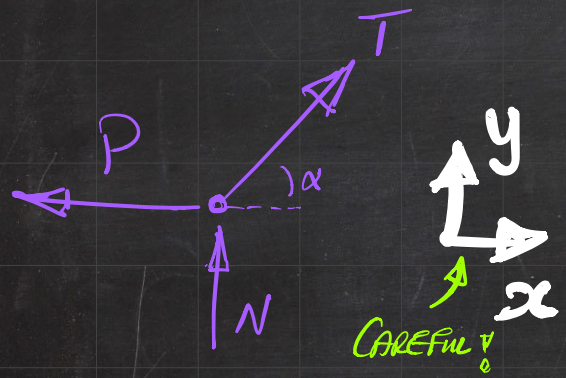
* $\Sigma F = 0$ , $\Sigma M_O = 0$



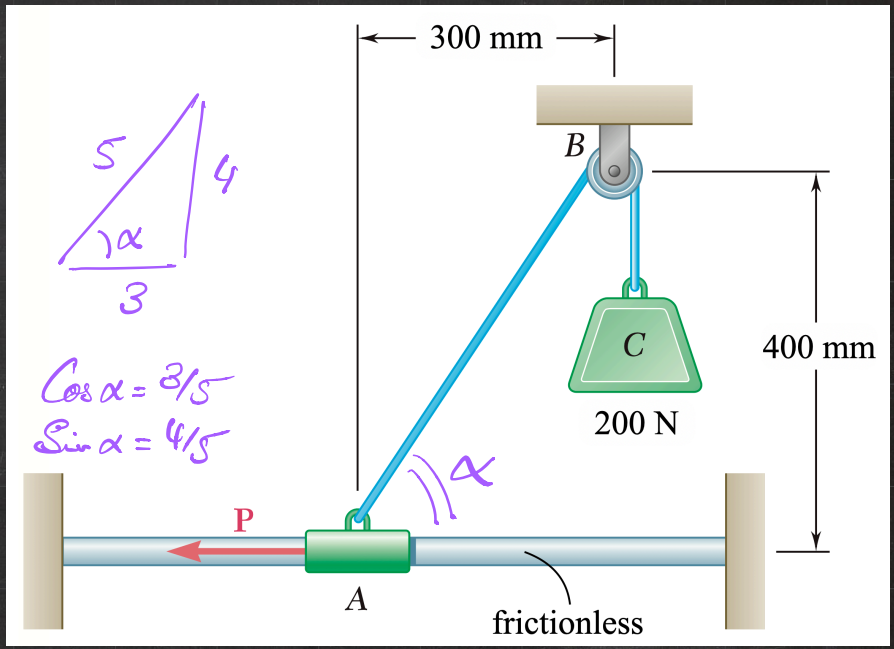
* FBD

* $\Sigma F = \emptyset$ , $\Sigma M_O = \emptyset$



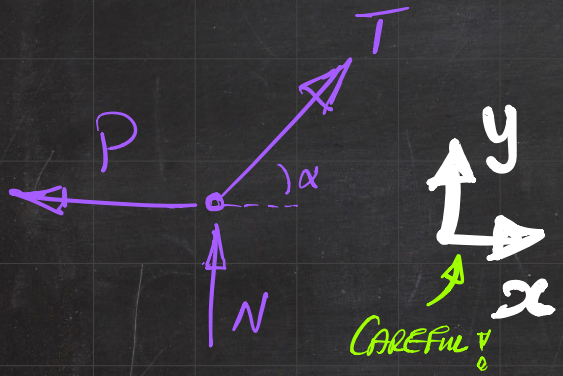

$\Sigma F_x = 0 \Rightarrow -P + T\cos\alpha = 0$

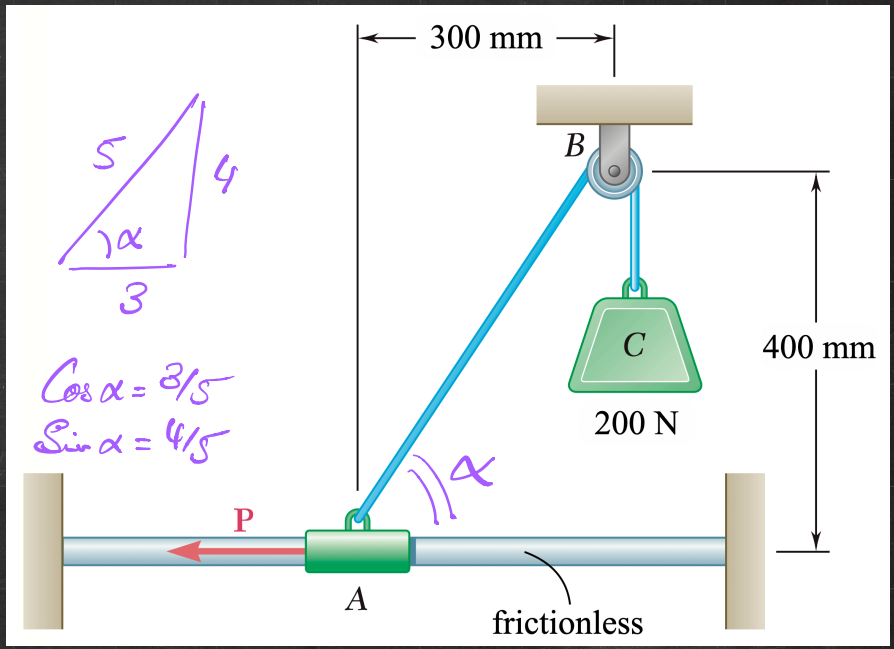
$\Sigma F_y = 0 \Rightarrow T\sin\alpha + N = 0$



