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PROBLEM 2.2.1

The planet Venus has a diameter of 7700 miles and a mass of $3.34(10^{23})$ slugs.

a. Determine the gravitational acceleration at the surface of the planet. Express your answer in units of (ft/s^2).

b. Your answer in **a** is what fraction of the gravitational acceleration at the surface of the earth?

GOAL : To (a) determine the force of gravity on the surface of Venus, and (b) calculate the gravity on Venus as a percentage of Earth's gravity.

GIVEN : Diameter ($d = 7700$ mi) and mass ($m_v = 3.34(10^{23})$ slugs) of Venus.

ASSUME : Earth's gravity ($g_e = 32.2$ ft/s^2).

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** (a):

$$F_g = \frac{Gm_1m_2}{r^2} = mg$$

$$g = \frac{Gm_v}{r^2}$$

$$r = \frac{d}{2} = \frac{7700 \text{ mi}}{2} \times \frac{5280 \text{ ft}}{1 \text{ mi}} = 20.328 \times 10^6 \text{ ft}$$

$$g_v = \frac{(3.439 \times 10^{-8} \text{ ft}^3/\text{slug s}^2)(3.34 \times 10^{23} \text{ slug})}{(20.328 \times 10^6 \text{ ft})^2}$$

$$= 27.796 \text{ ft/s}^2 \approx 27.8 \text{ ft/s}^2$$

RESULTS (a) The force of gravity on the surface of Venus is:

$$\boxed{g_v = 27.8 \text{ ft/s}^2}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\frac{g_v}{g_e} = \frac{27.8 \text{ ft/s}^2}{32.2 \text{ ft/s}^2} = 0.8632 \approx 86.3\%$$

RESULTS (b) The percentage of Earth's gravity is:

$$\boxed{g_v/g_e = 86.3\%}$$

CHECK : Since the radius and mass of Earth ($r_e = 20.902 \times 10^6$ ft, $m_e = 4.09 \times 10^{23}$ slugs) are slightly larger than those of Venus, the percentage seems reasonable.

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PROBLEM 2.2.2

Determine the gravitational force exerted by the moon on Earth, using the following data. Make sure to show your work.

Mass of moon: m_{moon}	$7.350(10^{22})$ kg
Mass of Earth: m_{Earth}	$5.976(10^{24})$ kg
Radius of moon: r_{moon}	$1.738(10^{6})$ m
Radius of Earth: r_{Earth}	$6.371(10^{6})$ m
Distance between moon and Earth	$3.844(10^{8})$ m

GOAL : Determine the gravitational force exerted by the moon on Earth.

GIVEN : Mass and radii of the heavenly bodies and the distances between them.

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

Note that the given distance between Earth and the moon is the average center-to-center distance, so you do not have to include the Earth and moon radii in the calculation.

$$||F_g|| = \frac{Gm_m m_e}{r^2} \tag{4.2}$$

$$\begin{aligned} ||F_g|| &= \frac{(6.673\times10^{-11}\ \text{m}^3/(\text{kg s}^2))(7.35\times10^{22}\ \text{kg})(5.976\times10^{24}\ \text{kg})}{(3.844\times10^{8}\ \text{m})^2} \\ &= 1.98\times10^{20}\ \text{N} \end{aligned}$$

RESULTS The gravitational force exerted by the moon on Earth is:

$$\boxed{||F_g|| = 1.98\times10^{20}\ \text{N}}$$

CHECK : Verify equations and check calculations.

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PROBLEM 2.2.3

Determine the gravitational force exerted by the sun on Earth, using the following data. Make sure to show your work.

Mass of sun: m_{sun}	$1.990(10^{30})$ kg
Mass of Earth: m_{Earth}	$5.976(10^{24})$ kg
Radius of sun: r_{sun}	$6.960(10^{8})$ m
Radius of Earth: r_{Earth}	$6.371(10^{6})$ m
Distance between sun and Earth	$1.496(10^{11})$ m

GOAL : Determine the gravitational force exerted by the sun on Earth.

GIVEN : Mass and radii of the heavenly bodies and the distances between them.

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** (b):

Note that the given distance between Earth and the sun is the average center-to-center distance, so you do not have to include the Earth and sun radii in the calculation.

$$||F_g|| = \frac{Gm_s m_e}{r^2} \tag{4.2}$$

$$\begin{aligned} ||F_g|| &= \frac{(6.673\times10^{-11}\ \text{m}^3/(\text{kg s}^2))(1.99\times10^{30}\ \text{kg})(5.976\times10^{24}\ \text{kg})}{((1.496\times10^{11}\ \text{m})^2} \\ &= 3.55\times10^{22}\ \text{N} \end{aligned}$$

RESULTS (b) The gravitational force exerted by the sun on the Earth is:

$$\boxed{||F_g|| = 3.55\times10^{22}\ \text{N}}$$

CHECK : Verify equations and check calculations.

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PROBLEM 2.2.4

Determine the force of gravity acting on a satellite when it is in orbit 20.2×10^6 m above the surface of Earth. Its weight when on the surface of Earth is 8450 N. Use the following data as needed.

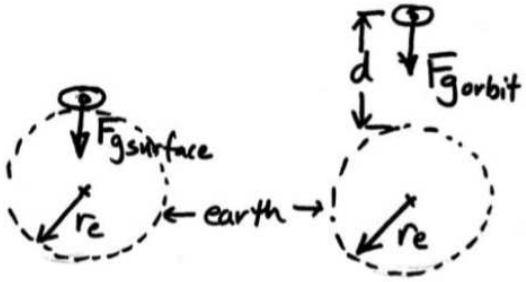
Mass of Earth: m_{Earth}	$5.976(10^{24})$ kg
Radius of Earth: r_{Earth}	$6.371(10^6)$ m

GOAL : Determine the force of gravity acting on a satellite.

GIVEN : Weight of the satellite on the surface of Earth (8450 N) and its altitude (20.2×10^6 m). Earth's radius (6.371×10^6 m)

ASSUME : None

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_{g_{\text{surface}}} = 8450\ \text{N} = \frac{Gm_s m_e}{r_e^2} \tag{4.2}$$

$$F_{g_{\text{orbit}}} = \frac{Gm_s m_e}{(r_e + d)^2}$$

$$F_{g_{\text{orbit}}}(r_e + d)^2 = (8450\,\text{N})(r_e)^2$$

$$F_{g_{\text{orbit}}} = \frac{(8450\,\text{N})(r_e)^2}{(r_e + d)^2}$$

$$= \frac{(8450\,\text{N})(6.371 \times 10^6\,\text{m})^2}{(6.371 \times 10^6\,\text{m} + 20.2 \times 10^6\,\text{m})^2} = 485.8\,\text{N}$$

RESULTS :

$$\boxed{F_{g_{\text{orbit}}} = 486\ \text{N}}$$

CHECK : Calculating the mass of the satellite from the weight and applying (4.2) directly yields the same answer.

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PROBLEM 2.2.5

At what distance, in kilometers, from the surface of Earth on a line from center to center, would the gravitational force of Earth on a body be exactly balanced by the gravitational force of the moon on the body? Use the following data as needed.

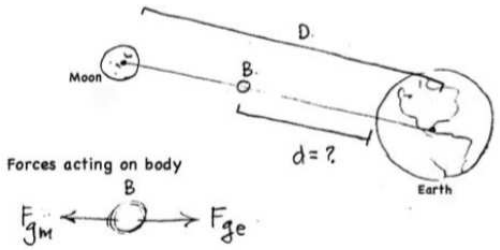
Mass of moon: m_{moon}	$7.350(10^{22})$ kg
Mass of Earth: m_{Earth}	$5.976(10^{24})$ kg
Radius of moon: r_{moon}	$1.738(10^{6})$ m
Radius of Earth: r_{Earth}	$6.371(10^{6})$ m
Distance between moon and Earth	$3.844(10^{8})$ m

GOAL : Find the distance at which the gravitational force between a body and Earth is the same as that between the body and the moon.

GIVEN : Data given in exercise 4.2.3.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$||F_{g_m}|| = ||F_{g_e}||$$

$$\frac{Gm_B m_m}{(D-d-r_e)^2} = \frac{Gm_B m_e}{(d+r_e)^2}$$

$$\frac{m_m}{m_e} = \frac{(D-d-r_e)^2}{(d+r_e)^2}$$

$$(d+r_e)\sqrt{\frac{m_m}{m_e}} = D-d-r_e$$

$$d = \frac{D-r_e\left(1+\sqrt{m_m/m_e}\right)}{1+\sqrt{m_m/m_e}}$$

$$d = \frac{(3.844\times10^{8}\text{ m})-(6.371\times10^{6}\text{ m})\left(1+\sqrt{\frac{7.350\times10^{22}\text{ kg}}{5.976\times10^{24}\text{ kg}}}\right)}{1+\sqrt{\frac{7.350\times10^{22}\text{ kg}}{5.976\times10^{24}\text{ kg}}}}$$

$$d = 3.397\times10^{8}\text{ m}$$

RESULTS : The distance from the Earth's surface is:

$$\boxed{d = 340\times10^{3}\text{ km}}$$

CHECK : Find the distance from the moon and ensure that the sum of the distances equals the total distance from the Earth to the moon.

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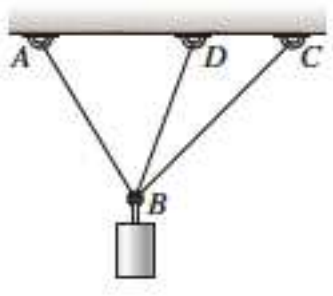
PROBLEM 2.3.1

Consider the system shown. Match each part of the system listed on the left with the type of force that is operating listed on the right.

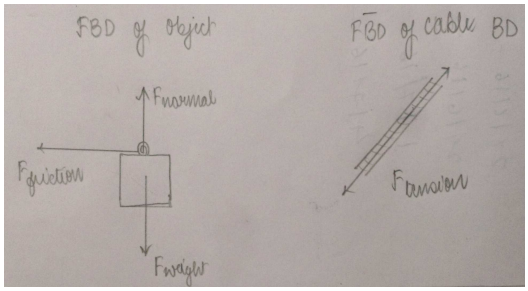


GOAL : To match the parts of system with the type of force they are operating.

GIVEN : Diagram of the system.

ASSUME : The cables can only experience tension.

DRAW :



RESULTS :

Part of the System	**Type of Force**
Cable *AB*-eyelet interface at *B*	Normal Contact Force
	Friction Force
Within cable *BD*	Tension Force
Weight of Object	Gravity Force
None	Compression Force

CHECK : Check through table to verify accuracy.

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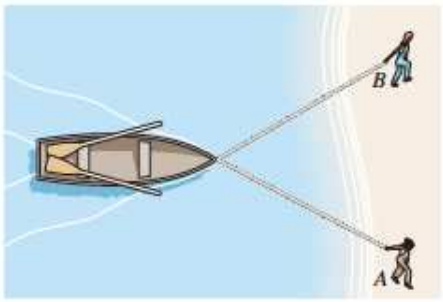
PROBLEM 2.3.2

Consider the boat being puled ashore by the two people as shown. Match the type of force that is operating listed on the left with a part of the system listed on the right. You may use part of the system more than once.

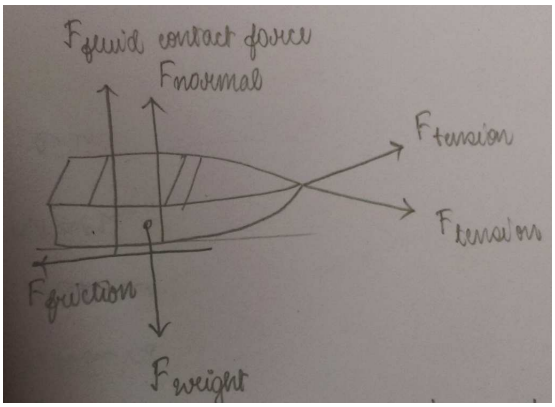


GOAL : To match the type of forces that are operating with the part of the system.

GIVEN : The diagram of boat being pulled ashore by two people.

ASSUME : Ropes only act in tension.

DRAW :



RESULTS :

Type of Force	**Part of System**
Normal Contact Force	Boat Water Interface
	Person *A*-ground interface
Tension Force	Within rope *B* (Also within rope *A*)
Gravity Force	Weight of Boat (Also weight person *A*, *B*)
Friction Force	Person *A*-ground interface (also person *B*)
	Boat Water Interface
Fluid Contact Force	Boat Water Interface

CHECK : Check through table to verify accuracy.

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PROBLEM 2.3.3

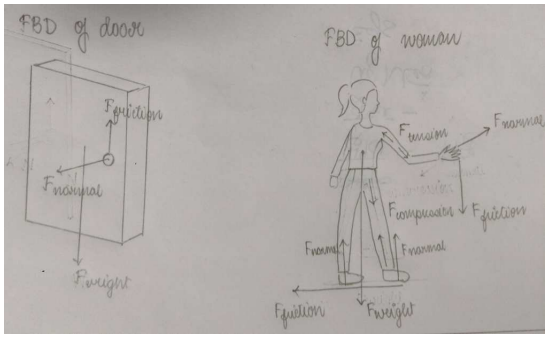
Consider the woman turning the door handle as shown. Match the type of force that is operating listed on the left with a part of the system listed on the right. You may use part of the system more than once.

GOAL : To match the type of forces that are operating with the part of the system.

GIVEN : The diagram of a woman turning the door handle.

ASSUME : Door can only open by being pushed.

DRAW :



RESULTS :

Type of Force	**Part of System**
Normal Contact Force	Hand-door knob interface
Tension Force	Within woman's arm muscle
Gravity Force	Door Weight
Friction Force	Hand-Door knob interface
Compression Force	Within woman's leg bone

CHECK : Check through table to verify accuracy.

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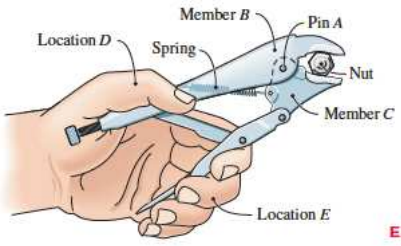
PROBLEM 2.4.1

A person grips a pair of locking jaw pliers (more commonly known as vise-grips), as shown, in order to tighten a nut onto a bolt. Three cases (systems) are described in the top row of **Table 4.4.1**. For each system, identify the external (E) and internal (I) forces by completing **Table 4.4.1**. Leave blank those squares associated with a force not applied to the system under consideration.



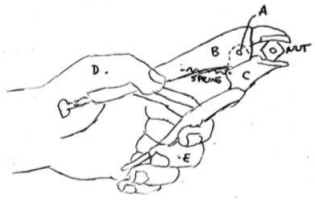
EX 2.4.1

GOAL : To identify the external and internal force.

GIVEN : Picture of a person gripping a pair of locking jaw pliers.

ASSUME : None necessary.

DRAW : The hand and pliers:



RESULTS :

Case 1: The pair of vice-grips and the nut are defined as the system.
Case 2: The pair of vice-grips are defined as the system.
Case 3: The nut is defined as the system.

Forces	**Case 1**	**Case 2**	**Case 3**
Tension in spring	I	I	—
Normal contact force between pin A and member B	I	I	—
Normal contact force between nut and member B	I	E	E
Normal contact force between nut and member C	I	E	E
Normal contact force and friction forces between thumb and vice grips at D	E	E	—
Normal and friction forces between fingers and vice grips at E	E	E	—
Weight of vice grips	E	E	—
Weight of the nut	E	—	E
Weight of bolt	—	—	—
Normal contact force and friction forces between nut and bolt	E	—	E

CHECK : Look over each case to ensure accuracy.

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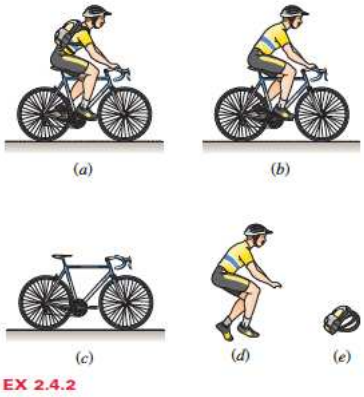
PROBLEM 2.4.2

A cyclist is bicycling down the road. Five cases (systems) are described in the top row of **Table 2.4.2** and in the figure below. For each system, identify the external (E) and internal (I) forces by completing **Table 2.4.2**. Leave blank the squares associated with a force not applied to the system under consideration.



EX 2.4.2

GOAL : To identify the external and internal forces.

GIVEN : Picture of a cyclist bicycling down the road.

ASSUME and **DRAW** : None necessary.

RESULTS :

Case 1: The cyclist (including her backpack) and the bicycle are defined as the system.
Case 2: The cyclist (not including her backpack) and the bicycle are defined as the system.
Case 3: The bicycle is defined as the system.
Case 4: The cyclist is defined as the system.
Case 5: The backpack is defined as the system.

CHECK : Check through table to verify accuracy.

Forces	Case 1	Case 2	Case 3	Case 4	Case 5
Chain tension	I	I	I	—	—
Weight of the bicycle	E	E	E	—	—
Weight of cyclist	E	E	—	E	—
Weight of backpack	E	—	—	—	E
Normal contact and friction forces between the rider's hands and the handlebars	I	I	E	E	—
Normal contact and friction forces between the rider's seat and the bicycle seat	I	I	E	E	—
Normal contact force where the rider's foot presses on the pedal	I	I	E	E	—
Normal contact force between the front fork and the front wheel hub	I	I	I	—	—
Normal contact force between the cyclist's back and her backpack	I	E	—	E	E
Tension in the backpack shoulder strap	I	—	—	—	I
Normal contact forces between the tires and the road	E	E	E	—	—
Wind forces acting on the bicycle	E	E	E	—	—
Wind force acting on the cyclist	E	E	—	E	—
Tension in the cyclist's back muscles	I	I	—	I	—

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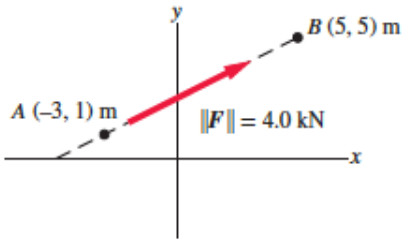
PROBLEM 2.5.1

The line of action of the 4.0-kN force $\boldsymbol{F}$ runs through the points A and B as shown. Find the unit vector along the line of action of the force.



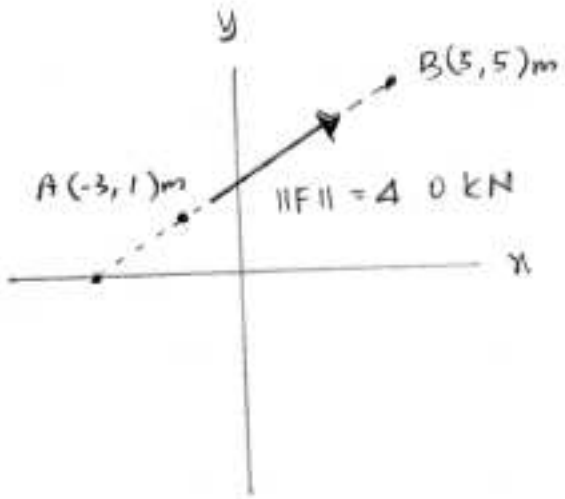
EX 2.5.2

GOAL : To find the unit vector.

GIVEN : Magnitude and sense of force, coordinates of two points.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = \tan^{-1}\left(\frac{5-1}{5+3}\right) = 26.56^\circ$$

$$\cos\theta_x = 0.894$$

$$\sin\theta_x = \cos\theta_y = 0.447$$

$$\mathbf{u} = \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}}$$
$$= 0.894\,\hat{\mathbf{i}} + 0.447\,\hat{\mathbf{j}}$$

RESULTS :

$$\boxed{\mathbf{u} = 0.894\,\hat{\mathbf{i}} + 0.447\,\hat{\mathbf{j}}}$$

CHECK : Verify the math by using different triginometric relationships, such as finding the length of the vector from A to B ($\sqrt{80}$) and then using the sine and cosine identities directly.

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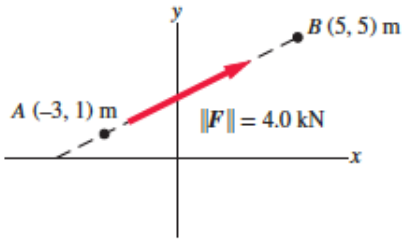
PROBLEM 2.5.2

The line of action of the 4.0-kN force $\boldsymbol{F}$ runs through the points A and B as shown. Express $\boldsymbol{F}$ in vector notation.



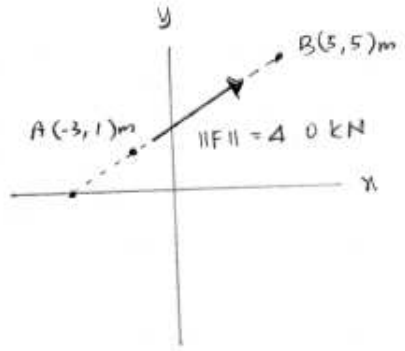
EX 2.5.2

GOAL : To express a force in vector notation.

GIVEN : Magnitude and sense of force, coordinates of two points.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Find the unit vector (4-5-1):

$$\theta_x = \tan^{-1}\left(\frac{5-1}{5+3}\right) = 26.57^\circ$$

$$\cos\theta_x = 0.8944$$

$$\cos\theta_y = \sin\theta_x = 0.4473$$

$$\mathbf{u} = \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}}$$
$$= 0.8944\,\hat{\mathbf{i}} + 0.4473\,\hat{\mathbf{j}}$$

$$\boldsymbol{F} = ||\boldsymbol{F}||\boldsymbol{u} = (4.0\,\text{kN})(0.8944\,\hat{\mathbf{i}} + 0.4473\,\hat{\mathbf{j}})$$
$$= (3.58\,\hat{\mathbf{i}} + 1.789\,\hat{\mathbf{j}})\,\text{kN}$$

RESULTS :

$$\boxed{\boldsymbol{F} = (3.58\,\hat{\mathbf{i}} + 1.789\,\hat{\mathbf{j}})\,\text{kN}}$$

CHECK : Find the magnitude of $\boldsymbol{F}$ and ensure it is still 4.0 kN

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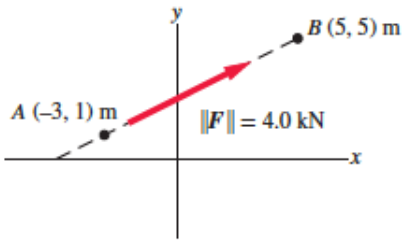
PROBLEM 2.5.3

The line of action of the 4.0-kN force $\boldsymbol{F}$ runs through the points A and B as shown. Find the space angles that describe the direction of the force vector.



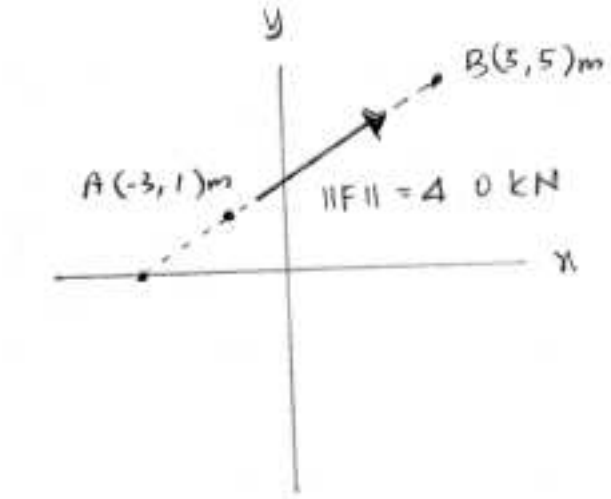
EX 2.5.2

GOAL : To find the space angles that describe the direction of the force.

GIVEN : Magnitude and sense of force, coordinates of two points.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = \tan^{-1}\left(\frac{5-1}{5+8}\right) = 26.56°$$

$$\theta_y = 90 - \theta_x = 63.43°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 29.7°\\ \theta_y &= 60.3°\\ \theta_z &= 90°\end{aligned}}$$

CHECK : Visual inspection, as well as use of other trigonometric identities verifies the result.

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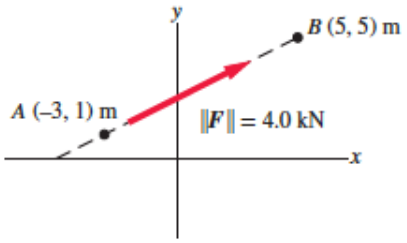
PROBLEM 2.5.4

The line of action of the 4.0-kN force $\boldsymbol{F}$ runs through the points A and B as shown. Express $\boldsymbol{F}$ in terms of its magnitude and the angles θ and ϕ.



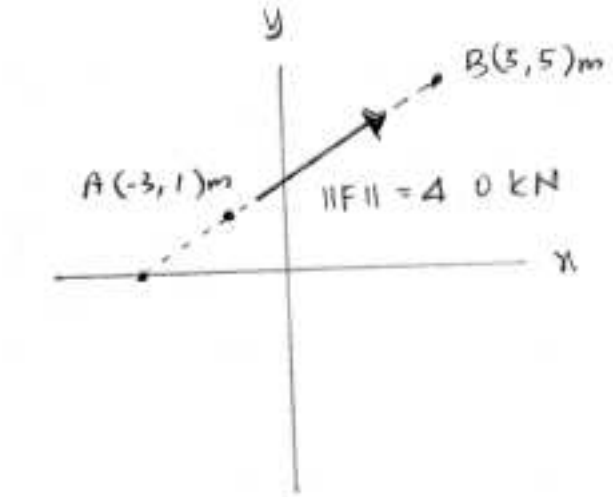
EX 2.5.2

GOAL : Express a force in terms of its magnitude and spherical coordinate angles.

GIVEN : Magnitude and sense of force, coordinates of two points.

ASSUME : Planar, thus $\theta_z = \phi = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = \tan^{-1}\left(\frac{3+1}{3+4}\right) = 26.56°$$

$\phi = 90°$ because the vector lies in the xy plane which is $90°$ from the z axis.

$$\cos\theta_x = \sin\phi\cos\theta$$

$$\cos\theta = \frac{\cos\theta_x}{\sin\phi} = \frac{\cos\theta_x}{1}$$

$$\cos\theta = \cos\theta_x \quad \Rightarrow \quad \theta = \theta_x$$

RESULTS :

$$\boxed{\begin{aligned} F &= 4.0\,\text{kN} \\ \theta &= 26.56° \\ \phi &= 90° \end{aligned}}$$

CHECK : Ensure that the result is in the correct quadrant and that the angles appear in the correct orientation.

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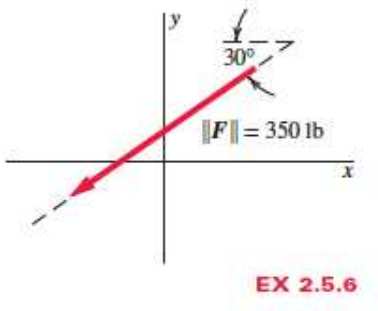
PROBLEM 2.5.5

The line of action of the 350 lb force $\boldsymbol{F}$ is oriented at 30° to the horizontal as shown. Find the unit vector $\boldsymbol{u}$ in the direction of $\boldsymbol{F}$ in terms of unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.



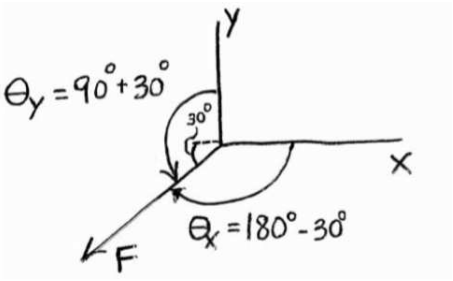
EX 2.5.6

GOAL : To find the unit vector along the direction of the force.

GIVEN : Magnitude and sense of force, angle relative to horizontal.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\hat{\boldsymbol{u}} = \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}} \qquad (4.10C)$$

$$\begin{aligned}\hat{\boldsymbol{u}} &= \cos 150^\circ\,\hat{\mathbf{i}} + \cos 120^\circ\,\hat{\mathbf{j}}\\ &= -\cos 30^\circ\,\hat{\mathbf{i}} - \cos 30^\circ\,\hat{\mathbf{j}}\\ &= -0.866\,\hat{\mathbf{i}} - 0.500\,\hat{\mathbf{j}}\end{aligned}$$

RESULTS :

$$\boxed{\hat{\boldsymbol{u}} = -0.866\,\hat{\mathbf{i}} - 0.500\,\hat{\mathbf{j}}}$$

CHECK : Ensure that the magnitude of the unit vector is $\|u\| = 1$.

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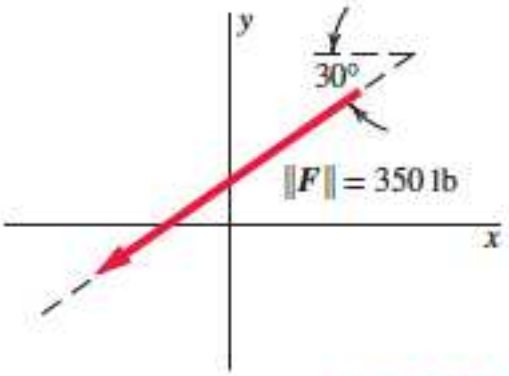
PROBLEM 2.5.6

The line of action of the 350 lb force $\boldsymbol{F}$ is oriented at 30° to the horizontal as shown. Express $\boldsymbol{F}$ in terms of the unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.



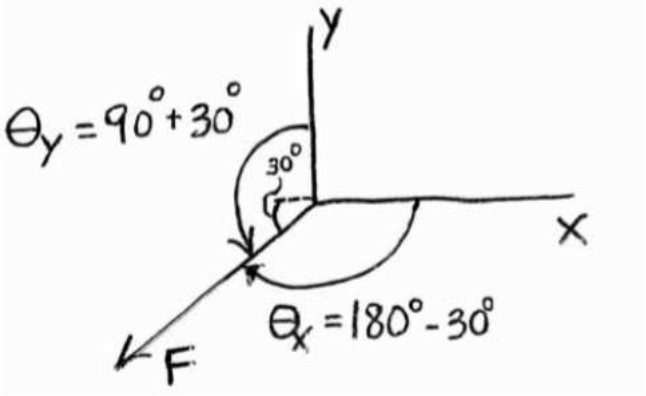
EX 2.5.6

GOAL : To express a force in terms of cartesian unit vectors.

GIVEN : Magnitude and sense of force, angle relative to horizontal.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\hat{\boldsymbol{u}} = \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}} \qquad (4.10C)$$

$$\begin{aligned}\hat{\boldsymbol{u}} &= \cos 150^\circ\,\hat{\mathbf{i}} + \cos 120^\circ\,\hat{\mathbf{j}} \\ &= -\cos 30^\circ\,\hat{\mathbf{i}} - \cos 30^\circ\,\hat{\mathbf{j}} \\ &= -0.866\,\hat{\mathbf{i}} - 0.500\,\hat{\mathbf{j}}\end{aligned}$$

$$\boldsymbol{F} = (350\text{ lb})\hat{\boldsymbol{u}} = (-303\,\hat{\mathbf{i}} - 175\,\hat{\mathbf{j}})\text{ lb}$$

RESULTS :

$$\boxed{\boldsymbol{F} = (-303\,\hat{\mathbf{i}} - 175\,\hat{\mathbf{j}})\text{ lb}}$$

CHECK : Calculate the magnitude and angle of $\boldsymbol{F}$ and compare to the given information.

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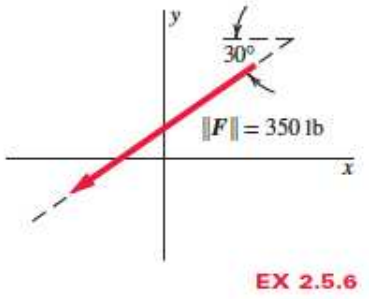
PROBLEM 2.5.7

The line of action of the 350 lb force $\boldsymbol{F}$ is oriented at 30° to the horizontal as shown. Find the space angles that describe the direction of the force vector.



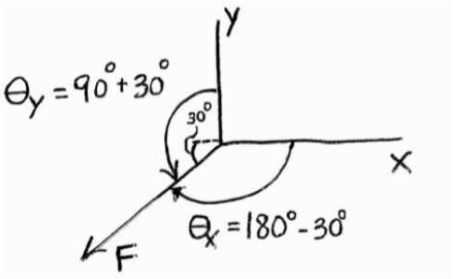
EX 2.5.6

GOAL : To find the space angles that describe the direction of the force.

GIVEN : Magnitude and sense of force, angle relative to horizontal.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = 180° - 30° = 150°$$

$$\theta_y = 90° + 30° = 120°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 150° \\ \theta_y &= 120°\end{aligned}}$$

CHECK : Visual inspection.

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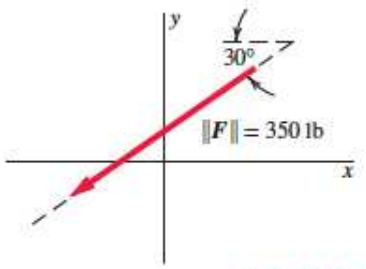
PROBLEM 2.5.8

The line of action of the 350 lb force $\boldsymbol{F}$ is oriented at 30° to the horizontal as shown. Express $\boldsymbol{F}$ in terms of its magnitude and the angles θ and ϕ.



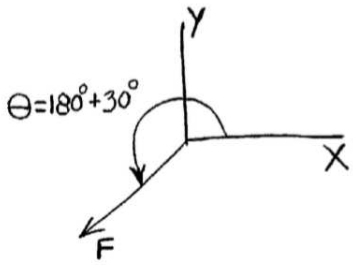
EX 2.5.6

GOAL : To find express a force in terms of its magnitude and its angles.

GIVEN : Magnitude and sense of force, angle relative to horizontal.

ASSUME : Planar, thus $\phi = \theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta = 180° + 30° = 210°$$

RESULTS :

$$\boxed{\begin{aligned} ||\boldsymbol{F}|| &= 350\,\text{lb} \\ \theta &= 210° \\ \phi &= 90° \end{aligned}}$$

CHECK : Ensure angles are measured from correct axes.

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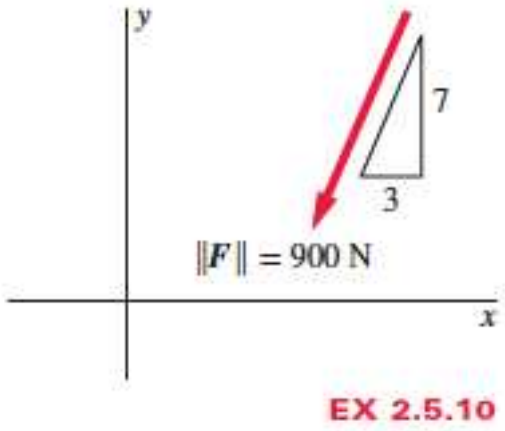
PROBLEM 2.5.9

The slope of the 900 N force is specified as shown. Find the unit vector along the line of action of the force.



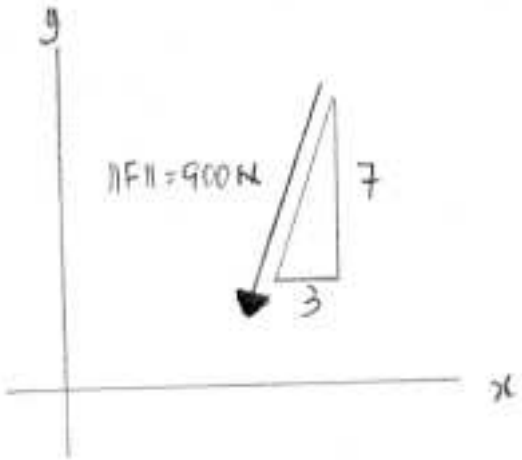
EX 2.5.10

GOAL : Find the unit vector along the line of action of F.

GIVEN : The magnitude of the force is 900 N and the vertical to horizontal orientation of the force vector has a ratio of -7/-3.

ASSUME : The force is planar.

DRAW : The force in the x-y plane:



FORMULATE EQUATIONS and **SOLVE** : To find the unit vector in the direction of F, normalize the given ratio:

$$u = \frac{-3}{\sqrt{(-3)^2+(-7)^2}}\,\hat{\mathbf{i}} + \frac{-7}{\sqrt{(-3)^2+(-7)^2}}\,\hat{\mathbf{j}}$$
$$= -\frac{3}{\sqrt{58}}\,\hat{\mathbf{i}} - \frac{7}{\sqrt{58}}\,\hat{\mathbf{j}}$$

RESULTS :

$$u = -\frac{3}{\sqrt{58}}\,\hat{\mathbf{i}} - \frac{4}{\sqrt{58}}\,\hat{\mathbf{j}} = -0.393\,\hat{\mathbf{i}} - 0.919\,\hat{\mathbf{j}}$$

CHECK : To check this result, we can verify that the magnitude of u is 1, and that the unit vector is pointing in the same direction as F.

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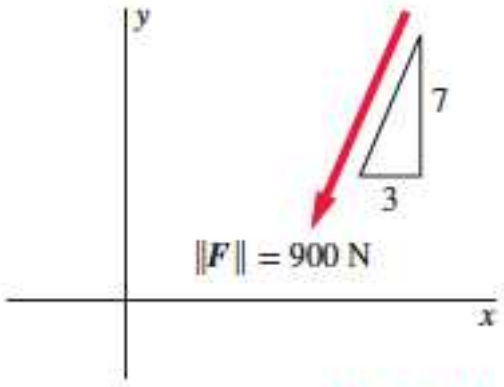
PROBLEM 2.5.10

The slope of the 900 N is specified as shown. Express $\boldsymbol{F}$ in terms of the unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.