* FBD

* $\Sigma F = \emptyset$ , $\Sigma M_O = \emptyset$




$$\Sigma F_x = 0 \Rightarrow -P + T\cos\alpha = 0$$

$$\Sigma F_y = 0 \Rightarrow T\sin\alpha + N = 0$$

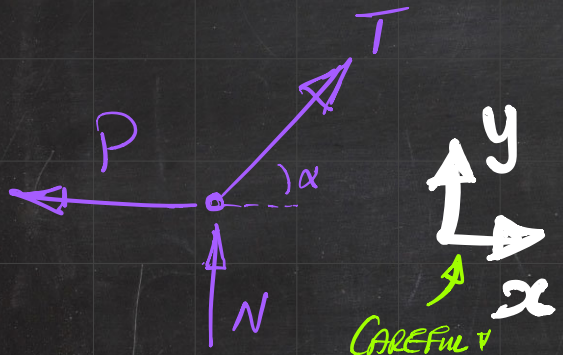
$\Longrightarrow$ $T = 200$

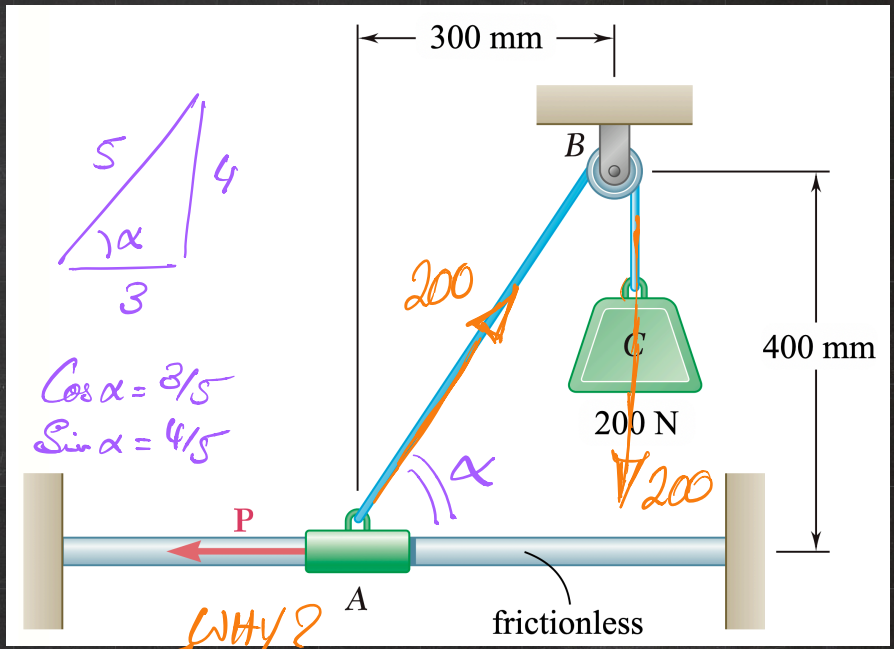
$P = 120\ N$

$N = -160\ N$ ← OPPOSITE DIRECTION

* FBD

* $\Sigma F = 0$ , $\Sigma M_O = 0$

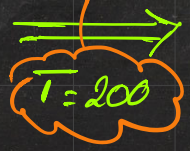



$$\Sigma F_x = 0 \Rightarrow -P + T\cos\alpha = 0$$

$$\Sigma F_y = 0 \Rightarrow T\sin\alpha + N = 0$$

WHY?




$P = 120\ N$

$N = -160\ N$ ← OPPOSITE DIRECTION

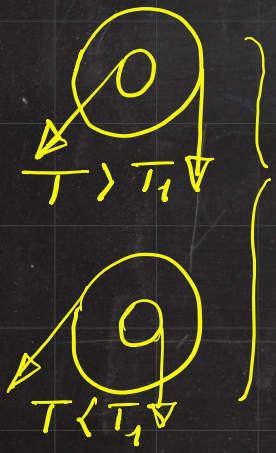
$P = 200$ NOT BECAUSE IT IS THE SAME ROPE!

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BUT BECAUSE OF EQUILIBRIUM OF PULLEY!

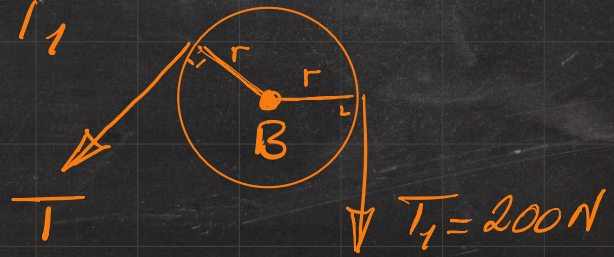
$P = 200$ NOT BECAUSE IT IS THE SAME ROPE!

BUT BECAUSE OF EQUILIBRIUM OF PULLEY!




$\Sigma M_B = 0 \Rightarrow T = T_1$

STILL THE SAME ROPE!