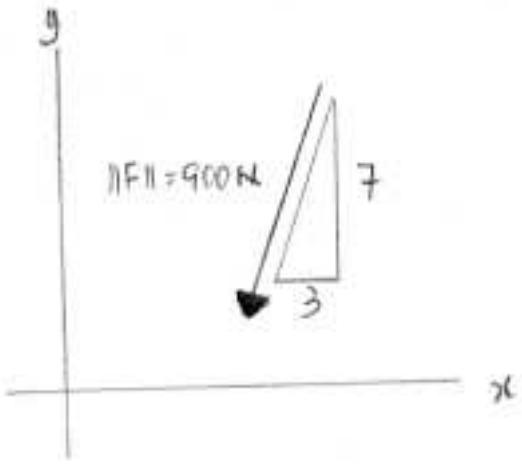
EX 2.5.10

GOAL : To express a force in terms of unit vectors.

GIVEN : The magnitude of the force is 900 N and the vertical to horizontal orientation of the force vector has a ratio of -7/-3.

ASSUME : The force is planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$u = \frac{-3}{\sqrt{(-3)^2+(-7)^2}}\,\hat{\mathbf{i}} + \frac{-7}{\sqrt{(-3)^2+(-7)^2}}\,\hat{\mathbf{j}}$$
$$= -\frac{3}{\sqrt{58}}\,\hat{\mathbf{j}} - \frac{4}{\sqrt{58}}\,\hat{\mathbf{j}}$$

$$\boldsymbol{F} = (900\,\text{N})\hat{\boldsymbol{u}} = (-355.0\,\hat{\mathbf{i}} - 827.0\,\hat{\mathbf{j}})\,\text{N}$$

RESULTS :

$$\boxed{\boldsymbol{F} = (-355.0\,\hat{\mathbf{i}} - 827.0\,\hat{\mathbf{j}})\,\text{N}}$$

CHECK : Ensure the magnitude of $\boldsymbol{F}$ is unchanged and that the slope is correct.

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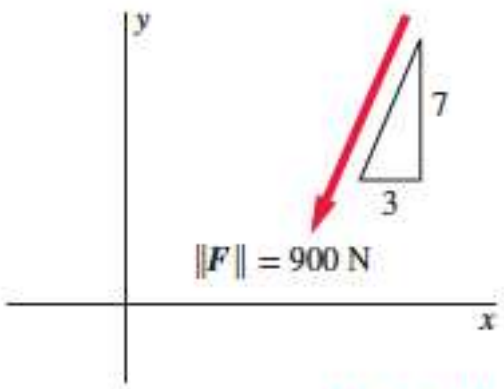
PROBLEM 2.5.11

The slope of the 900 N force is specified as shown. Find the space angles that describe the direction of the force vector.



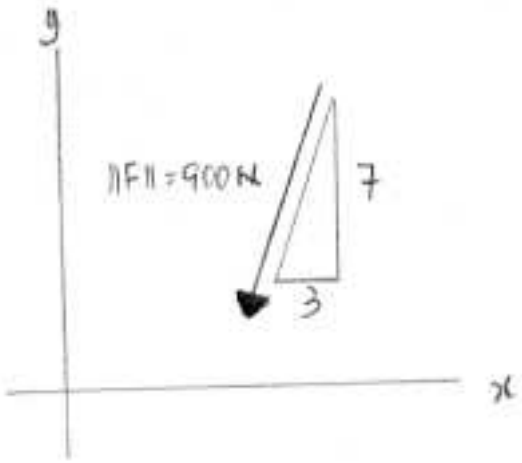
EX 2.5.10

GOAL : To find the space angles that describe the direction of the force.

GIVEN : The magnitude of the force is 900 N and the vertical to horizontal orientation of the force vector has a ratio of -7/-3.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = \cos^{-1}\left(\frac{-3}{\sqrt{58}}\right) = 113.20°$$

$$\theta_y = \cos^{-1}\left(\frac{-7}{\sqrt{58}}\right) = 156.80°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 113.2°\\ \theta_y &= 156.8°\end{aligned}}$$

CHECK : For space angles, the value must be positive and between 0 and 180 degrees. Make sure they look correct graphically.

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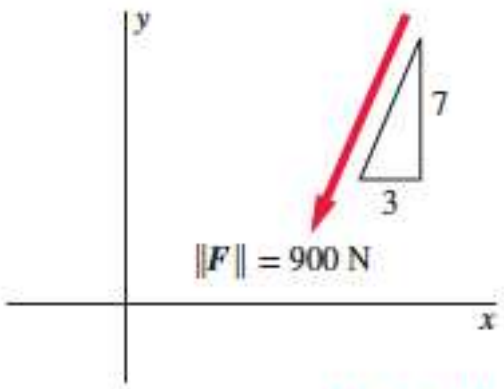
PROBLEM 2.5.12

The slope of the 900 N force is specified as shown. Express $\boldsymbol{F}$ in terms of its magnitude and the angles θ and ϕ.



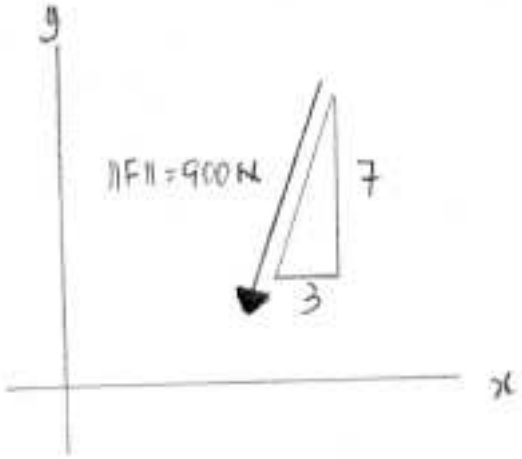
EX 2.5.10

GOAL : To express a force in terms of its magnitude and angles.

GIVEN : Magnitude and orientation of force in terms of "rise" and "run".

ASSUME : Planar, thus $\phi = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta = 180° + \cos^{-1}\left(\frac{3}{\sqrt{58}}\right) = 246.8°$$

RESULTS :

$$\boxed{\begin{aligned} ||\boldsymbol{F}|| &= 900\,\text{N} \\ \theta &= 247° \\ \phi &= 90° \end{aligned}}$$

CHECK : Verify angle θ visually from the positive x-axis in a ccw direction.

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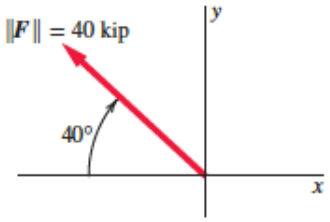
PROBLEM 2.5.13

The 40-kip force is oriented at 40° relative to the horizontal, as shown (1 kip = 1000 lb). Find the unit vector $\boldsymbol{u}$ in the direction of $\boldsymbol{F}$ in terms of unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.



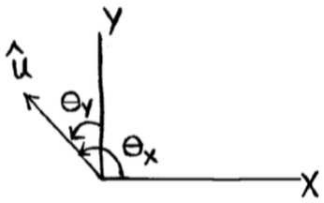
EX 2.5.13

GOAL : To find the unit vector in the direction of the force.

GIVEN : The force magnitude and the angle between the force and the x-axis.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\hat{\boldsymbol{u}} = \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}}$$

$$\begin{aligned}\hat{\boldsymbol{u}} &= \cos(180^\circ - 40^\circ)\,\hat{\mathbf{i}} + \cos(90^\circ - 40^\circ)\,\hat{\mathbf{j}} \\ &= -0.766\,\hat{\mathbf{i}} + 0.643\,\hat{\mathbf{j}}\end{aligned}$$

RESULTS :

$$\boxed{\hat{\boldsymbol{u}} = -0.766\,\hat{\mathbf{i}} + 0.643\,\hat{\mathbf{j}}}$$

CHECK : Ensure that $\|\hat{\boldsymbol{u}}\| = 1$ and that the direction is correct.

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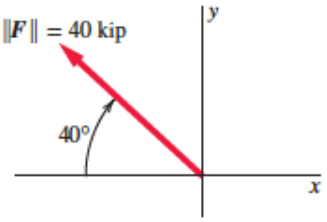
PROBLEM 2.5.14

The 40-kip force is oriented at 40° relative to the horizontal, as shown (1 kip = 1000 lb). Express $\boldsymbol{F}$ in terms of the unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.



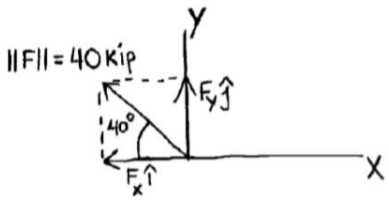
EX 2.5.13

GOAL : To find express a force in terms of unit vectors.

GIVEN : The force magnitude and the angle between the force and the x-axis.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\hat{\boldsymbol{u}} &= \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}} \\ &= \cos(180^\circ - 40^\circ)\,\hat{\mathbf{i}} + \cos(90^\circ - 40^\circ)\,\hat{\mathbf{j}} \\ &= -0.766\,\hat{\mathbf{i}} + 0.643\,\hat{\mathbf{j}}\end{aligned}$$

$$\begin{aligned}\boldsymbol{F} &= F_x\,\hat{\mathbf{i}} + F_y\,\hat{\mathbf{j}} = (40\,\text{kip})\hat{\boldsymbol{u}} \\ &= (-30.64\,\hat{\mathbf{i}} + 25.71\,\hat{\mathbf{j}})\,\text{kip}\end{aligned}$$

RESULTS :

$$\boxed{\boldsymbol{F} = (-30.6\,\hat{\mathbf{i}} + 25.7\,\hat{\mathbf{j}})\,\text{kip}}$$

CHECK : Ensure that $\|\boldsymbol{F}\| = \sqrt{F_x{}^2 + F_y{}^2}$ is correct and that the angle is preserved.

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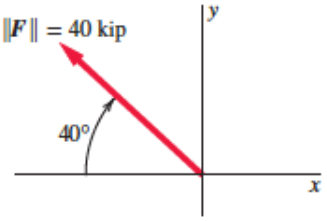
PROBLEM 4.5.15

The 40-kip force is oriented at 40° relative to the horizontal, as shown (1 kip = 1000 lb). Find the space angles that describe the direction of the force vector.



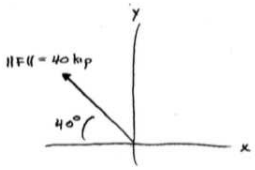
EX 2.5.13

GOAL : To find the space angles that describe the direction of the force.

GIVEN : The force magnitude and the angle between the force and the x-axis.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = 180° - 40° = 140°$$

$$\theta_y = 90° - 40° = 50°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 140° \\ \theta_y &= 50° \\ \theta_z &= 90°\end{aligned}}$$

CHECK : Verify visually.

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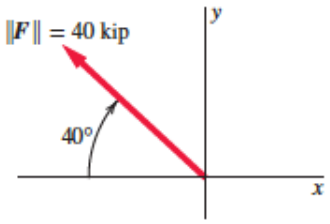
PROBLEM 2.5.16

The 40-kip force is oriented at 40° relative to the horizontal, as shown (1 kip = 1000 lb). Express $\boldsymbol{F}$ in terms of its magnitude and the angles θ and ϕ using spherical coordinates.



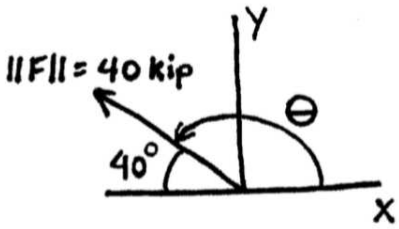
EX 2.5.13

GOAL : To express a force in terms of its magnitude and angles.

GIVEN : The force magnitude and the angle between the force and the x-axis.

ASSUME : Planar, thus $\phi = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta = 180° - 40° = 140°$$

RESULTS :

$$\boxed{\begin{aligned} ||\boldsymbol{F}|| &= 40\,\text{kip} \\ \theta &= 140° \\ \phi &= 90° \end{aligned}}$$

CHECK : Verify visually, remembering that the angles are measured ccw from the positive x and z axes.

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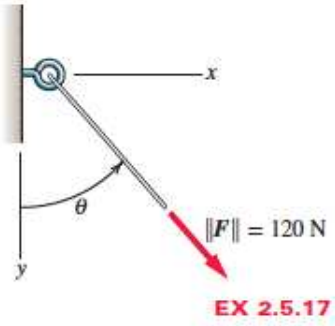
PROBLEM 2.5.17

The cable pulls on the eyebolt with a tensile force of 120 N, and $\theta = 30^\circ$. Determine the scalar components of the force with respect to the *xyz* coordinate system. Redraw the figure, showing the tension force in terms of its rectangular component vectors.

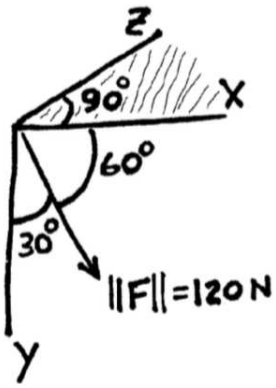


GOAL : To find the scalar components of a force and sketch a force in terms of its components.

GIVEN : The force magnitude and the angle between the force and the y-axis..

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

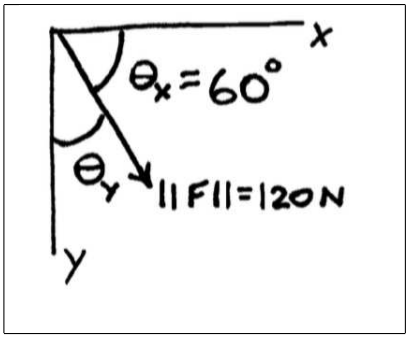
$$F_x = (120\,\text{N})\sin 30^\circ = 60\,\text{N}$$

$$F_y = (120\,\text{N})\cos 30^\circ = 104\,\text{N}$$

$$F_z = (120\,\text{N})\cos 90^\circ = 0\,\text{N}$$

RESULTS :

$$\boxed{\begin{aligned} F_x &= 60\,\text{N} \\ F_y &= 104\,\text{N} \\ F_z &= 0\,\text{N} \end{aligned}}$$



CHECK : Re-combine the force components ($\sqrt{(60\,\text{N})^2 + (104\,\text{N})^2} = 120\,\text{N}$) to ensure the magnitude is correct.

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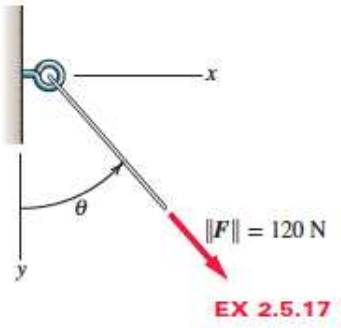
PROBLEM 2.5.18

The cable pulls on the eyebolt with a tensile force of 120 N, and $\theta = 30^\circ$. Find the unit vector $\boldsymbol{u}$ in the direction of $\boldsymbol{F}$ in terms of unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.

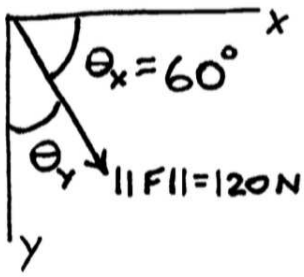


GOAL : Find the unit vector along the direction of a force.

GIVEN : The force magnitude and the angle between the force and the y-axis.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\hat{\boldsymbol{u}} = \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}}$$

$$\cos\theta_x = \cos(60^\circ) = \sin(30^\circ)$$

$$\hat{\boldsymbol{u}} = \sin(30^\circ)\,\hat{\mathbf{i}} + \cos(30^\circ)\,\hat{\mathbf{j}} = 0.500\,\hat{\mathbf{i}} + 0.866\,\hat{\mathbf{j}}$$

RESULTS :
Note the orientation of the axes. The y axis acts downward.

$$\boxed{\hat{\boldsymbol{u}} = 0.500\,\hat{\mathbf{i}} + 0.866\,\hat{\mathbf{j}}}$$

CHECK : Ensure the magnitude of the unit vector is 1 and the direction looks correct.

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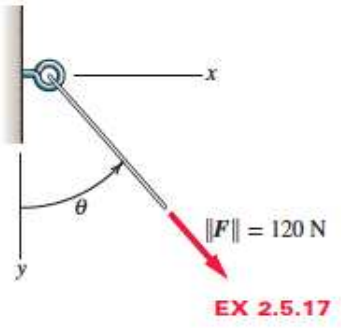
PROBLEM 2.5.19

The cable pulls on the eyebolt with a tensile force of 120 N, and θ = 30°. Determine the space angles that describe the direction of the force vector.

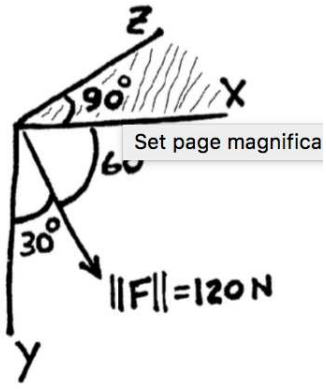


GOAL : To find the space angles that describe the direction of the force.

GIVEN : The force magnitude and the angle between the force and the y-axis.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = 90° - \theta = 60°$$

$$\theta_y = \theta = 30°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 60°\\ \theta_y &= 30°\\ \theta_z &= 90°\end{aligned}}$$

CHECK : Check visually.

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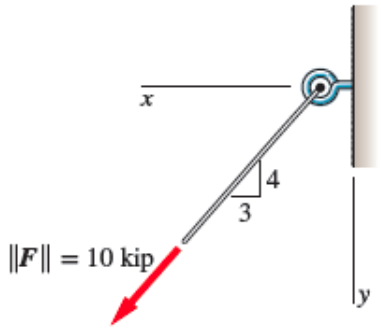
PROBLEM 2.5.20

The cable pulls on the eyebolt with a tensile force of 10 kip as shown. Determine the unit vector along the line of action of the force.

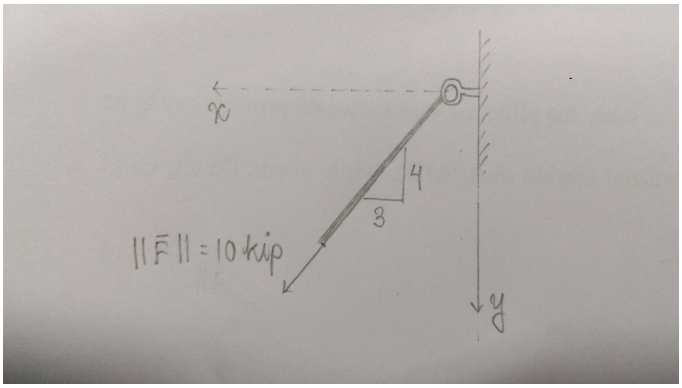


GOAL : To find the unit vector along the direction of the force.

GIVEN : Magnitude and orientation, with respect to a defined set of coordinate axes, of a force acting on a eyebolt.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\hat{\boldsymbol{u}} = \frac{3}{5}\,\hat{\mathbf{i}} + \frac{4}{5}\,\hat{\mathbf{j}} = 0.600\,\hat{\mathbf{i}} + 0.800\,\hat{\mathbf{j}}$$

RESULTS :

$$\boxed{\hat{\boldsymbol{u}} = 0.600\,\hat{\mathbf{i}} + 0.800\,\hat{\mathbf{j}}}$$

CHECK : Ensure that the magnitude of the unit vector is one and the vector is visually in the correct direction (Note the direction of the given coordinate axes).

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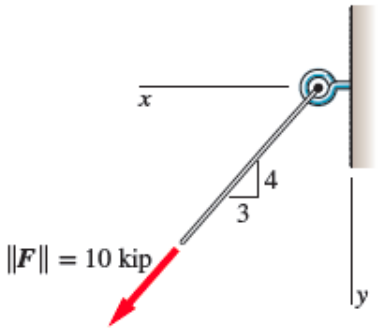
PROBLEM 2.5.21

The cable pulls on the eyebolt with a tensile force of 10 kip as shown. Determine the scalar components of the force with respect to the *xyz* coordinate system.

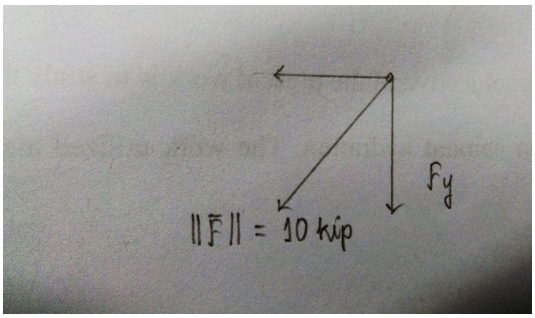


GOAL : Find the components of the force.

GIVEN : Magnitude and orientation, with respect to a defined set of coordinate axes, of a force acting on a eyebolt.

ASSUME : Planar, thus $F_z = 0\,\text{lb}$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_x = (10\,\text{kip})\left(\frac{3}{5}\right) = 6.0\,\text{kip}$$

$$F_y = (10\,\text{kip})\left(\frac{4}{5}\right) = 8.0\,\text{kip}$$

RESULTS :

$$\boxed{\begin{aligned} F_x &= 6.0\,\text{lb} \\ F_y &= 8.0\,\text{lb} \\ F_z &= 0.0\,\text{lb} \end{aligned}}$$

CHECK : Verify the magnitude is the same ($\sqrt{(6\,\text{kip})^2 + (8\,\text{kip})^2} = 10\,\text{kip}$) and the direction appears correct.

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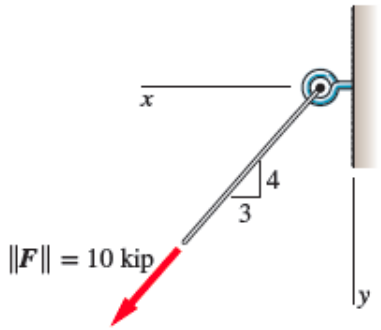
PROBLEM 2.5.22

The cable pulls on the eyebolt with a tensile force of 10 kip as shown. Find the space angles that describe the direction of the force vector. I

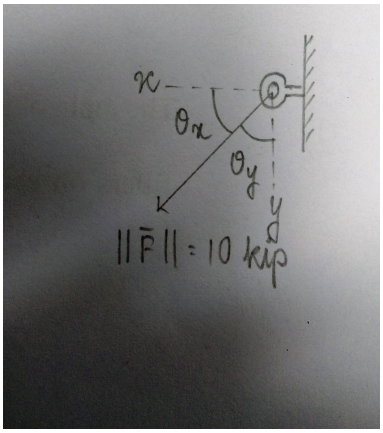


GOAL : To find the space angles that describe the direction of the force.

GIVEN : Magnitude and orientation, with respect to a defined set of coordinate axes, of a force acting on a eyebolt.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = \cos^{-1}\left(\frac{3}{5}\right) = 53.13°$$

$$\theta_y = \cos^{-1}\left(\frac{4}{5}\right) = 36.87°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 53.1°\\ \theta_y &= 36.9°\\ \theta_z &= 90°\end{aligned}}$$

CHECK : Verify visually using figure.

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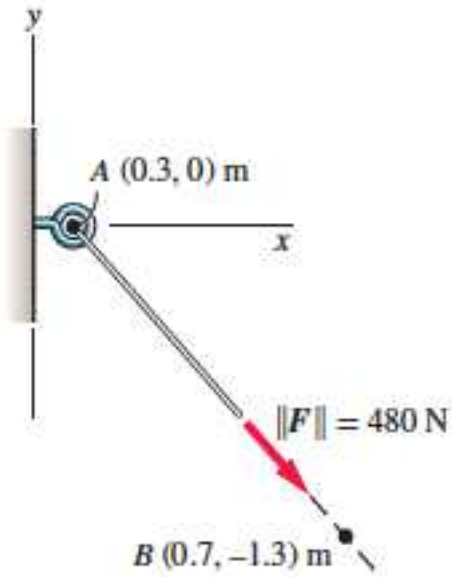
PROBLEM 2.5.23

The cable pulls on the eyebolt with a tensile force of 480 N. Coordinates along the line of action of the force are as given in the following figure. Determine the unit vector along the line of action of the force.

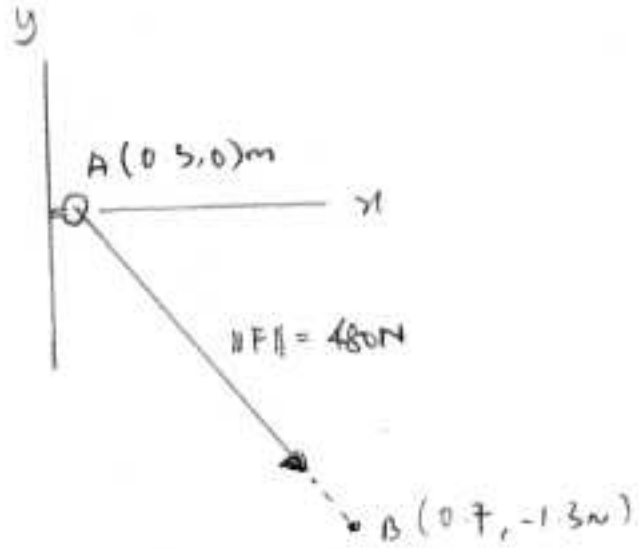


GOAL : To find the unit vector the direction of the force.

GIVEN : Coordinate system, magnitude of force, and coordinates of two points on its line of action.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$d = \sqrt{(0.7\,\text{m} - 0.3\,\text{m})^2 + (-1.3\,\text{m} - 0\,\text{m})^2} = 1.36\,\text{m}$$

$$\hat{\boldsymbol{u}} = \frac{0.7\,\text{m} - 0.3\,\text{m}}{d}\,\hat{\mathbf{i}} + \frac{-1.3\,\text{m} - 0\,\text{m}}{d}\,\hat{\mathbf{j}}$$
$$= \frac{0.4\,\text{m}}{1.36\,\text{m}}\,\hat{\mathbf{i}} - \frac{1.3\,\text{m}}{1.36\,\text{m}}\,\hat{\mathbf{j}} = 0.294\,\hat{\mathbf{i}} - 0.956\,\hat{\mathbf{j}}$$

RESULTS :

$$\boxed{\hat{\boldsymbol{u}} = 0.294\,\hat{\mathbf{i}} - 0.956\,\hat{\mathbf{j}}}$$

CHECK : Ensure the magnitude of the unit vector is 1 and the direction is correct.

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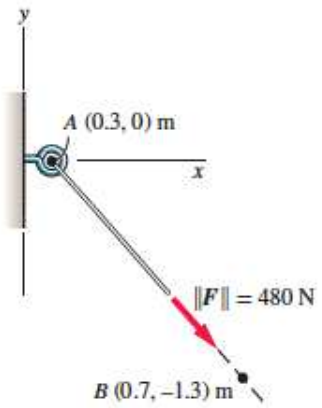
PROBLEM 2.5.24

The cable pulls on the eyebolt with a tensile force of 480 N. Coordinates along the line of action of the force are as given in the following figure. Determine the scalar components of the force with respect to the *xyz* coordinate system.

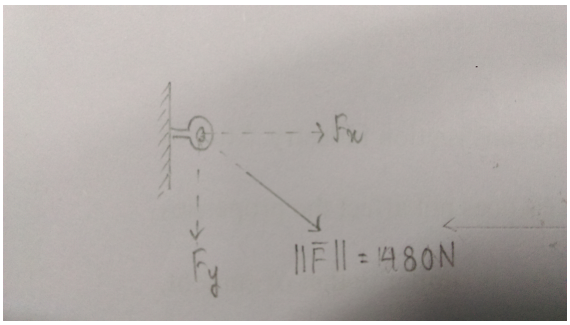


GOAL : To find the scalar components of a force.

GIVEN : Coordinate system, magnitude of force, and coordinates of two points on its line of action.

ASSUME : Planar, thus $F_z = 0\,\text{N}$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_x = \|F\|u_x = (480\,\text{N})\left(\frac{0.4}{\sqrt{0.4^2+(-1.3)^2}}\right) = 141.2\,\text{N}$$

$$F_y = \|F\|u_y = (480\,\text{N})\left(\frac{-1.3}{\sqrt{0.4^2+(-1.3)^2}}\right) = -458.8\,\text{N}$$

RESULTS :

$$\boxed{\begin{aligned} F_x &= 141.2\,\text{N} \\ F_y &= -458.8\,\text{N} \\ F_z &= 0\,\text{N} \end{aligned}}$$

CHECK : Ensure the magnitude is unchanged ($\sqrt{(141.2\,\text{N})^2+(-458.8\,\text{N})^2} = 4800\,\text{N}$).

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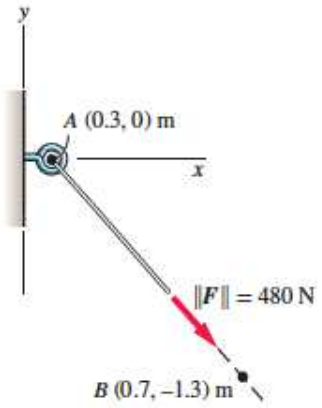
PROBLEM 2.5.25

The cable pulls on the eyebolt with a tensile force of 480 N. Coordinates along the line of action of the force are as given in the following figure. Find the space angles that describe the direction of the force vector.

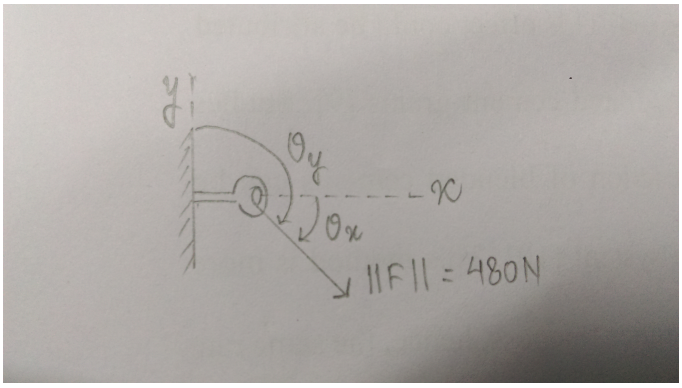


GOAL : To find the space angles that describe the direction of the force.

GIVEN : Coordinate system, magnitude of force, and coordinates of two points on its line of action.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\theta_x = \tan^{-1}\left(\frac{1.3}{0.7-0.3}\right) = 72.9°$$

$$\theta_y = 90 + \theta_x = 162.9°$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 72.9°\\ \theta_y &= 162.9°\\ \theta_z &= 90°\end{aligned}}$$

CHECK : Check visually using figure.

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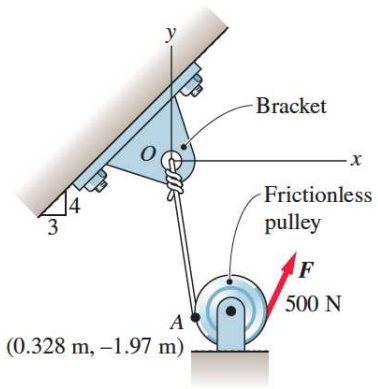
PROBLEM 2.5.26

A cable wrapped around a frictionless pulley pulls on the bracket at O with a force of 500N. Express $\boldsymbol{F}_{OA}$ in terms of the unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.

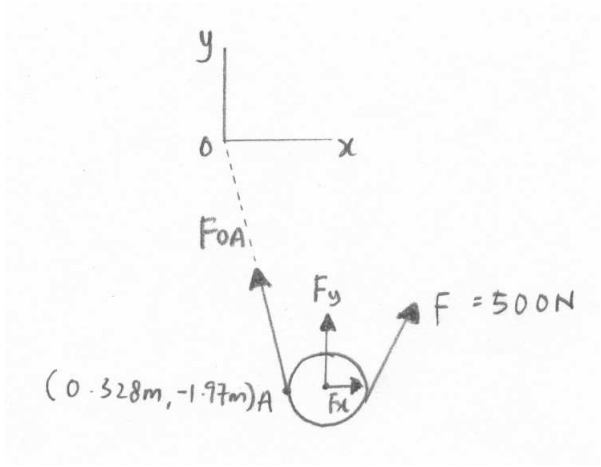


GOAL : To express $\boldsymbol{F}_{OA}$ in terms of the unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.

GIVEN : Coordinate system, magnitude of force, and coordinates of two points on its line of action.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Finding unit vector of OA, $\boldsymbol{u}_{OA}$.

$$\begin{aligned}\boldsymbol{OA} &= \sqrt{(0.328m-0)^2+(-1.97m-0)^2}\\ &= 1.997m\\ \boldsymbol{u}_{OA} &= \frac{0.328m-0m}{1.997m}\,\hat{\mathbf{i}}+\frac{-1.97m-0m}{1.997m}\,\hat{\mathbf{j}}\\ &= 0.1642\,\hat{\mathbf{i}}-0.9865\,\hat{\mathbf{j}}\end{aligned}$$

RESULTS :
With the unit vector, we will multiply the force of 500 N with it to write $\boldsymbol{F}_{OA}$ in terms of $\boldsymbol{i}$ and $\boldsymbol{j}$. We get

$$\boxed{\boldsymbol{F}_{OA} = 82.1N\,\hat{\mathbf{i}}-493.3N\,\hat{\mathbf{j}}}$$

CHECK : Check the calculations.

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PROBLEM 2.5.27

Researchers tested the seismic resistance of a scaled model of a bridge bent by pulling the specimen to the side with force F, which was applied via a cable as shown. If the line of action of F is $\boldsymbol{u} = 0.993\boldsymbol{i} - 0.120\boldsymbol{j}$, and the horizontal component of F required to pull the bent over is 37.7kips, determine $||\boldsymbol{F}||$.

Sharon Wood

GOAL : To find the magnitude of the force.

GIVEN : The unit vector, the horizontal component of force F

ASSUME : Planar.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

We know that

$$\boldsymbol{F} = ||\boldsymbol{F}||\boldsymbol{u}$$

which leads us to

$$\boldsymbol{F} = ||\boldsymbol{F}||\boldsymbol{u}_x\,\hat{\mathbf{i}} + ||\boldsymbol{F}||\boldsymbol{u}_y\,\hat{\mathbf{j}}$$

We are given that

$$F_x = 37.7kips$$

which means

$$F_x = ||\boldsymbol{F}||\boldsymbol{u}_x = 37.7kips$$

We know $\boldsymbol{u}_x = 0.993$, and this means we can solve for $||\boldsymbol{F}||$.

RESULTS :

$$\boxed{||\boldsymbol{F}|| = 38.0kips}$$

CHECK : Ensure that the formulation and the calculation is correct.

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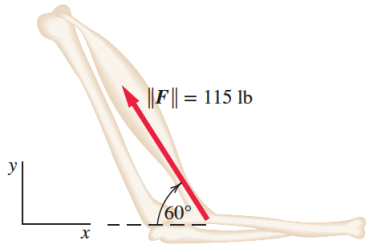
PROBLEM 2.5.28

A student, training for a triathlon, lifts a 10 lb weight and generates a 115 lb force in the biceps brachii as shown.

a. Determine the unit vector along the line of action of, and with the same sense as, the muscle force.

b. Find the space angles that describe the direction of the force vector.

c. Write the force in Cartesian vector notation.



GOAL : To (a) determine the unit vector, (b) find the space angles and (c) write the force in Cartesian vector notation.

GIVEN : The force direction and force magnitude, coordinate axes

ASSUME : Planar.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

(a) For unit vector, we use trigonometry and we get

$$\begin{aligned} \boldsymbol{u} &= \cos 60^\circ\,\hat{\mathbf{i}} + \sin 60^\circ \\ &= -0.5\,\hat{\mathbf{i}} + 0.8660\,\hat{\mathbf{j}} \end{aligned}$$

(b) To find the space angles, we do the following.

$$\begin{aligned} \cos\theta_x &= -0.5 \\ \cos\theta_y &= 0.8660 \end{aligned}$$

(c) To write the force in Cartesian vector notation, we multiply the magnitude with the unit vector.

$$\boldsymbol{F} = ||\boldsymbol{F}||\boldsymbol{u}$$

RESULTS :
With the above, we get
(a)

$$\boxed{-0.5\,\hat{\mathbf{i}} + 0.8660\,\hat{\mathbf{j}}}$$

(b)

$$\boxed{\theta_x = 120^\circ}$$

$$\boxed{\theta_y = 30^\circ}$$

(c)

$$\boxed{\boldsymbol{F} = -57.5\text{ lb}\,\hat{\mathbf{i}} + 99.6\text{ lb}\,\hat{\mathbf{j}}}$$

CHECK : Ensure that the formulation and the calculation is correct.

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PROBLEM 2.5.29

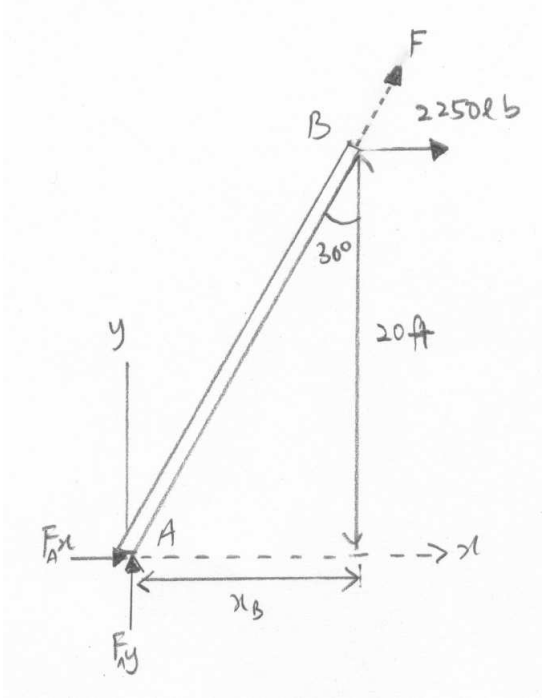
After a fire destroyed a building's roof, shoring consisting of steel pipes was used to stabilize the walls as shown in Figure 1. The shoring is attached to the all at 20 ft above the ground and at 30° from vertical and lies in a plane perpendicular to the wall. The force applied by the shoring acs along the axis of the pipe and applies a 2250 lb horizontal force to the wall at B. Find the Cartesian vector $\boldsymbol{F}$ that describes the force applied by the shoring to the wall.