# VECTORS IN 3D SPACE

$$\mathbf{F} = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix}$$

$$\mathbf{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k}$$

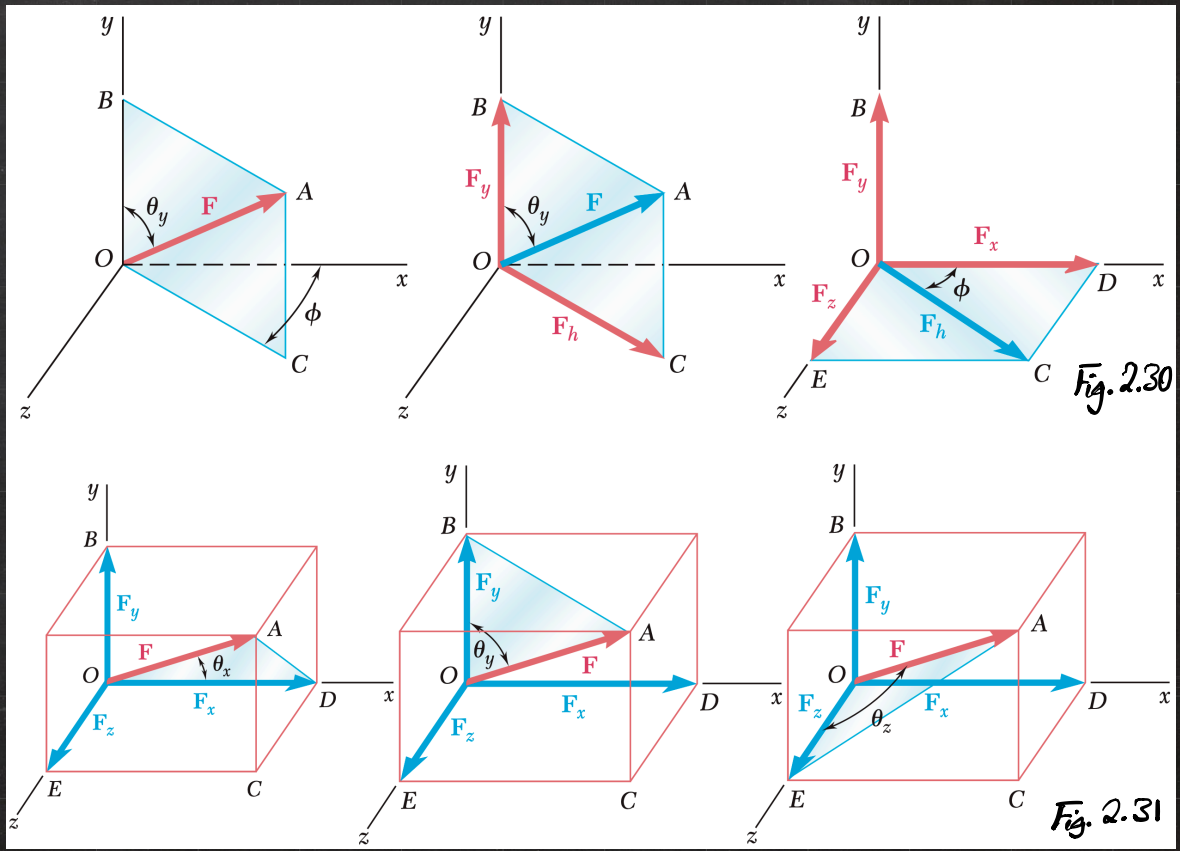



Fig. 2.30

Fig. 2.31

$$\mathbf{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k}$$

$$F_x = F\cos\theta_x$$

$$F_y = F\cos\theta_y$$

$$F_z = F\cos\theta_z$$

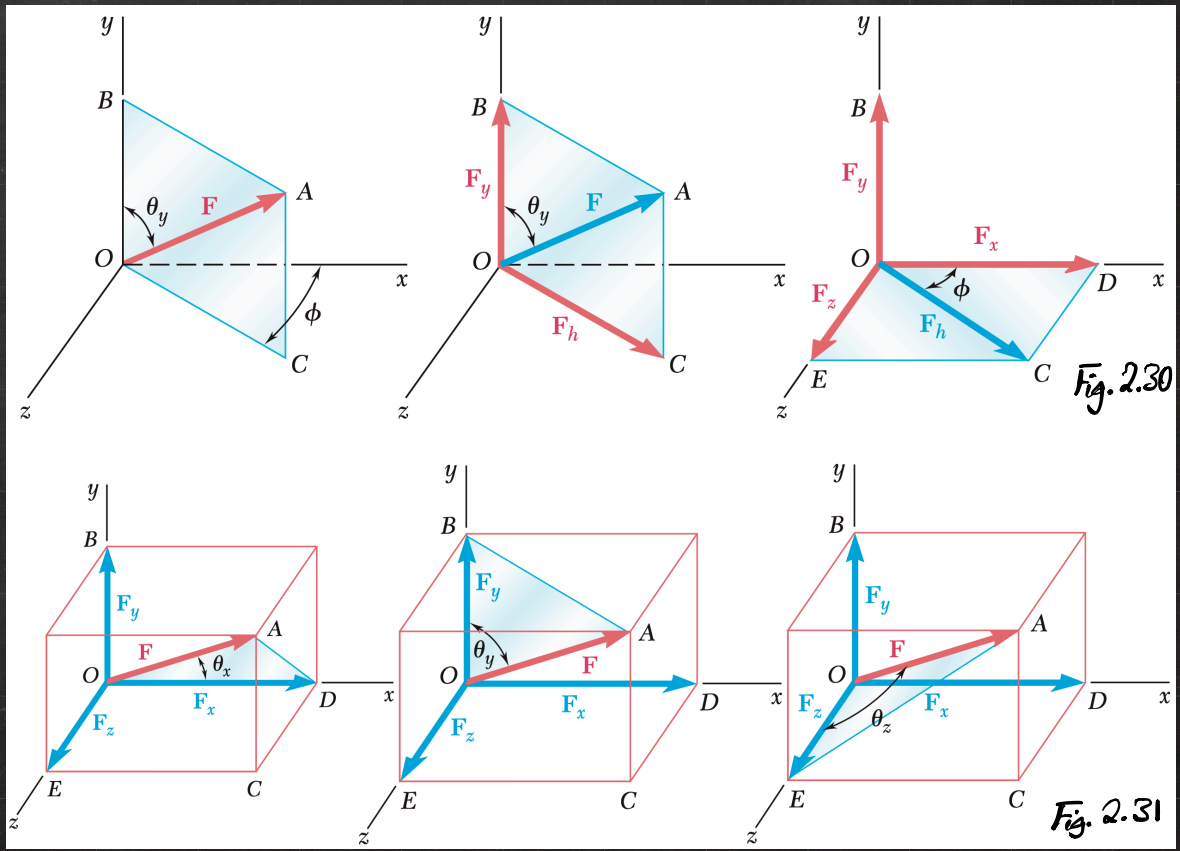



Fig. 2.30

Fig. 2.31

$$\mathbb{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k}$$

$$F_x = F\cos\theta_x$$

$$F_y = F\cos\theta_y$$

$$F_z = F\cos\theta_z$$

$$\mathbb{F} = F\left[\cos\theta_x \hat{i} + \cos\theta_y \hat{j} + \cos\theta_z \hat{k}\right]$$

$$|\mathbb{F}| = F \Rightarrow \left|\cos\theta_x \hat{i} + \cos\theta_y \hat{j} + \cos\theta_z \hat{k}\right| = 1$$

$$\mathbb{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k}$$

$$F_x = F\cos\theta_x$$

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$$|\mathbb{F}| = F \Rightarrow \left|\cos\theta_x \hat{i} + \cos\theta_y \hat{j} + \cos\theta_z \hat{k}\right| = 1$$

UNIT VECTOR

$$\vec{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k}$$

$$F_x = F\cos\theta_x$$

$$F_y = F\cos\theta_y$$

$$F_z = F\cos\theta_z$$

$$\vec{F} = F\left[\cos\theta_x \hat{i} + \cos\theta_y \hat{j} + \cos\theta_z \hat{k}\right]$$

$$|\vec{F}| = F \Rightarrow \left|\cos\theta_x \hat{i} + \cos\theta_y \hat{j} + \cos\theta_z \hat{k}\right| = 1$$

UNIT VECTOR

$$\Rightarrow \vec{F} = F\vec{\lambda}$$

DIRECTOR

$$\vec{\lambda} = \cos\theta_x \hat{i} + \cos\theta_y \hat{j} + \cos\theta_z \hat{k}$$

$$\mathbf{F} = F\boldsymbol{\lambda}$$

$$\boldsymbol{\lambda} = \begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix}, \quad |\boldsymbol{\lambda}| = 1$$

$$\lambda_x = \cos\theta_x = F_x/F$$

$$\lambda_y = \cos\theta_y = F_y/F$$

$$\lambda_z = \cos\theta_z = F_z/F$$

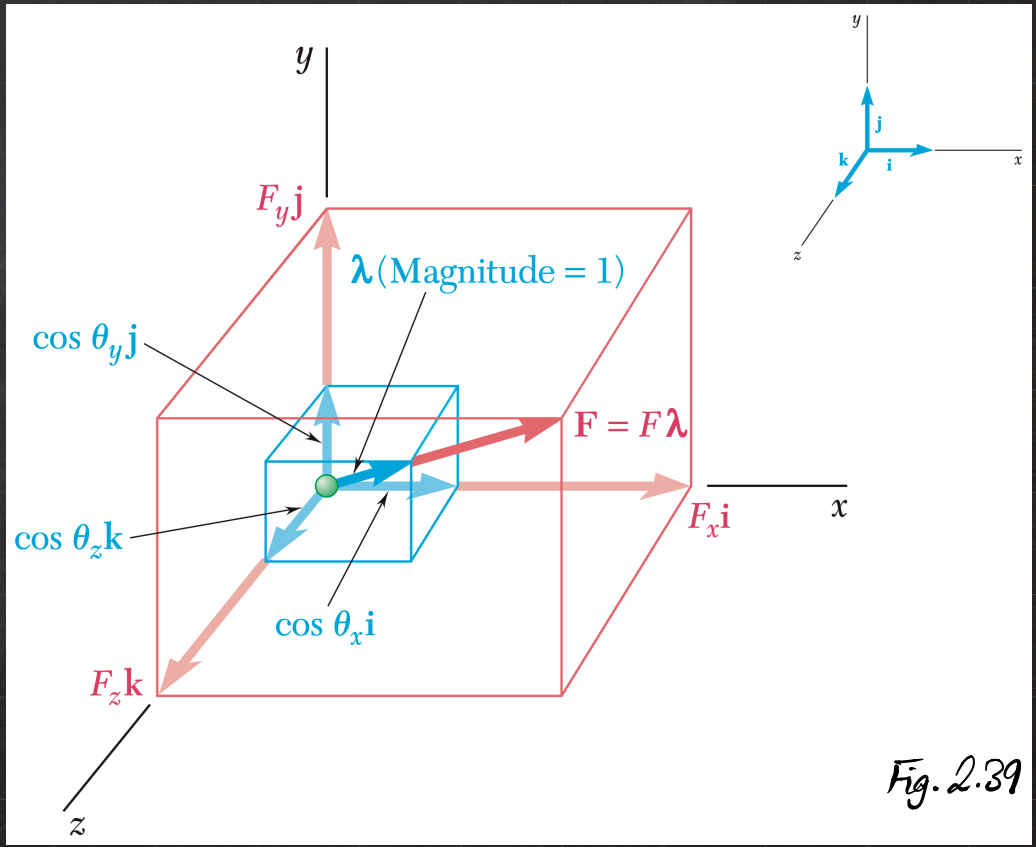



Fig. 2.39

$$\mathbb{F} = F\lambda$$

$$\lambda = \begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix}, \quad |\lambda| = 1$$

$$\lambda_x = \cos\theta_x = F_x/F$$

$$\lambda_y = \cos\theta_y = F_y/F$$

$$\lambda_z = \cos\theta_z = F_z/F$$

$$\lambda = |\lambda| = \sqrt{\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z} = 1$$

$$\mathbb{F} = F\,\lambda\!\!\!|$$

$$\lambda\!\!\!| = \begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix}, \quad |\lambda\!\!\!|| = 1$$

$$\lambda_x = \cos\theta_x = F_x/F$$

$$\lambda_y = \cos\theta_y = F_y/F$$

$$\lambda_z = \cos\theta_z = F_z/F$$

$$\lambda = |\lambda\!\!\!|| = \sqrt{\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z} = 1$$

$$\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z = 1$$

$$\mathbb{F} = F\,\lambda$$

$$\lambda = \begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix}, \quad |\lambda| = 1$$

$$\lambda_x = \cos\theta_x = F_x/F$$

$$\lambda_y = \cos\theta_y = F_y/F$$

$$\lambda_z = \cos\theta_z = F_z/F$$

$$\lambda = |\lambda| = \sqrt{\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z} = 1$$

$$\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z = 1$$

HOW DOES THIS WORK FOR 2D ?

$$\mathbb{F} = F\,\lambda\!\!\!|$$

$$\lambda\!\!\!| = \begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix}, \quad |\lambda\!\!\!|| = 1$$

$$\lambda_x = \cos\theta_x = F_x/F$$

$$\lambda_y = \cos\theta_y = F_y/F$$

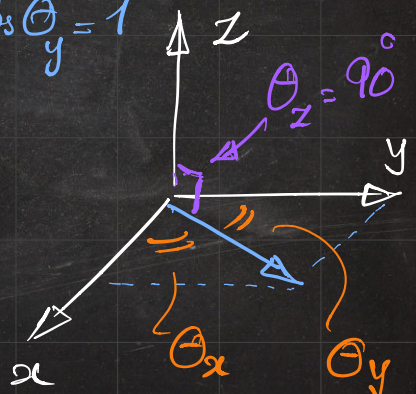
$$\lambda_z = \cos\theta_z = F_z/F$$

$$\lambda = |\lambda\!\!\!|| = \sqrt{\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z} = 1$$

$$\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z = 1$$

HOW DOES THIS WORK FOR 2D ?

$\hookrightarrow \theta_z = 90^\circ \Rightarrow \cos^2\theta_x + \cos^2\theta_y = 1$



$$\mathbb{F} = F\,\lambda\!\!\!|\!|$$

$$\lambda\!\!\!|\!| = \begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix}, \quad |\lambda\!\!\!|\!|| = 1$$

$$\lambda_x = \cos\theta_x = F_x/F$$

$$\lambda_y = \cos\theta_y = F_y/F$$

$$\lambda_z = \cos\theta_z = F_z/F$$

$$\lambda = |\lambda\!\!\!|\!|| = \sqrt{\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z} = 1$$

$$\cos^2\theta_x + \cos^2\theta_y + \cos^2\theta_z = 1$$

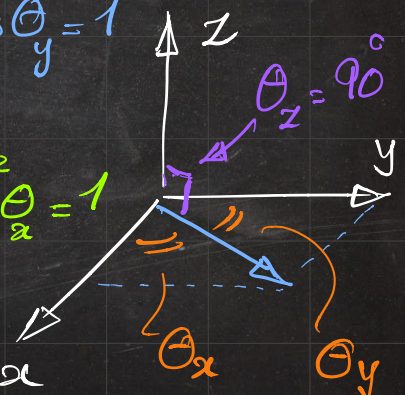
HOW DOES THIS WORK FOR 2D ?