GOAL : To find the Cartesian vector *vvF* that describes the force applied by the shoring to the wall.

GIVEN : The dimension of the shoring, the horizontal force applied by the shoring.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

We first obtain the coordinate at B.

$$\tan 30^\circ = \frac{x_B}{20}$$
$$x_B = 11.55\,\text{ft}$$

We get B (11.55ft, 20ft)
To get the length of AB, and subsequently the unit vector,

$$\boldsymbol{AB} = \sqrt{(11.55\,\text{ft}-0)^2+(20\,\text{ft}-0)}$$
$$= 23.10\,\text{ft}$$
$$\boldsymbol{u}_{AB} = \frac{11.55\,\text{ft}-0}{23.10\,\text{ft}}\,\hat{\mathbf{i}} + \frac{20\,\text{ft}-0}{23.10\,\text{ft}}\,\hat{\mathbf{j}}$$
$$= 0.5\,\hat{\mathbf{i}} + 0.8658\,\hat{\mathbf{j}}$$

RESULTS :
We know that we can we can write the force vector in Cartesian by multiplying the force magnitude with the unit vector, $\boldsymbol{F} = ||\boldsymbol{F}||\boldsymbol{u}$. With that, we can write,

$$\boldsymbol{F} = ||\boldsymbol{F}||0.5\,\hat{\mathbf{i}} + 0.8658\,\hat{\mathbf{j}}$$

We are told that the horizontal force exerted by the shoring is 2250 lb. This means

$$||\boldsymbol{F}||0.5 = 2250\,\text{lb}$$

and we get

$$\boxed{||\boldsymbol{F}|| = 4500\,\text{lb}}$$

CHECK : Ensure that the formulation and the calculation is correct.

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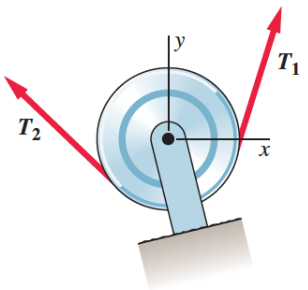
PROBLEM 2.5.30

The frictionless pulley is such that the magnitude of $\boldsymbol{T_1}$ is equal to the magnitude of $\boldsymbol{T_2}$. For $\boldsymbol{T_1}$ = 25.9 kN$\boldsymbol{i}$ + 96.6 kN$\boldsymbol{j}$ and $\boldsymbol{T_2}$ = −90.6 kN$\boldsymbol{i}$ + 42.3 kN$\boldsymbol{j}$, prove that the magnitudes of these two forces are equal.

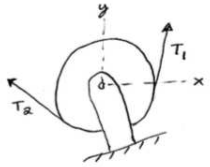


GOAL : Show that the magnitudes of two forces are equal.

GIVEN : Coordinate system, frictionless pulley and forces acting the rope in terms of their components:
$\boldsymbol{T}_1 = (25.9\,\hat{\mathbf{i}} + 96.6\,\hat{\mathbf{j}})$ kN and
$\boldsymbol{T}_2 = (-90.6\,\hat{\mathbf{i}} + 42.3\,\hat{\mathbf{j}})$ kN.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\|\boldsymbol{T}_1\| = \sqrt{25.9^2 + 96.6^2} = 100\,\text{kN}$$

$$\|\boldsymbol{T}_2\| = \sqrt{(-90.6)^2 + 42.3^2} = 100\,\text{kN}$$

RESULTS :

$$\boxed{\|\boldsymbol{T}_1\| = \|\boldsymbol{T}_2\| = 100\,\text{kN}}$$

CHECK : Verify calculations.

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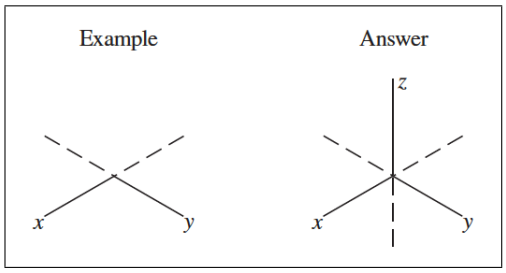
PROBLEM 2.5.31

For each of the partial coordinate systems shown, add the missing axis so as to form a right-handed coordinate system. Select which of the complete coordinate system is a right handed orthogonal coordinate system.



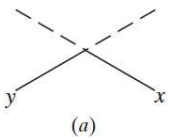
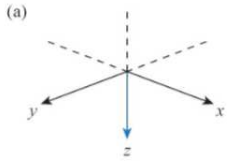
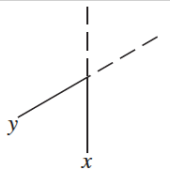
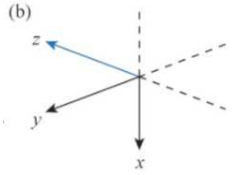
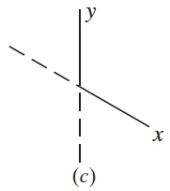
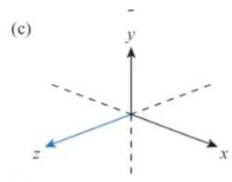
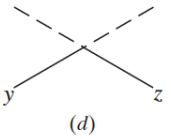
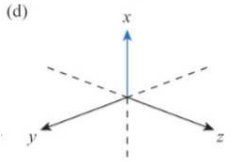
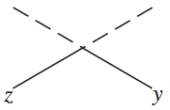
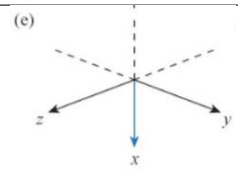
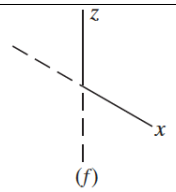
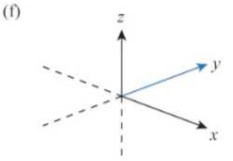
GOAL : To sketch the third axis, so that the two given axis and the third constitute a right handed system.

GIVEN : Pictures of two axes.

ASSUME : None necessary.

DRAW : See below.

RESULTS :

Partial Coordinate System	Answer
 (a)	 (a)
 (b)	 (b)
 (c)	 (c)
 (d)	 (d)
 (e)	 (e)
 (f)	 (f)

CHECK : Verify using the right-hand rule.

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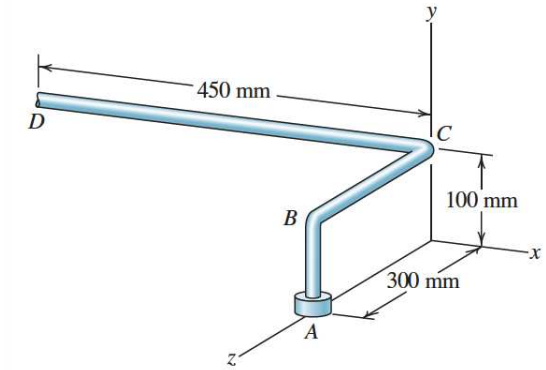
PROBLEM 2.5.32

For the pipe assembly shown, determine the unit vector that lies along a line between

a. points A and B

b. points A and C

c. points A and D

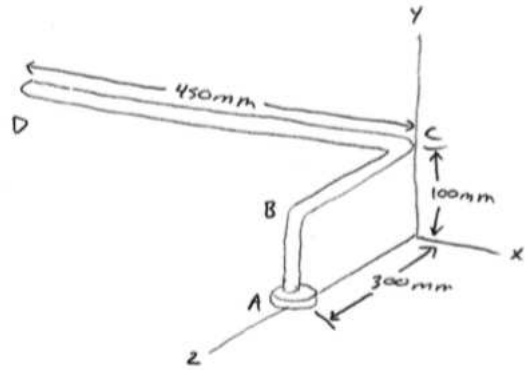


GOAL : Write unit vectors for (a) from A to B, (b) from A to C, and (c) from A to D.

GIVEN : Sketch of a non-planar component with dimensions, a coordinate system.

ASSUME : None needed

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\boldsymbol{u}_{AB} = 0\,\hat{\mathbf{i}} + \frac{100\,\text{mm}}{100\,\text{mm}}\,\hat{\mathbf{j}} + 0\,\hat{\mathbf{k}} = 1\,\hat{\mathbf{j}}$$

RESULTS (a): From A to B:

$$\boxed{\boldsymbol{u}_{AB} = 1\,\hat{\mathbf{j}}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$l_{AC} = \sqrt{(100\,\text{mm})^2 + (300\,\text{mm})^2}$$

$$\begin{aligned}\boldsymbol{u}_{AC} &= 0\,\hat{\mathbf{i}} + \frac{100\,\text{mm}}{l_{AC}}\,\hat{\mathbf{j}} + \frac{-300\,\text{mm}}{l_{AC}}\,\hat{\mathbf{k}} \\ &= 0.316\,\hat{\mathbf{j}} - 0.949\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS (b): From A to C:

$$\boxed{\boldsymbol{u}_{AC} = 0.316\,\hat{\mathbf{j}} - 0.949\,\hat{\mathbf{k}}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$l_{AD} = \sqrt{(450\,\text{mm})^2 + (100\,\text{mm})^2 + (300\,\text{mm})^2} = 550\,\text{mm}$$

$$\begin{aligned}\boldsymbol{u}_{AD} &= \frac{-450\,\text{mm}}{l_{AD}}\,\hat{\mathbf{i}} + \frac{100\,\text{mm}}{l_{AD}}\,\hat{\mathbf{j}} + \frac{-300\,\text{mm}}{l_{AD}}\,\hat{\mathbf{k}} \\ &= -0.818\,\hat{\mathbf{i}} + 0.182\,\hat{\mathbf{j}} - 0.545\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS (c): From A to D:

$$\boxed{\boldsymbol{u}_{AD} = -0.818\,\hat{\mathbf{i}} + 0.182\,\hat{\mathbf{j}} - 0.545\,\hat{\mathbf{k}}}$$

CHECK : Ensure that the magnitude of each unit vector is 1.

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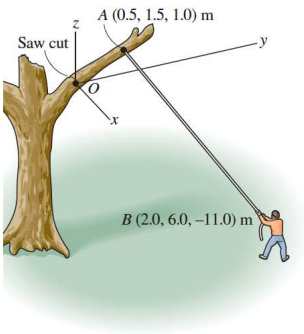
PROBLEM 2.5.33

The tree trimmer is pulling on the branch with a force of 150 N.

a. find the unit vector along the line of action of this force

b. determine the x, y, z components of the force pulling on the branch and write t he force in Cartesian vector notation

c. how would your answer change if you wrote the force vector acting on the man instead of on the branch?

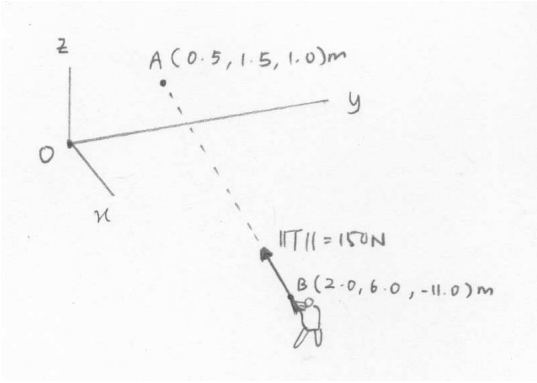


GOAL : To (a) find the unit vector along the line of action, (b) determine the components of the force and (c) determine how the answer changes if the force is acting on the man instead.

GIVEN : Sketch of a non-planar man with dimensions, a coordinate system.

ASSUME : None needed

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\begin{aligned}\boldsymbol{AB} &= \sqrt{(2.0-0.5)\,\mathrm{m}^2+(6.0-1.5)\,\mathrm{m}^2+(-11.0-1)\,\mathrm{m}^2}\\ &= 12.90\,\mathrm{m}\\ \boldsymbol{u}_{AB} &= \frac{(2.0-0.5)\,\mathrm{m}}{12.90\,\mathrm{m}}\,\hat{\mathbf{i}}+\frac{(6.0-1.5)\,\mathrm{m}}{12.90\,\mathrm{m}}\,\hat{\mathbf{j}}+\frac{(-11.0-1)\,\mathrm{m}}{12.90\,\mathrm{m}}\,\hat{\mathbf{k}}\\ &= 0.1163\,\hat{\mathbf{i}}+0.3488\,\hat{\mathbf{j}}-0.9302\,\hat{\mathbf{k}}\end{aligned}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}\boldsymbol{F} &= ||\boldsymbol{F}||\boldsymbol{u}_{AB}\\ &= 150\,\mathrm{N}(0.1163\,\hat{\mathbf{i}}+0.3488\,\hat{\mathbf{j}}-0.9302\,\hat{\mathbf{k}})\\ &= 17.45\,\mathrm{N}\,\hat{\mathbf{i}}+52.3\,\mathrm{N}\,\hat{\mathbf{j}}-139.5\,\mathrm{N}\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS (a):

$$\boxed{\boldsymbol{u}_{AB} = 0.1163\,\hat{\mathbf{i}}+0.3488\,\hat{\mathbf{j}}-0.9302\,\hat{\mathbf{k}}}$$

RESULTS (b):

$$\boxed{\boldsymbol{F} = 17.45\,\mathrm{N}\,\hat{\mathbf{i}}+52.3\,\mathrm{N}\,\hat{\mathbf{j}}-139.5\,\mathrm{N}\,\hat{\mathbf{k}}}$$

RESULTS (c):
If we write the force vector acting on the man, it will be the opposite of the force vector acting on the tree.

$$\boxed{\boldsymbol{F}_{onMan} = -17.45\,\mathrm{N}\,\hat{\mathbf{i}}-52.3\,\mathrm{N}\,\hat{\mathbf{j}}+139.5\,\mathrm{N}\,\hat{\mathbf{k}}}$$

CHECK : Ensure that the magnitude of each unit vector is 1 and calculations are correct.

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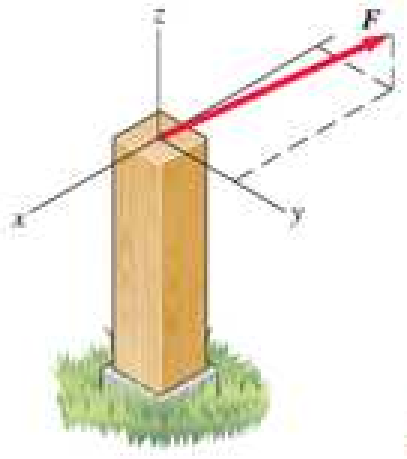
PROBLEM 2.5.34

A student applies a force $\boldsymbol{F}$ = (–16 lb$\boldsymbol{i}$ + 4 lb$\boldsymbol{j}$ + 6 lb$\boldsymbol{k}$) to the top of a fence post.

a. The post will fail by tipping if the magnitude of the applied force is greater than 50 lb. Determine if the student should be worried about the post failing.

b. Find the unit vector along the line of action of the force.

c. Find the space angles that describe the direction of the force vector.



EX 2.5.34

GOAL : Determine (a) the magnitude of the force, (b) the unit vector along the force, and (c) the space angles. Answer if the tipping force seems comparable to the exerted force.

GIVEN : The force $\boldsymbol{F} = (-16\,\hat{\mathbf{i}} + 4\,\hat{\mathbf{j}} + 6\,\hat{\mathbf{k}})$ lb, its point of application, and a coordinate system.

ASSUME : None necessary.

DRAW :

FORMULATE EQUATIONS and **SOLVE** (a) and (b):

$$\hat{\boldsymbol{u}} = \frac{F_x}{\|\boldsymbol{F}\|}\,\hat{\mathbf{i}} + \frac{F_y}{\|\boldsymbol{F}\|}\,\hat{\mathbf{j}} + \frac{F_z}{\|\boldsymbol{F}\|}\,\hat{\mathbf{k}}$$

$$\|\boldsymbol{F}\| = \sqrt{(-16\,\text{lb})^2 + (4\,\text{lb})^2 + (6\,\text{lb})^2} = 17.55\,\text{lb}$$

$$\begin{aligned}\hat{\boldsymbol{u}} &= \frac{-16\,\text{lb}}{\|\boldsymbol{F}\|}\,\hat{\mathbf{i}} + \frac{4\,\text{lb}}{\|\boldsymbol{F}\|}\,\hat{\mathbf{j}} + \frac{6\,\text{lb}}{\|\boldsymbol{F}\|}\,\hat{\mathbf{k}} \\ &= -0.912\,\hat{\mathbf{i}} + 0.228\,\hat{\mathbf{j}} + 0.342\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS (a): The magnitude of the force

$$\|\boldsymbol{F}\| = 17.6\,\text{lb}$$

No, the amount of force is not enough to tip the post.

RESULTS (b): The unit vector along the line of action of the force is:

$$\hat{\boldsymbol{u}} = -0.912\,\hat{\mathbf{i}} + 0.228\,\hat{\mathbf{j}} + 0.342\,\hat{\mathbf{k}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$\theta_x = \cos^{-1}\frac{F_x}{\|\boldsymbol{F}\|} = \cos^{-1}(-0.912) = 155.7^\circ$$

$$\theta_y = \cos^{-1}\frac{F_y}{\|\boldsymbol{F}\|} = \cos^{-1}(0.228) = 76.8^\circ$$

$$\theta_z = \cos^{-1}\frac{F_z}{\|\boldsymbol{F}\|} = \cos^{-1}(0.342) = 70.0^\circ$$

RESULTS (c): The space angles are:

$$\theta_x = 155.7^\circ$$
$$\theta_y = 76.8^\circ$$
$$\theta_z = 70.0^\circ$$

CHECK : Ensure the unit vector has magnitude 1 and visually check the angles with the figure.

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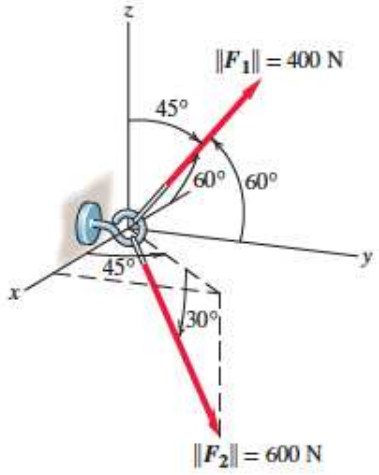
PROBLEM 2.5.35

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to the hook, as shown below. Express $\boldsymbol{F}_1$ in Cartesian vector notation. Note the orientation of the axes.

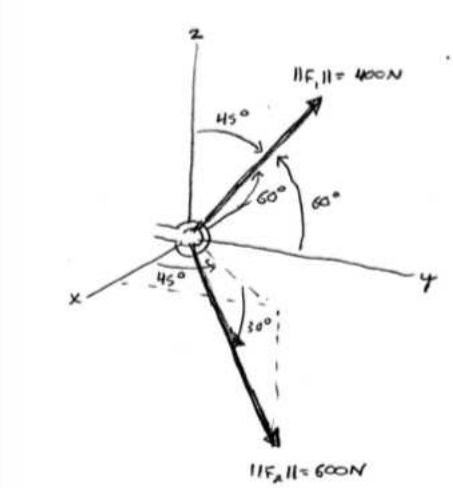


GOAL : To express each force in vector notation.

GIVEN : Magnitude and orientation of forces applied to a hook.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Using equations (4.7) and (4.11):

For $\boldsymbol{F}_1$:

$$\boldsymbol{F}_1 = (400\,\text{N})(-\cos 60^\circ\,\hat{\mathbf{i}} + \cos 60^\circ\,\hat{\mathbf{j}} + \cos 45^\circ\,\hat{\mathbf{k}})$$

$$\boldsymbol{F}_1 = (-200\,\hat{\mathbf{i}} + 200\,\hat{\mathbf{j}} + 282.8\,\hat{\mathbf{k}})\ \text{N}$$

RESULTS :

$$\boxed{\boldsymbol{F}_1 = (-200\,\hat{\mathbf{i}} + 200\,\hat{\mathbf{j}} + 282.8\,\hat{\mathbf{k}})\ \text{N}}$$

CHECK : Visually check the direction, and ensure the magnitudes of the forces are correct.

$$\|\boldsymbol{F}_1\| = \sqrt{(-200\,\text{N})^2 + (200\,\text{N})^2 + (282.8\,\text{N})^2}$$
$$= 400\,\text{N}$$

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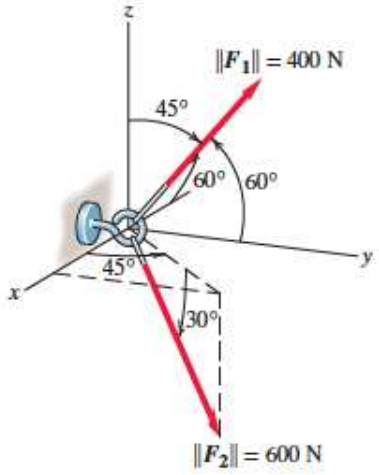
PROBLEM 2.5.36

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to the hook, as shown below. Express $\boldsymbol{F_2}$ in Cartesian vector notation. Note the orientation of the axes.

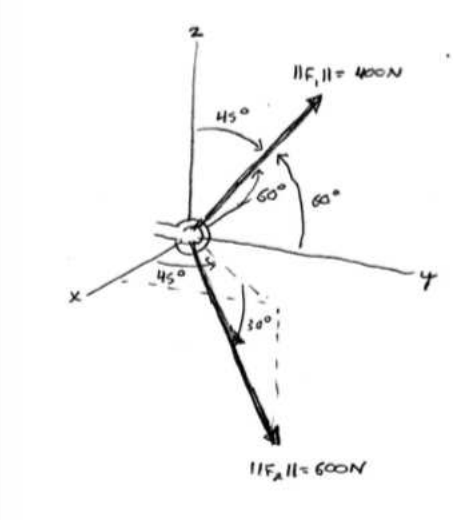


GOAL : To express each force in vector notation.

GIVEN : Magnitude and orientation of forces applied to a hook.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Using equations (4.7) and (4.11):

For $\boldsymbol{F}_2$:

$$\boldsymbol{F}_2 = ||\boldsymbol{F}_2||(\cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}} + \cos\theta_z\,\hat{\mathbf{k}})$$

$$\cos\theta_x = (\sin\phi)(\cos\theta)$$
$$\cos\theta_y = (\sin\phi)(\sin\theta)$$
$$\cos\theta_z = \cos\phi$$

$$\begin{aligned}\boldsymbol{F}_2 &= ||\boldsymbol{F}_2||((\sin\phi)(\cos\theta)\,\hat{\mathbf{i}} + (\sin\phi)(\sin\theta)\,\hat{\mathbf{j}} + \cos\phi\,\hat{\mathbf{k}}) \\ &= (600\,\text{N})[(\sin 120^\circ)(\cos 45^\circ)\,\hat{\mathbf{i}} \\ &\quad + (\sin 120^\circ)(\sin 45^\circ)\,\hat{\mathbf{j}} + \cos 120^\circ\,\hat{\mathbf{k}}] \\ &= (367.42\,\hat{\mathbf{i}} + 367.42\,\hat{\mathbf{j}} - 300\,\hat{\mathbf{k}})\ \text{N}\end{aligned}$$

RESULTS :

$$\boxed{\boldsymbol{F}_2 = (367.4\,\hat{\mathbf{i}} + 367.4\,\hat{\mathbf{j}} - 300\,\hat{\mathbf{k}})\ \text{N}}$$

CHECK : Visually check the direction, and ensure the magnitudes of the forces are correct.

$$\begin{aligned}||\boldsymbol{F}_2|| &= \sqrt{(367.42\,\text{N})^2 + (367.42\,\text{N})^2 + (-300\,\text{N})^2} \\ &= 600\,\text{N}\end{aligned}$$

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PROBLEM 2.5.37

The x component of a 120-lb force $\boldsymbol{F}$ is twice as large as the y component and the z-component is zero.

a. Find the unit vector along the line of action of the force.

b. Express $\boldsymbol{F}$ in terms of the unit vectors $\boldsymbol{i}$ and $\boldsymbol{j}$.

c. Find the space angles that describe the direction of the force vector.

d. Express $\boldsymbol{F}$ in terms of its magnitude and the angles θ and ϕ.

GOAL : Find (a) the unit vector, (b) the force in terms of $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$, (c) the space angles and (d) the force in terms of magnitude and angles.

GIVEN : $\|\boldsymbol{F}\| = 120$ lb and the x-component of $\boldsymbol{F}$ is twice the y-component.

ASSUME : Planar (thus $\theta_z = \phi = 90^\circ$) and that the force is in the first quadrant (pos-x, pos-y). (Solutions for the third quadrant (neg-x, neg-y) are also given.)

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** (a):

$$\sqrt{(u_x)^2 + (u_y)^2} = \sqrt{(2u_y)^2 + (u_y)^2} = 1$$

$$5u_y^2 = 1 \qquad u_y = 0.447$$

$$u_x = 2u_y = 0.894$$

RESULTS (a): The unit vector is

$$\boxed{\hat{\boldsymbol{u}} = 0.894\,\hat{\mathbf{i}} + 0.447\,\hat{\mathbf{j}}}$$

An equally correct solution is

$$\boxed{\hat{\boldsymbol{u}} = -0.894\,\hat{\mathbf{i}} - 0.447\,\hat{\mathbf{j}}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\boldsymbol{F} = \|\boldsymbol{F}\|\boldsymbol{u} = (120\text{ lb})(0.894\,\hat{\mathbf{i}} + 0.447\,\hat{\mathbf{j}}) = (107.3\,\hat{\mathbf{i}} + 53.7\,\hat{\mathbf{j}})\text{ lb}$$

RESULTS (b): The force is

$$\boxed{\begin{array}{l}\boldsymbol{F} = 107.3\,\hat{\mathbf{i}} + 53.7\,\hat{\mathbf{j}}\text{ lb} \\ \text{or} \\ \boldsymbol{F} = -107.3\,\hat{\mathbf{i}} - 53.7\,\hat{\mathbf{j}}\text{ lb}\end{array}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$\theta_x = \tan^{-1}\left(\frac{1}{2}\right) = 26.6^\circ$$

$$\theta_y = 90^\circ - \theta_x = 63.4^\circ$$

RESULTS (c): The space angles are

$$\boxed{\begin{array}{l}\theta_x = 26.6^\circ \\ \theta_y = 63.4^\circ \\ \theta_z = 90^\circ\end{array}}$$

For $\boldsymbol{F} = -107.3\,\hat{\mathbf{i}} - 53.7\,\hat{\mathbf{j}}$ lb use

$$\boxed{\begin{array}{l}\theta_x = 153.4^\circ \\ \theta_y = 116.6^\circ \\ \theta_z = 90^\circ\end{array}}$$

FORMULATE EQUATIONS and **SOLVE** (d):

$$\theta = \theta_x = 26.6^\circ$$

RESULTS (d): The magnitude and angles are

$$\boxed{\begin{array}{l}\|\boldsymbol{F}\| = 120\text{ lb} \\ \theta = 26.6^\circ \\ \phi = 90^\circ\end{array}}$$

For $\boldsymbol{F} = -107.3\,\hat{\mathbf{i}} - 53.7\,\hat{\mathbf{j}}$ lb use

$$\boxed{\begin{array}{l}\|\boldsymbol{F}\| = 120\text{ lb} \\ \theta = 206.6^\circ \\ \phi = 90^\circ\end{array}}$$

CHECK : Ensure that $F_x = 2F_y$ and that the magnitude is correct.

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PROBLEM 2.5.38

If the magnitude of the x component of a 240-N force is three times as large as the magnitude of the y component and the force lies in the xy plane, determine all possible values of space angle θ_x.

GOAL : Find all possible space angles that describe the direction of the given force.

GIVEN : The force lies in the x-y plane. The magnitude of the force is 240 N, and the x-component of the force is three times larger than the y-component. Space angles are defined to between 0° and 180°.

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

$$\theta_{x,1} = \tan^{-1}\left(\frac{1}{3}\right) = 18.4^\circ$$

$$\theta_{x,2} = 180^\circ - \tan^{-1}\left(\frac{1}{3}\right) = 161.6^\circ$$

RESULTS : The possible space angles are:

$\theta_{x1} = 18.4^\circ$	$\theta_{y1} = 71.6^\circ$
$\theta_{x2} = 18.4^\circ$	$\theta_{y2} = 108.4^\circ$
$\theta_{x3} = 161.6^\circ$	$\theta_{y3} = 108.4^\circ$
$\theta_{x4} = 161.6^\circ$	$\theta_{y4} = 71.6^\circ$

CHECK : Review the rules for space angles, and verify calculations.

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PROBLEM 2.5.39

If the magnitude of the y component of a 25-lb force is five times as large as the magnitude of the x component and the force lies in the xy plane, determine all possible values of space angle θ_x.

GOAL : Find all possible space angles that describe the direction of the given force.

GIVEN : The force lies in the x-y plane. The magnitude of the force is 25 lb, and the y-component of the force is five times larger than the x-component. Space angles are defined to between 0° and 180°.

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

$$\theta_{x,1} = \tan^{-1}\left(\frac{5}{1}\right) = 78.7^\circ$$

$$\theta_{x,2} = 180^\circ - \tan^{-1}\left(\frac{5}{1}\right) = 101.3^\circ$$

RESULTS : The possible space angles are:

$\theta_{x1} = 78.7^\circ$	$\theta_{y1} = 11.3^\circ$
$\theta_{x2} = 78.7^\circ$	$\theta_{y2} = 168.7^\circ$
$\theta_{x3} = 101.3^\circ$	$\theta_{y3} = 168.7^\circ$
$\theta_{x4} = 101.3^\circ$	$\theta_{y4} = 11.3^\circ$

CHECK : Review the rules for space angles, and verify calculations.

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PROBLEM 2.5.40

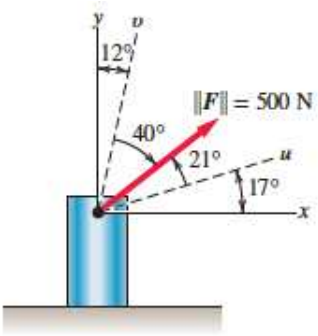
A 500-N force $\boldsymbol{F}$ is applied to the post shown.

a. Determine the magnitude of the x and y components of $\boldsymbol{F}$.

b. Determine the magnitude of the u and v components of $\boldsymbol{F}$.

c. Comment on whether the following are true or false mathematical statements:

$$\|\boldsymbol{F}\| = \sqrt{(F_x)^2+(F_y)^2}$$
$$\|\boldsymbol{F}\| = \sqrt{(F_u)^2+(F_v)^2}$$



GOAL : Find (a) the projection of the force onto the x-y coordinates, (b) the projection of the force on the u-v coordinates, (c) comment on the two given statements.

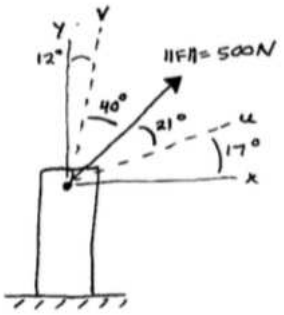
GIVEN : Magnitude and orientation with respect to two different coordinate systems of a force applied to a post. For (c), two mathematical statements are given:

$$||\boldsymbol{F}|| = \sqrt{(F_x)^2+(F_y)^2}$$

$$||\boldsymbol{F}|| = \sqrt{(F_u)^2+(F_v)^2}$$

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$F_x = (500\,\text{N})\cos(21^\circ+17^\circ) = 394.0\,\text{N}$$

$$F_y = (500\,\text{N})\cos(12^\circ+40^\circ) = 307.8\,\text{N}$$

RESULTS (a): The projection onto the x-y coordinates gives:

$$\boxed{\begin{aligned} F_x &= 394\,\text{N} \\ F_y &= 309\,\text{N} \end{aligned}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$F_u = (500\,\text{N})\cos(21^\circ) = 466.8\,\text{N}$$

$$F_v = (500\,\text{N})\cos(40^\circ) = 383.0\,\text{N}$$

RESULTS (b): The projection onto the u-v coordinates gives:

$$\boxed{\begin{aligned} F_u &= 467\,\text{N} \\ F_v &= 383\,\text{N} \end{aligned}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$\sqrt{(394.0\,\text{N})^2+(307.8\,\text{N})^2} = 499.98\,\text{N} \approx 500\,\text{N} \quad \text{True}$$

$$\sqrt{(466.8\,\text{N})^2+(383.0\,\text{N})^2} = 603.8\,\text{N} \neq 500\,\text{N} \quad \text{False}$$

RESULTS :

The first statement is true, the second is false.

This is because the u-v axes are not orthogonal.

CHECK : Step (c) verified that the magnitude of the force from (a) was correct. Check calcluations to verify part (b).

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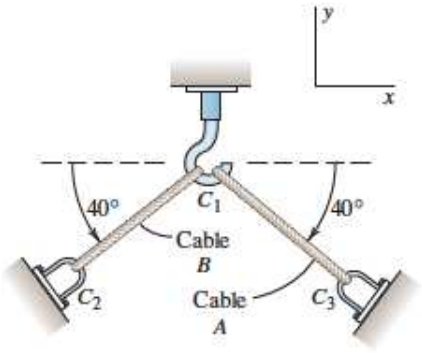
PROBLEM 2.5.41

Cables A and B act on the hook at C_1, as shown below. The tension in Cable A is 500 lb and the tension in Cable B is 400 lb. Express in Cartesian vector notation the force that Cable A applies on the hook at C_1.

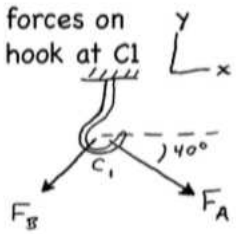


GOAL : Express the force of cable A acting at C_1 in vector notation.

GIVEN : Two cables at specified angles applied to a hook. The force in cable A is 500 lb and cable B is 400 lb.

ASSUME : The system is planar and that cable B is also at a 40° angle from the horizontal.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_x = 500\,\text{lb}\cos 40^\circ = 383.0\,\text{lb}$$

$$F_y = -500\,\text{lb}\sin 40^\circ = -321.4\,\text{lb}$$

RESULTS (a): The force of cable A on C_1 is:

$$\boxed{\boldsymbol{F}_{A,C_1} = (383\,\hat{\mathbf{i}} - 321\,\hat{\mathbf{j}})\,\text{lb}}$$

CHECK : Verify the magnitudes of the cable forces. $\|\boldsymbol{F}\| = \sqrt{F_x{}^2 + F_y{}^2}$

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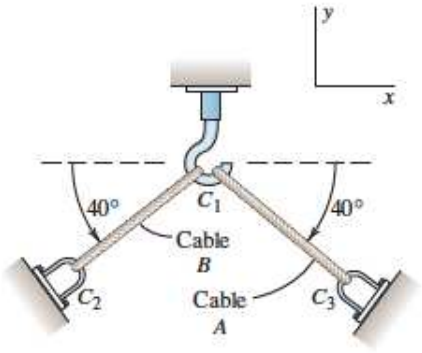
PROBLEM 2.5.42

Cables A and B act on the hook at C_1, as shown below. The tension in Cable A is 500 lb and the tension in Cable B is 400 lb. Express in Cartesian vector notation the force that Cable B applies on the bracket at C_2.

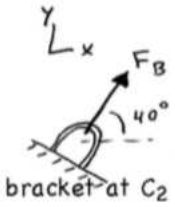


GOAL : Express the following in vector notation the force of cable B acting at C_2.

GIVEN : Two cables at specified angles applied to a hook. The force in cable A is 500 lb and cable B is 400 lb.

ASSUME : The system is planar and that cable B is also at a 40° angle from the horizontal.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_x = 400\,\text{lb}\cos 40^\circ = 306.4\,\text{lb}$$

$$F_y = 400\,\text{lb}\sin 40^\circ = 257.1\,\text{lb}$$

RESULTS (b): The force of cable B on C_2 is:

$$\boxed{\boldsymbol{F}_{B,C_2} = (306\,\hat{\mathbf{i}} + 257\,\hat{\mathbf{j}})\,\text{lb}}$$

CHECK : Verify the magnitudes of the cable forces. $\|\boldsymbol{F}\| = \sqrt{F_x{}^2 + F_y{}^2}$

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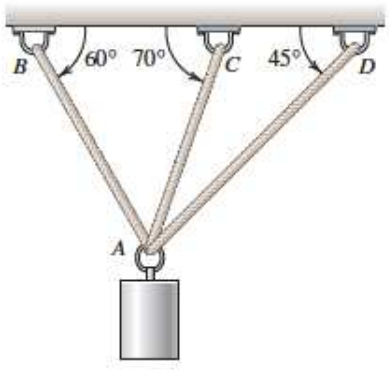
PROBLEM 2.5.43

The tension in the supporting cable AB is 20 kip. Write the cable tension force in vector notation.

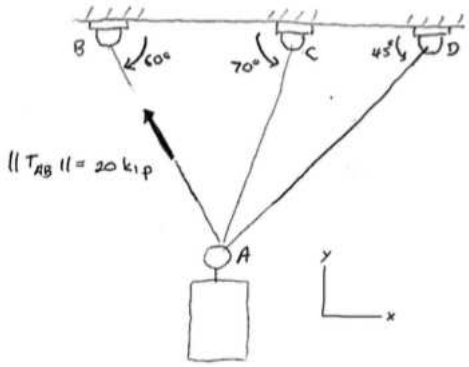


GOAL : To write the cable tension in vector notation.

GIVEN : The orientation of a cable and the magnitude ($\boldsymbol{T}_{AB} = 20\,\text{kip}$) of the tension in the cable.

ASSUME : Planar, with a standard xy coordinate system and the we are looking at the tension of the cable acting on A.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{T}_{AB} &= ||\boldsymbol{T}_{AB}||(-\cos 60^\circ\,\hat{\mathbf{i}} + \sin 60\,\hat{\mathbf{j}}) \\ &= (20\,\text{kip})(-0.5\,\hat{\mathbf{i}} + 0.866\,\hat{\mathbf{j}})\,\text{kip}\end{aligned}$$

RESULTS : (NOTE: the tension acting on B is the negative of $\boldsymbol{T}_{AB}$).

$$\boxed{\boldsymbol{T}_{AB} = (-10.0\,\hat{\mathbf{i}} + 17.3\,\hat{\mathbf{j}})\,\text{kip}}$$

CHECK : Verify that $\boldsymbol{T}_{AB} = 20\,\text{kip}$.