$\hookrightarrow \theta_z = 90^\circ \Rightarrow \cos^2\theta_x + \cos^2\theta_y = 1$

$\hookrightarrow \theta_y = 90^\circ - \theta_x$

$$\cos^2\theta_x + \sin^2\theta_x = 1$$

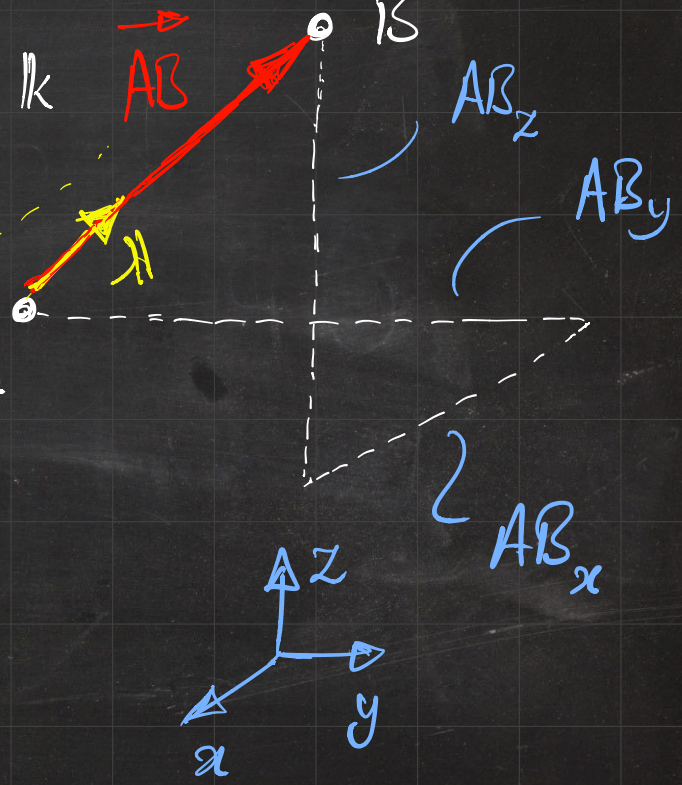
$$\cos\theta_y = \cos(90^\circ - \theta_x) = \sin\theta_x$$



$$\lambda = \frac{\vec{AB}}{|\vec{AB}|} = \lambda_x \hat{i} + \lambda_y \hat{j} + \lambda_z \hat{k}$$

$\vec{AB} = |\vec{AB}|\,\lambda$ ⇐

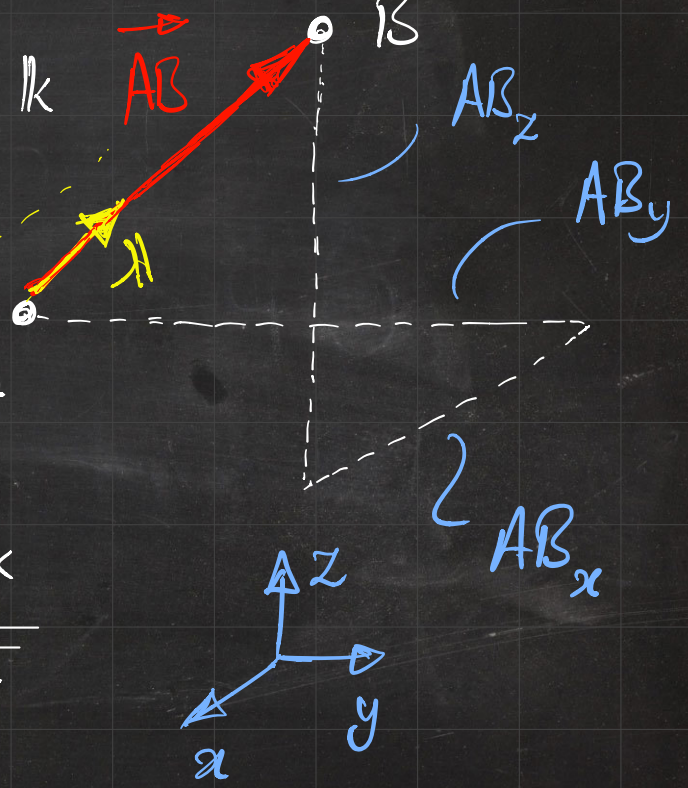
DIRECTOR



$$\lambda = \frac{\vec{AB}}{|\vec{AB}|} = \lambda_x \hat{i} + \lambda_y \hat{j} + \lambda_z \hat{k}$$

$$\vec{AB} = |\vec{AB}|\,\lambda$$

DIRECTOR



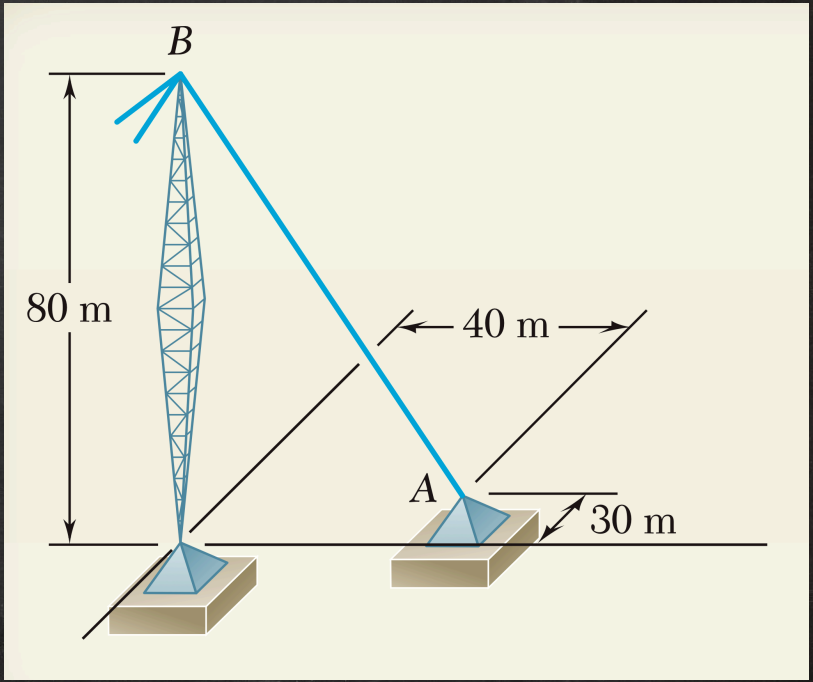

$$\lambda = \frac{[x_B - x_A]\hat{i} + [y_B - y_A]\hat{j} + [z_B - z_A]\hat{k}}{\sqrt{[x_B - x_A]^2 + [y_B - y_A]^2 + [z_B - z_A]^2}}$$

# Exercise 3 . [ similar to ... P. 50 ... 2.7 ]

THE TENSION IN THE WIRE IS 2500 N.

... DETERMINE ...

- COMPONENTS OF THE FORCE ACTING ON BOLT A.
- THE ANGLES $\theta_x, \theta_y, \theta_z$ DEFINING THE DIRECTION OF THE FORCE.

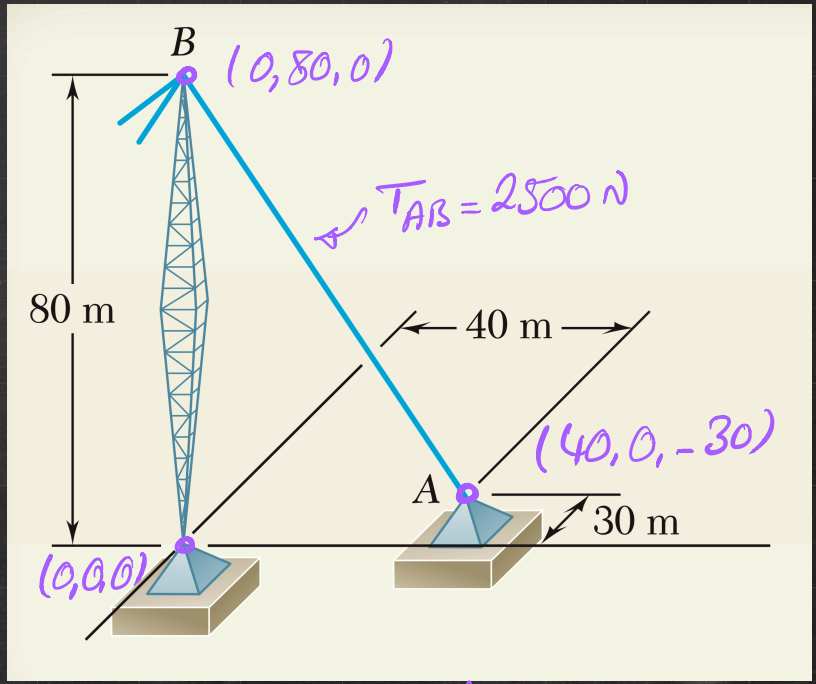


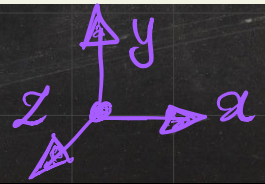
2500

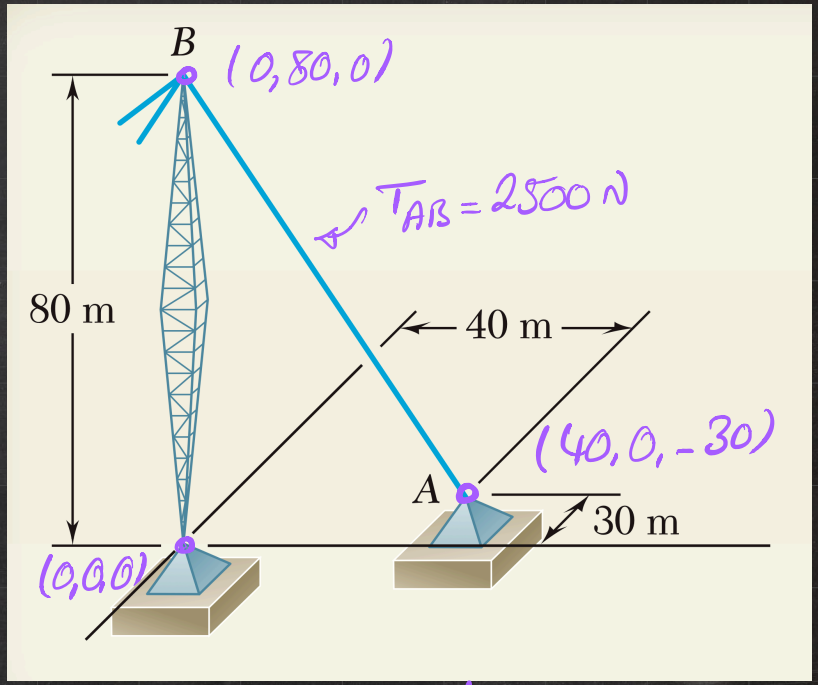
$$\vec{T}_{AB} = T_{AB}\,\lambda$$

$$\lambda = \frac{\vec{AB}}{|\vec{AB}|} = \frac{-40\,i + 80\,j + 80\,k}{\sqrt{40^2 + 80^2 + 80^2}}$$

$\sqrt{40^2 + 80^2 + 80^2} = 94.3$





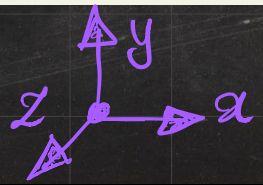

$$\vec{T}_{AB} = T_{AB}\,\lambda$$

$$\lambda = \frac{\vec{AB}}{|\vec{AB}|} = \frac{-40\,i + 80\,j + 30\,k}{\sqrt{40^2 + 80^2 + 30^2}}$$

$$\sqrt{40^2 + 80^2 + 30^2} = 94.3$$

$$\Rightarrow \lambda = \frac{1}{94.3}\left[-40\,i + 80\,j + 30\,k\right]$$

$$\Rightarrow \vec{T}_{AB} = -1050\,i + 2100\,j + 800\,k$$



2500

$$\vec{T}_{AB} = T_{AB}\,\vec{\lambda}$$

$$\vec{\lambda} = \frac{\vec{AB}}{|\vec{AB}|} = \frac{-40\,\hat{i} + 80\,\hat{j} + 30\,\hat{k}}{\sqrt{40^2 + 80^2 + 30^2}}$$

$$\sqrt{40^2 + 80^2 + 30^2} \simeq 94.3$$

$$\Rightarrow \vec{\lambda} = \frac{1}{94.3}\left[-40\,\hat{i} + 80\,\hat{j} + 30\,\hat{k}\right]$$

$$\Rightarrow \vec{T}_{AB} \simeq -1050\,\hat{i} + 2100\,\hat{j} + 800\,\hat{k}$$