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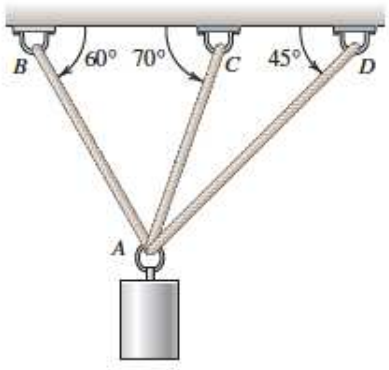
PROBLEM 2.5.44

The tension in the supporting cable AD is 10 kN. Write the cable tension force in vector notation.

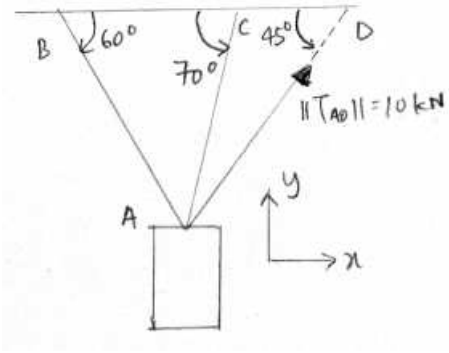


GOAL : To write the cable tension in vector notation.

GIVEN : The orientation of a cable, and the magnitude ($\boldsymbol{T}_{AD} = 10\,\text{kN}$) of the tension in the cable.

ASSUME : Planar, with a standard xy coordinate system, looking at the cable tension acting on A.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{T}_{AD} &= ||\boldsymbol{T}_{AD}||(\cos 45^\circ\,\hat{\mathbf{i}} + \sin 45\,\hat{\mathbf{j}}) \\ &= (10\,\text{kN})(0.707\,\hat{\mathbf{i}} + 0.707\,\hat{\mathbf{j}})\end{aligned}$$

RESULTS : (NOTE: the tension acting on D is the negative of $\boldsymbol{T}_{AD}$).

$$\boxed{\boldsymbol{T}_{AD} = (7.07\,\hat{\mathbf{i}} + 7.07\,\hat{\mathbf{j}})\,\text{kN}}$$

CHECK : Verify that $\boldsymbol{T}_{AD} = 10\,\text{kN}$.

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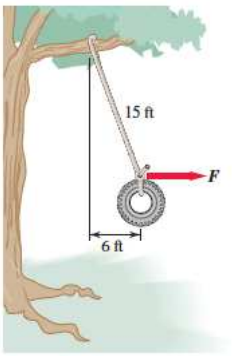
PROBLEM 2.5.45

A tire swing hanging on a 15 ft rope is pulled 6 ft to the side by a 22-lb horizontal force $\boldsymbol{F}$ as shown. The horizontal component of the force in the rope holding up the swing is equal $||\boldsymbol{F}||$. Determine the tension force holding up the swing, and write it in Cartesian vector notation.

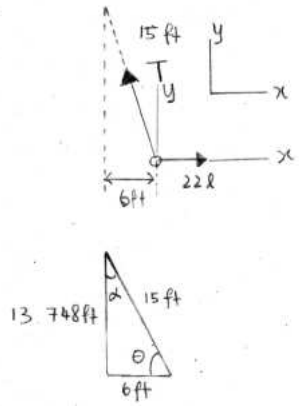


GOAL : To determine the tension force holding the tire and write it in Cartesian vector notation.

GIVEN : Magnitude of $||\boldsymbol{F}||$, geometry of the tire-rope system.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Using the triangle formed with the system and trigonometric relations, we can find the space angles of force $\boldsymbol{T}$. From the triangle, we can find θ and α.

$$\theta = \cos^{-1}(\frac{6}{15}) = 66.42^\circ$$

$$\alpha = \sin^{-1}(\frac{6}{15}) = 23.58^\circ$$

With that, we can get the space angles.

$$\theta_x = 180^\circ - \theta = 113.58^\circ$$

and

$$\theta_y = \alpha = 23.58^\circ$$

With that, we can get the unit vector along the line of action of $\boldsymbol{T}$.

$$\begin{aligned}\boldsymbol{u} &= \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}} \\ &= -0.400\,\hat{\mathbf{i}} + 0.917\,\hat{\mathbf{j}}\end{aligned}$$

We know that the horizontal component of $\boldsymbol{T}$ is equal to $||\boldsymbol{F}||$, which is 22 lb. This means

$$||\boldsymbol{T}||(0.400) = 22\,\text{lb} \tag{1}$$

RESULTS :
With equation (1), we can solve for $\boldsymbol{T}$. Then, we can solve for the vertical component to write $\boldsymbol{T}$ in the Cartesian vector notation. This gives

$$\boxed{\begin{aligned}\boldsymbol{T} &= 55\,\text{lb} \\ \boldsymbol{T} &= -22\,\text{lb}\,\hat{\mathbf{i}} + 50.4\,\text{lb}\,\hat{\mathbf{j}}\end{aligned}}$$

CHECK : Visually check the direction, and ensure the magnitudes of the forces are correct. We can also ensure the magnitude of the unit vector is 1.

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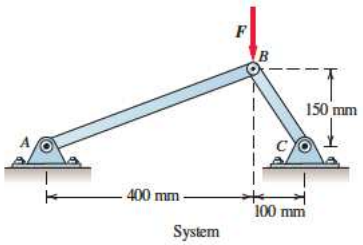
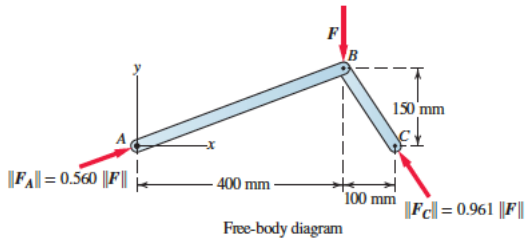
PROBLEM 2.5.46

The free-body diagram shows the forces acting on links *AB* and *BC*. Express each force in terms of its rectangular component vectors.



System



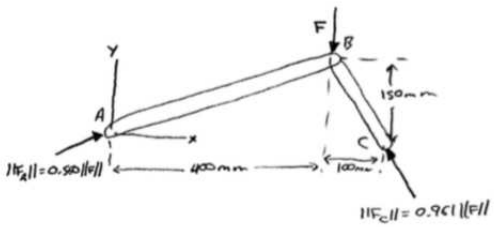
Free-body diagram

GOAL : Determine the rectangular components of the forces acting on the links.

GIVEN : Geometry of frame built of two links, and magnitudes and directions of forces acting on the links.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_{Ax} = ||\boldsymbol{F}_A|| \frac{400\,\text{mm}}{\sqrt{(400\,\text{mm})^2 + (150\,\text{mm})^2}} = 0.524||\boldsymbol{F}||$$

$$F_{Ay} = ||\boldsymbol{F}_A|| \frac{150\,\text{mm}}{\sqrt{(400\,\text{mm})^2 + (150\,\text{mm})^2}} = 0.197||\boldsymbol{F}||$$

$$F_{Cx} = ||\boldsymbol{F}_C|| \frac{-100\,\text{mm}}{\sqrt{(-100\,\text{mm})^2 + (150\,\text{mm})^2}} = -0.533||\boldsymbol{F}||$$

$$F_{Cy} = ||\boldsymbol{F}_C|| \frac{150\,\text{mm}}{\sqrt{(-100\,\text{mm})^2 + (150\,\text{mm})^2}} = 0.800||\boldsymbol{F}||$$

RESULTS :

$$\boldsymbol{F}_A = \boldsymbol{F}_{Ax} + \boldsymbol{F}_{Ay}$$
$$\boldsymbol{F}_A = 0.524||\boldsymbol{F}||\ \hat{\mathbf{i}} + 0.197||\boldsymbol{F}||\ \hat{\mathbf{j}}$$
$$\boldsymbol{F}_C = \boldsymbol{F}_{Cx} + \boldsymbol{F}_{Cy}$$
$$\boldsymbol{F}_C = -0.533||\boldsymbol{F}||\ \hat{\mathbf{i}} + 0.800||\boldsymbol{F}||\ \hat{\mathbf{j}}$$

CHECK : Ensure that $\sqrt{F_x^2 + F_y^2} = \|F\|$.

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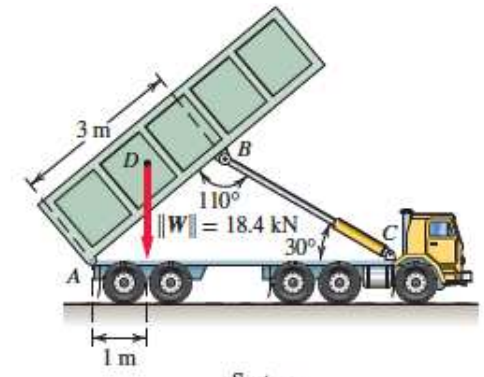
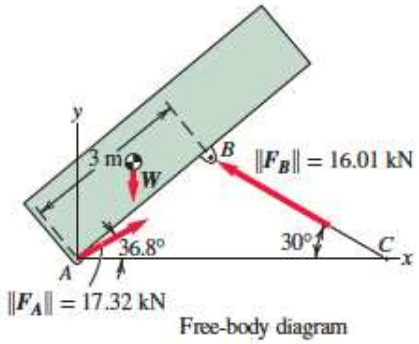
PROBLEM 2.5.47

The free-body diagram shows the forces acting on the bed of a dump truck. Express each force in terms of its rectangular component vectors.



System



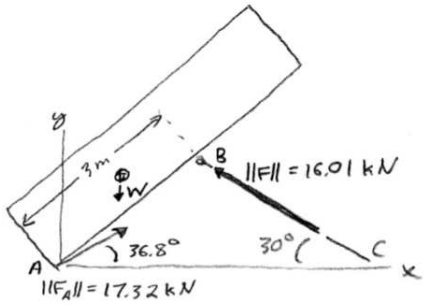
Free-body diagram

GOAL : Determine the rectangular components of the given forces.

GIVEN : The magnitude, orientation and point of application of forces acting on the bed of a dump truck.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$F_{Ax} = ||\boldsymbol{F}_A|| \cos 36.8^\circ = (17.32\,\text{kN}) \cos 36.8^\circ = 13.87\,\text{kN}$$

$$F_{Ay} = ||\boldsymbol{F}_A|| \sin 36.8^\circ = (17.32\,\text{kN}) \sin 36.8^\circ = 10.38\,\text{kN}$$

$$F_{Bx} = ||\boldsymbol{F}_B|| \cos 30^\circ = (-16.01\,\text{kN}) \cos 30^\circ = -13.87\,\text{kN}$$

$$F_{By} = ||\boldsymbol{F}_B|| \sin 30^\circ = (16.01\,\text{kN}) \sin 30^\circ = 8.01\,\text{kN}$$

RESULTS :

$$\boldsymbol{F}_A = \boldsymbol{F}_{Ax} + \boldsymbol{F}_{Ay}$$
$$\boldsymbol{F}_A = 13.87\,\text{kN}\ \hat{\mathbf{i}} + 10.38\,\text{kN}\ \hat{\mathbf{j}}$$
$$\boldsymbol{F}_B = \boldsymbol{F}_{Bx} + \boldsymbol{F}_{By}$$
$$\boldsymbol{F}_B = -13.87\,\text{kN}\ \hat{\mathbf{i}} + 8.01\,\text{kN}\ \hat{\mathbf{j}}$$

CHECK : Verify calculations and ensure the magnitudes of the two forces are preserved.

$$||\boldsymbol{F}_A|| = \sqrt{(F_{Ax})^2 + (F_{Ay})^2}$$
$$= \sqrt{(-13.87\,\text{kN})^2 + (8.01\,\text{kN})^2} = 17.32\,\text{kN}$$
$$||\boldsymbol{F}_B|| = \sqrt{(F_{Bx})^2 + (F_{By})^2}$$
$$= \sqrt{(13.87\,\text{kN})^2 + (10.38\,\text{kN})^2} = 16.01\,\text{kN}$$

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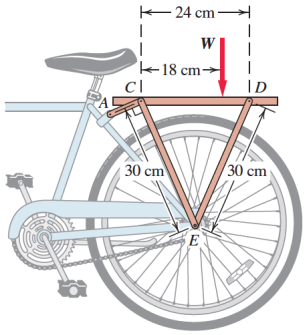
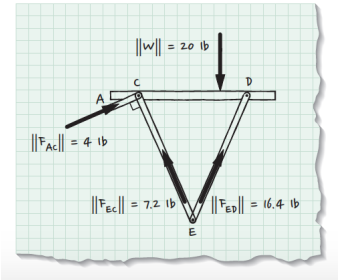
PROBLEM 2.5.48

The free-body diagram shows the forces acting on a bike rack. Express each force in terms of its rectangular component vectors.



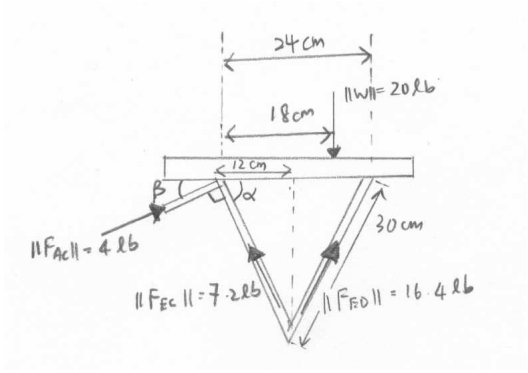


GOAL : Determine the rectangular components of the given forces.

GIVEN : The magnitude, orientation and point of application of forces acting on a bike rack.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

To obtain the geometry of the system.

$$\begin{aligned}\cos\alpha &= \frac{12\text{cm}}{30\text{cm}}\\ &= 66.42^\circ\\ \beta &= 180^\circ - 90^\circ - 66.42^\circ\\ &= 23.58^\circ\end{aligned}$$

After that, we write each for in vector notations.

$$\begin{aligned}\boldsymbol{F}_{AC} &= 4\,\text{lb}\cos 23.58^\circ\,\hat{\mathbf{i}} + 4\,\text{lb}\sin 23.58^\circ\,\hat{\mathbf{j}}\\ \boldsymbol{F}_{EC} &= -7.2\,\text{lb}\cos 66.42^\circ\,\hat{\mathbf{i}} + 7.2\,\text{lb}\sin 66.42^\circ\,\hat{\mathbf{j}}\\ \boldsymbol{F}_{ED} &= 16.4\,\text{lb}\cos 66.42^\circ\,\hat{\mathbf{i}} + 16.4\,\text{lb}\sin 66.42^\circ\,\hat{\mathbf{j}}\end{aligned}$$

RESULTS :

$$\boxed{\begin{aligned}\boldsymbol{F}_{AC} &= 3.67\,\text{lb}\,\hat{\mathbf{i}} + 1.600\,\text{lb}\,\hat{\mathbf{j}}\\ \boldsymbol{F}_{EC} &= -2.88\,\text{lb}\,\hat{\mathbf{i}} + 6.60\,\text{lb}\,\hat{\mathbf{j}}\\ \boldsymbol{F}_{ED} &= 6.56\,\text{lb}\,\hat{\mathbf{i}} + 15.03\,\text{lb}\,\hat{\mathbf{j}}\end{aligned}}$$

CHECK : Ensure the calculations are correct.

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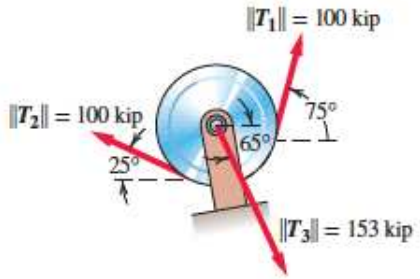
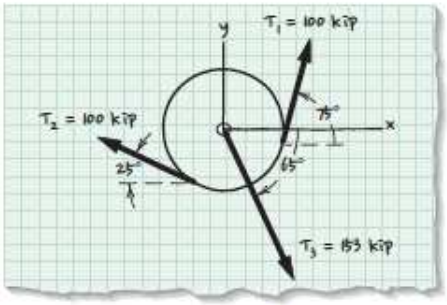
PROBLEM 2.5.49

The free-body diagram shows the forces acting on a frictionless pulley. Express each force in terms of its rectangular component vectors.



System



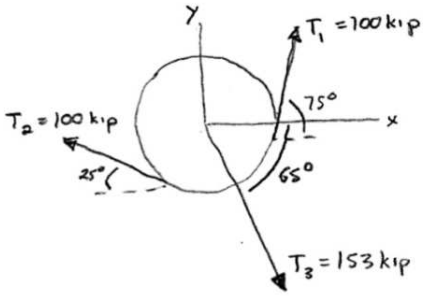
Free-body diagram

GOAL : Express each force in terms of its rectangular component vectors.

GIVEN : The free-body diagram of a pulley.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$
\begin{aligned}
T_{1x} &= 100\,\text{kip}(\cos 75^\circ) = 25.88\,\text{kip} \\
T_{1y} &= (100\,\text{kip})\sin 75^\circ = 96.59\,\text{kip} \\
T_{2x} &= (-100\,\text{kip})\cos 25^\circ = -90.63\,\text{kip} \\
T_{2y} &= (100\,\text{kip})\sin 25^\circ = 42.26\,\text{kip} \\
T_{3x} &= (153\,\text{kip})\cos 65^\circ = 64.66\,\text{kip} \\
T_{3y} &= (-153\,\text{kip})\sin 65^\circ = -138.67\,\text{kip}
\end{aligned}
$$

RESULTS :

$$
\begin{aligned}
&\boldsymbol{T}_1 = \boldsymbol{T}_{1x} + \boldsymbol{T}_{1y} \\
&\boldsymbol{T}_1 = 25.9\,\text{kip}\ \hat{\mathbf{i}} + 96.6\,\text{kip}\ \hat{\mathbf{j}} \\
&\boldsymbol{T}_2 = \boldsymbol{T}_{2x} + \boldsymbol{T}_{2y} \\
&\boldsymbol{T}_2 = -90.6\,\text{kip}\ \hat{\mathbf{i}} + 42.3\,\text{kip}\ \hat{\mathbf{j}} \\
&\boldsymbol{T}_3 = \boldsymbol{T}_{3x} + \boldsymbol{T}_{3y} \\
&\boldsymbol{T}_3 = 64.7\,\text{kip}\ \hat{\mathbf{i}} - 138.7\,\text{kip}\ \hat{\mathbf{j}}
\end{aligned}
$$

CHECK : Verify the magnitude of each force using $\sqrt{T_x^2 + T_y^2}$.