$$\Rightarrow F_x \simeq -1050\,\hat{i},\quad F_y \simeq 2100\,\hat{j},\quad F_z \simeq 800\,\hat{k}$$

$$\cos\theta_x = \lambda_x = -40/94.3 \Rightarrow \theta_x \simeq 115^\circ$$

$$\cos\theta_y = \lambda_y = 80/94.3 \Rightarrow \theta_y \simeq 32^\circ$$

$$\cos\theta_z = \lambda_z = 30/94.3 \Rightarrow \theta_z \simeq 71^\circ$$

RECALL

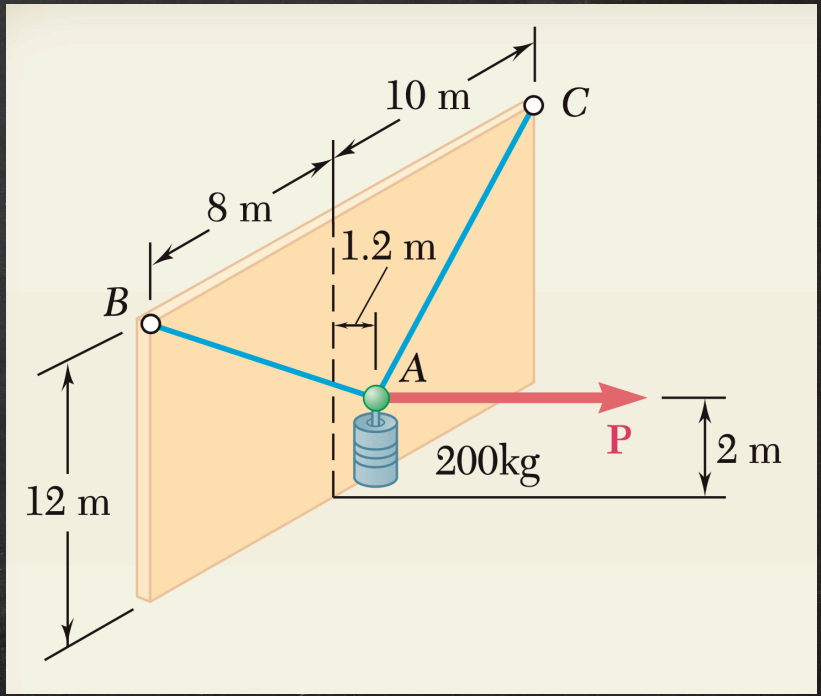
$$0 \leq \theta \leq 180^\circ$$

# Exercise 4 . [ similar to ... P. 58 ... 2.9 ]

THE 200 kg CYLINDER AT A IS SUPPORTED BY TWO CABLES AB, AC AND THE HORIZONTAL FORCE P PERPENDICULAR TO THE WALL.

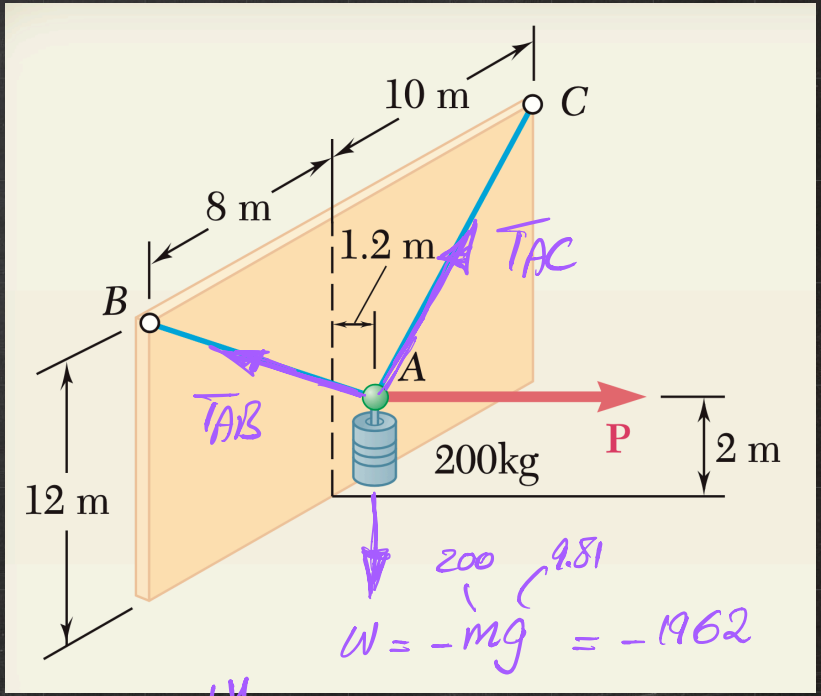
... DETERMINE ...

- THE MAGNITUDE OF P
- TENSION IN EACH CABLE



$$\vec{AB} = -1.2\,\hat{i} + 10\,\hat{j} + 8\,\hat{k}$$

$$\vec{AC} = -1.2\,\hat{i} + 10\,\hat{j} - 10\,\hat{k}$$

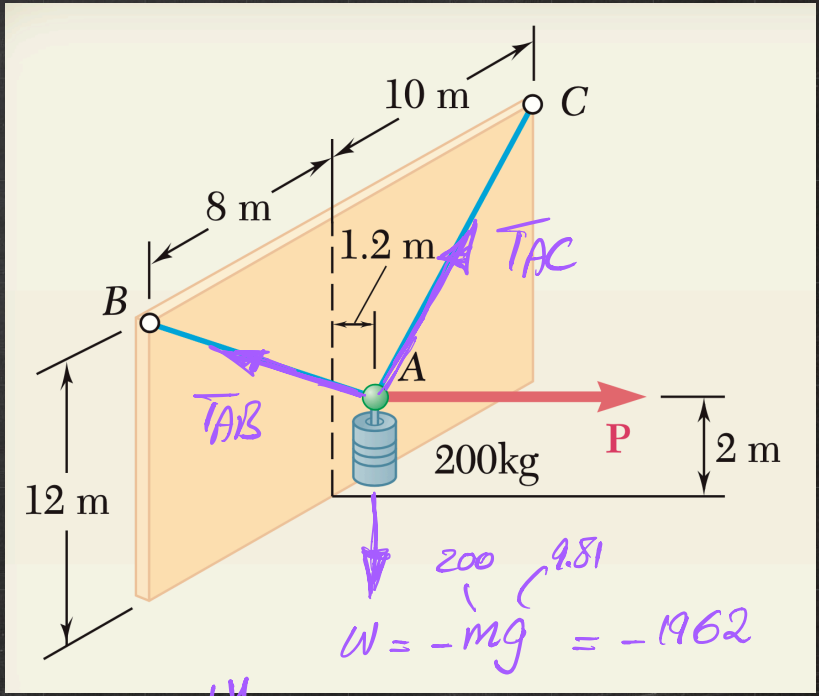


$$\vec{AB} = -1.2\,\hat{i} + 10\,\hat{j} + 8\,\hat{k}$$

$$\vec{AC} = -1.2\,\hat{i} + 10\,\hat{j} - 10\,\hat{k}$$

$$\hat{u}_{AB} = \frac{\vec{AB}}{|\vec{AB}|} \quad , \quad \hat{u}_{AC} = \frac{\vec{AC}}{|\vec{AC}|}$$

$$|\vec{AB}| \simeq 12.9 \qquad |\vec{AC}| \simeq 14.2$$



$$\vec{AB} = -1.2\,\hat{i} + 10\,\hat{j} + 8\,\hat{k}$$

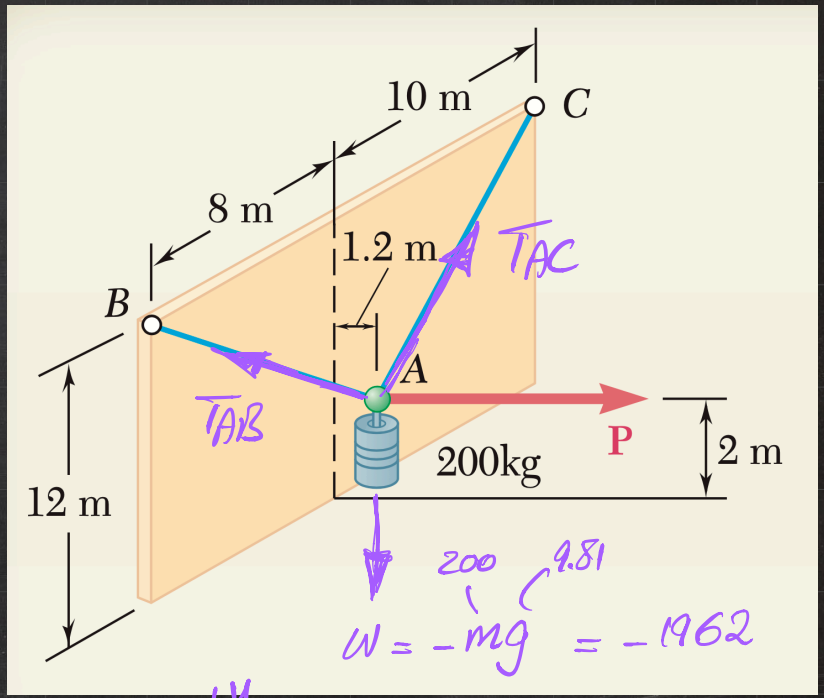
$$\vec{AC} = -1.2\,\hat{i} + 10\,\hat{j} - 10\,\hat{k}$$

$$\hat{n}_{AB} = \frac{\vec{AB}}{|\vec{AB}|}, \quad \hat{n}_{AC} = \frac{\vec{AC}}{|\vec{AC}|}$$

$$|\vec{AB}| \simeq 12.9, \quad |\vec{AC}| \simeq 14.2$$

$$\vec{T}_{AB} = T_{AB}\,\hat{n}_{AB}$$

$$\vec{T}_{AC} = T_{AC}\,\hat{n}_{AC}$$



$$\vec{AB} = -1.2\,\hat{i} + 10\,\hat{j} + 8\,\hat{k}$$

$$\vec{AC} = -1.2\,\hat{i} + 10\,\hat{j} - 10\,\hat{k}$$

$$\hat{n}_{AB} = \frac{\vec{AB}}{|\vec{AB}|}, \quad \hat{n}_{AC} = \frac{\vec{AC}}{|\vec{AC}|}$$

$|\vec{AB}| \simeq 12.9$, $|\vec{AC}| \simeq 14.2$

$$\vec{T}_{AB} = T_{AB}\,\hat{n}_{AB}$$

$$\vec{T}_{AC} = T_{AC}\,\hat{n}_{AC}$$

$$\Sigma \vec{F} = \vec{0} \Rightarrow \vec{T}_{AB} + \vec{T}_{AC} + \vec{P} + \vec{W} = \vec{0}$$

$T_{AB}\,\hat{n}_{AB}$ ✓ $\quad \vec{0}$

$T_{AC}\,\hat{n}_{AC}$ ✓ $\quad \vec{0}$

$P\,\hat{i}$ ? $\quad \vec{0}$

$-1962\,\hat{j}$ ✓ $\quad \vec{0}$

$$\vec{AB} = -1.2\,\hat{i} + 10\,\hat{j} + 8\,\hat{k}$$

$$\vec{AC} = -1.2\,\hat{i} + 10\,\hat{j} - 10\,\hat{k}$$

$$\hat{n}_{AB} = \frac{\vec{AB}}{|\vec{AB}|}, \quad \hat{n}_{AC} = \frac{\vec{AC}}{|\vec{AC}|}$$

$|\vec{AB}| \simeq 12.9$, $|\vec{AC}| \simeq 14.2$

$$\vec{T}_{AB} = T_{AB}\,\hat{n}_{AB}$$

$$\vec{T}_{AC} = T_{AC}\,\hat{n}_{AC}$$

$$\Sigma \vec{F} = 0 \Rightarrow \vec{T}_{AB} + \vec{T}_{AC} + \vec{P} + \vec{W} = 0$$

$\vec{T}_{AB}$ ($T_{AB}$, $\hat{n}_{AB}$ ✓) + $\vec{T}_{AC}$ ($T_{AC}$, $\hat{n}_{AC}$ ✓) + $P\,\hat{i}$ + $-1962\,\hat{j}$ ✓ = 0

$T_{AB}$ ?, $T_{AC}$ ?, $P$ ?

$\Rightarrow$ 3 EQUATIONS, 3 UNKNOWNS

$$\Rightarrow P = 235\ \text{N},\ \vec{T}_{AB} = 1402\ \text{N},\ \vec{T}_{AC} = 1238\ \text{N}$$

# MECHANICS AND MATERIALS I

## Introduction to Statics i

## Statics of Particles

## Chap. 2

[ Beer Johnston et al. 9th edition ]

Ali Javili

Bilkent University

# MECHANICS AND MATERIALS I

1

Ali Javili

Bilkent University