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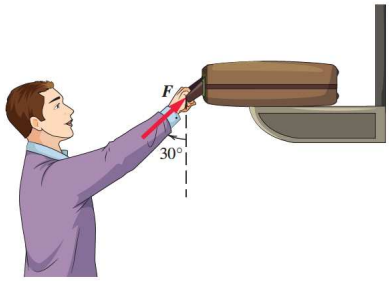
PROBLEM 2.5.50

The airline passenger is pushing a suitcase into an overhead bin. The vertical component of the pushing force is 20 lb.

a. What is the total force $\boldsymbol{F}$ the passenger is pushing with?

b. Write the force $\boldsymbol{F}$ in Cartesian vector notation.

c. Assuming the vertical component remains the same, how does $\boldsymbol{F}$ change, if the passenger increases his arm angle to 45°

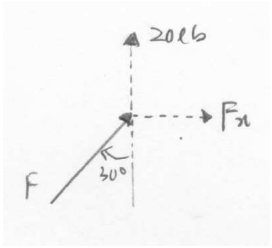


GOAL : To (a) find the total force $\boldsymbol{F}$ the passenger is pushing with, (b) write $\boldsymbol{F}$ in Cartesian vector notation and (c) find out how $\boldsymbol{F}$ changes when the passenger increases his arm angle to 45°.

GIVEN : The magnitude of the vertical component of the force and the dimension of the force.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

We know that

$$\begin{aligned}\boldsymbol{F} &= F_x\,\hat{\mathbf{i}} + F_y\,\hat{\mathbf{j}} \\ &= F_x\,\hat{\mathbf{i}} + 20\,\text{lb}\,\hat{\mathbf{j}}\end{aligned}$$

We can also write

$$\boldsymbol{F} = ||\boldsymbol{F}||(\sin 30^\circ\,\hat{\mathbf{i}} + \cos 30^\circ\,\hat{\mathbf{j}})$$

With that, we can write,

$$||\boldsymbol{F}||\cos 30^\circ = 20\,\text{lb}$$

RESULTS (a):

$$\boxed{||\boldsymbol{F}|| = 23.1\,\text{lb}}$$

RESULTS (b):

$$\boxed{\boldsymbol{F} = 11.55\,\text{lb}\,\hat{\mathbf{i}} + 20\,\text{lb}\,\hat{\mathbf{j}}}$$

RESULTS (c):

If θ is increased 45°,
$\boldsymbol{F}$ will increase (based on
the vertical component equation).

CHECK : Ensure the calculations were done correctly.

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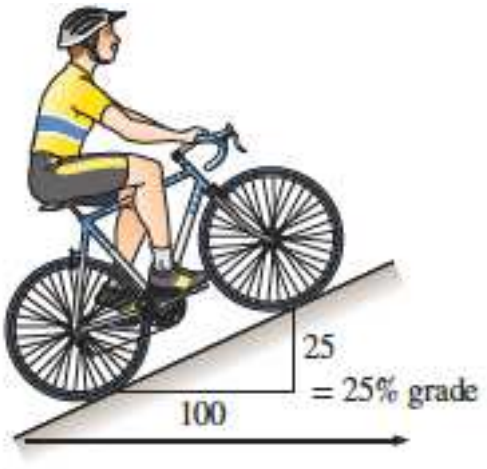
PROBLEM 2.5.51

The bicycle and cyclist below have a combined weight of 200 lb. As the bicycle moves up the 25% grade, how much of the 200-lb gravity force is directed down the incline? How much is directed perpendicular to the incline? "Percent grade" defines the rise (upward movement) relative to the run (horizontal movement). For example, for a 25% grade, for every 100 ft of horizontal movement (run) there is 25 ft of upward movement (rise).

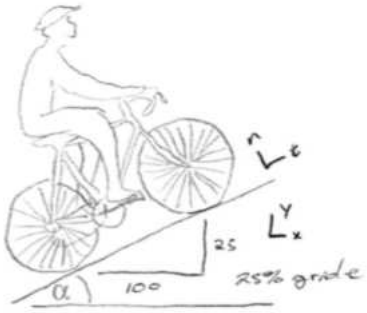


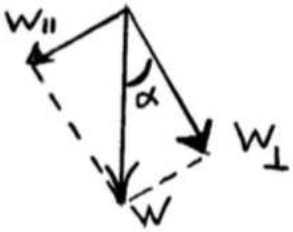
GOAL : To determine the components of the gravity force parallel and perpendicular to the slope.

GIVEN : The weight of the bike and rider (200 lb), slope of the incline.

ASSUME : Gravity acts downward.

DRAW :





FORMULATE EQUATIONS and **SOLVE** :

$$\alpha = \tan^{-1}(0.25) = 14.04^\circ$$

$$W_{\parallel} = (200\,\text{lb})\sin\alpha = 48.51\,\text{lb}$$

$$W_{\perp} = (200\,\text{lb})\cos\alpha = 194.03\,\text{lb}$$

RESULTS :

$W_{\parallel} = 48.5\,\text{lb}$ (down the incline)
$W_{\perp} = 194.0\,\text{lb}$ (perpendicular to the incline)

CHECK : Ensure the magnitude of the gravity force $\sqrt{W_{\parallel}^2 + W_{\perp}^2} = 200$ lb, and check intuition. For example does it make sense that $W_{\parallel} < W_{\perp}$?

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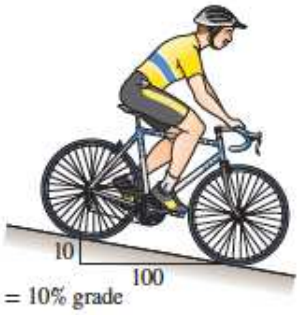
PROBLEM 2.5.52

The bicycle and cyclist have a combined weight of 200 lb. As the bicycle moves down the 10% grade how much of the 200 lb gravity force is directed down the incline? How much is directed perpecdicular to the incline?

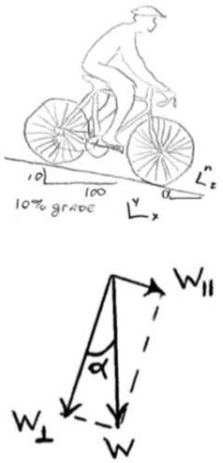


GOAL : To determine the components of the gravity force parallel and perpendicular to the slope.

GIVEN : The weight of the bike and rider (200 lb), slope of the incline.

ASSUME : Gravity acts downward.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\alpha = \tan^{-1}(0.10) = 5.71^\circ$$

$$W_{\parallel} = (200\,\text{lb})\sin\alpha = 19.90\,\text{lb}$$

$$W_{\perp} = (200\,\text{lb})\cos\alpha = 199.01\,\text{lb}$$

RESULTS :

$W_{\parallel} = 19.9\,\text{lb}$ (down the incline)

$W_{\perp} = 199.0\,\text{lb}$ (perpendicular to the incline)

CHECK : Ensure the magnitude of the gravity force $\sqrt{W_{\parallel}^2 + W_{\perp}^2} = 200$ lb, and check intuition. For example does it make sense that $W_{\parallel} < W_{\perp}$?

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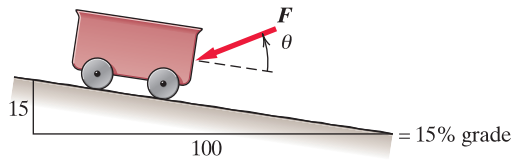
PROBLEM 2.5.53

A cart weighing 400 N is pushed up a 15% grade at a constant speed by the force $\boldsymbol{F}$ shown. Find the scalar components of the 400-N cartweight that are parallel and perpendicular to the slope. "Percent grade" defines the rise (upward movement) relative to the run (horizontal movement). For example, for a 15% grade, for every 100 m of horizontal movement (run) there is 15 m of upward movement (rise).

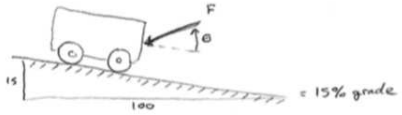


GOAL : To find the scalar components of the force of gravity on the cart parallel and perpendicular to the slope.

GIVEN : Sketch of a cart weighing 400 N on a 15% slope.

ASSUME : Gravity acts downward.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\alpha = \tan^{-1}\left(\frac{15}{100}\right) = 8.53^\circ$$

$$W_{\parallel} = (400\,\text{N})\sin\alpha = 59.3\ \text{N}$$

$$W_{\perp} = (400\,\text{N})\cos\alpha = 395.6\ \text{N}$$

RESULTS :

$$\boxed{\begin{aligned} W_{\parallel} &= 59.3\,\text{N} \\ W_{\perp} &= 396\,\text{N} \end{aligned}}$$

CHECK : Intuition confirms that the perpendicular force should be much larger, which is true.
Verify $\|\boldsymbol{W}\| = 400$ N.

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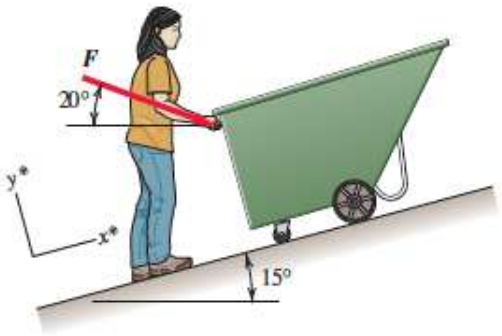
PROBLEM 2.5.54

In order to move a refuse container up a ramp at a constant velocity, a worker applies a 250-N force $\boldsymbol{F}$, as shown. Determine the components of $\boldsymbol{F}$ that are parallel to the ramp (x^* direction) and normal to the ramp (y^* direction).

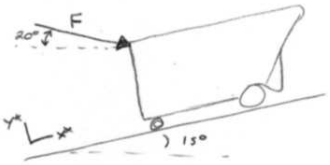


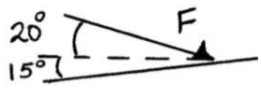
GOAL : Determine the components of the force parallel and perpendicular to the ramp.

GIVEN : Person exerts a force of 250 N at an angle of 20° to the horizontal. Slope of ramp is 15°

ASSUME : Planar.

DRAW :





FORMULATE EQUATIONS and **SOLVE** :

$$F_{\parallel} = (250\,\text{N})\cos(20^\circ + 15^\circ) = 204.8\ \text{N}$$

$$F_{\perp} = (250\,\text{N})\sin(20^\circ + 25^\circ) = 143.4\ \text{N}$$

RESULTS :

$F_{\parallel} = 205$ N (up the slope)

$F_{\perp} = 143$ N (perpendicular to the slope, in the negative y^*-direction)

CHECK : Ensure the magnitude of the applied force $\sqrt{F_{\parallel}^2 + F_{\perp}^2} = 250$ lb, and check intuition. For example does it make sense that $F_{\parallel} > F_{\perp}$?

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PROBLEM 2.5.55

Review the list of forces in the table shown.

a. Which of the forces in the table have the same magnitude?

b. Which items in the table represent the same force?

Item	Force
(1)	$\boldsymbol{F} = 28\ \text{kN}\boldsymbol{i} + 18\ \text{kN}\boldsymbol{j} - 38\ \text{kN}\boldsymbol{k}$
(2)	$\|\boldsymbol{F}\| = 50.5\ \text{kN}$, $\cos\theta_x = -0.554$, $\cos\theta_y = 0.356$, $\cos\theta_z = 0.752$
(3)	$\|\boldsymbol{F}\| = 50.5\ \text{kN}$, $\theta_x = 56.4°$, $\theta_y = 69.1°$ $\theta_z = 138.8°$
(4)	$\boldsymbol{F} = -28\ \text{kN}\boldsymbol{i} + 18\ \text{kN}\boldsymbol{j} + 38\ \text{kN}\boldsymbol{k}$
(5)	$\|\boldsymbol{F}\| = 50.5\ \text{kN}$, $\cos\theta_x = 0.554$, $\cos\theta_y = 0.356$, $\cos\theta_z = -0.752$
(6)	$\|\boldsymbol{F}\| = 50.5\ \text{kN}$, $\theta_x = 124°$, $\theta_y = 69.1°$, $\theta_z = 41.2°$

GOAL : Determine which of the given forces are the same and which of them have the same magnitude.

GIVEN : A table of forces.

ASSUME : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

Find the magnitude and direction cosines for each force:

(1)

$$\|\boldsymbol{F}\| = \sqrt{(28\ \text{kN})^2 + (18\ \text{kN})^2 + (-38\ \text{kN})^2} = 50.5\ \text{kN}$$

$$\cos\theta_x = \frac{28}{50.5} = 0.554$$

$$\cos\theta_y = \frac{18}{50.5} = 0.356$$

$$\cos\theta_z = \frac{-38}{50.5} = -0.752$$

(2)

$$\|\boldsymbol{F}\| = 50.5\ \text{kN}$$

$$\cos\theta_x = -0.554$$

$$\cos\theta_y = 0.356$$

$$\cos\theta_z = 0.752$$

(3)

$$\|\boldsymbol{F}\| = 50.5\ \text{kN}$$

$$\cos\theta_x = \cos 56.4° = 0.553$$

$$\cos\theta_y = \cos 69.1° = 0.356$$

$$\cos\theta_z = \cos 138.8° = -0.752$$

(4)

$$\|\boldsymbol{F}\| = \sqrt{(-28\ \text{kN})^2 + (18\ \text{kN})^2 + (38\ \text{kN})^2} = 50.5\ \text{kN}$$

$$\cos\theta_x = \frac{-28}{50.5} = -0.554$$

$$\cos\theta_y = \frac{18}{50.5} = 0.356$$

$$\cos\theta_z = \frac{38}{50.5} = 0.752$$

(5)

$$\|\boldsymbol{F}\| = 50.5\ \text{kN}$$

$$\cos\theta_x = 0.554$$

$$\cos\theta_y = 0.356$$

$$\cos\theta_z = -0.752$$

(6)

$$\|\boldsymbol{F}\| = 50.5\ \text{kN}$$

$$\cos\theta_x = \cos 124° = -0.559$$

$$\cos\theta_y = \cos 69.1° = 0.356$$

$$\cos\theta_z = \cos 41.2° = 0.752$$

RESULTS (a): The following forces have the same magnitude

1, 2, 3, 4, 5, 6

RESULTS (b): The following set of forces are the same

1, 3, and 5 are the same
2, 4, and 6 are the same

CHECK : Verify calculations. For thoroughness, one could also express each vector in an alternate form (i.e., vector notation).

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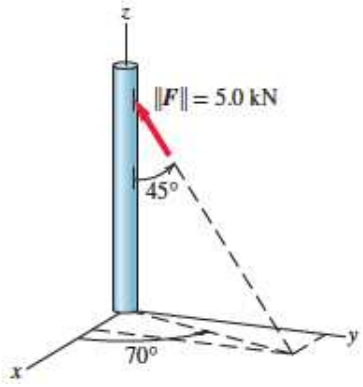
PROBLEM 2.5.56

A 5.0-kN force $\boldsymbol{F}$ acts on the vertical pole shown.

a. Determine the unit vector $\boldsymbol{u}$ along the line of action of $\boldsymbol{F}$ in terms of right-handed orthogonal unit vectors $\boldsymbol{i}, \boldsymbol{j}$ and $\boldsymbol{k}$.

b. Express $\boldsymbol{F}$ in Cartesian vector notation (use your answer from **a** as the starting point).

c. Find the space angles that describe the direction of $\boldsymbol{F}$.

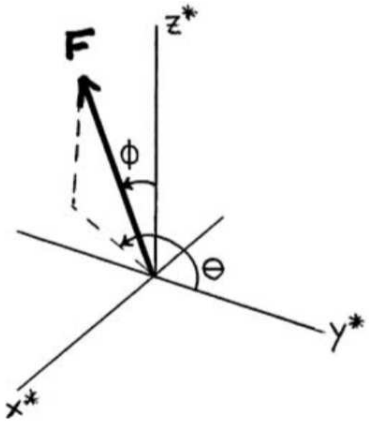


GOAL : Determine (a) the unit vector along $\boldsymbol{F}$, (b) expression for $\boldsymbol{F}$ in vector notation, and (c) the space angles.

GIVEN : Magnitude and orientation of non-planar force, a coordinate system.

ASSUME : None necessary.

DRAW : Draw $\boldsymbol{F}$ relative to a coordinate system with its origin on the line of action of $\boldsymbol{F}$ to identify ϕ and θ. We'll call this x^*, y^*, z^*.



FORMULATE EQUATIONS and **SOLVE** (a):

Using (4.7A) and (4.11):

$$\begin{aligned}\cos\theta_x &= (\sin\phi)(\cos\theta)\\ &= (\sin 45^\circ)(\cos(180^\circ + 70^\circ)) = -0.242\end{aligned}$$

$$\begin{aligned}\cos\theta_y &= (\sin\phi)(\sin\theta)\\ &= (\sin 45^\circ)(\sin(180^\circ + 70^\circ)) = -0.664\end{aligned}$$

$$\cos\theta_z = \cos\phi = \cos 45^\circ = 0.707$$

$$\begin{aligned}\hat{\boldsymbol{u}} &= \cos\theta_x\,\hat{\mathbf{i}} + \cos\theta_y\,\hat{\mathbf{j}} + \cos\theta_z\,\hat{\mathbf{k}}\\ &= -0.242\,\hat{\mathbf{i}} - 0.664\,\hat{\mathbf{j}} + 0.707\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS (a): The unit vector along $\boldsymbol{F}$ is:

$$\boxed{\hat{\boldsymbol{u}} = -0.242\,\hat{\mathbf{i}} - 0.664\,\hat{\mathbf{j}} + 0.707\,\hat{\mathbf{k}}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}\boldsymbol{F} &= ||\boldsymbol{F}||\boldsymbol{u} = 5\,\text{kN}(-0.242\,\hat{\mathbf{i}} - 0.664\,\hat{\mathbf{j}} + 0.707\,\hat{\mathbf{k}})\\ &= (-1.21\,\hat{\mathbf{i}} - 3.32\,\hat{\mathbf{j}} + 3.54\,\hat{\mathbf{k}})\,\text{kN}\end{aligned}$$

RESULTS (b): The force in vector notation:

$$\boxed{\boldsymbol{F} = (-1.21\,\hat{\mathbf{i}} - 3.32\,\hat{\mathbf{j}} + 3.54\,\hat{\mathbf{k}})\,\text{kN}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$\theta_x = \cos^{-1}((\sin\phi)(\cos\theta)) = \cos^{-1}(-0.242) = 104.0^\circ$$
$$\theta_y = \cos^{-1}((\sin\phi)(\sin\theta)) = \cos^{-1}(-0.664) = 131.6^\circ$$
$$\theta_z = \cos^{-1}(\cos\phi)) = 45.0^\circ$$

RESULTS (c): The space angles are:

$$\boxed{\begin{aligned}\theta_x &= 104^\circ\\ \theta_y &= 132^\circ\\ \theta_z &= 45.0^\circ\end{aligned}}$$

CHECK : Ensure the magnitude of the unit vector is 1 and that the direction is correct.

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PROBLEM 2.5.57

A break dancer is performing a trick in which he balances his entire body on one arm as shown. A compressive force $\boldsymbol{F}$ of magnitude 190 lb acts in his upper arm along a line defined by A at his elbow and B at his shoulder. Use Cartesian vector notation to express the compressive force acting on his shoulder at B.

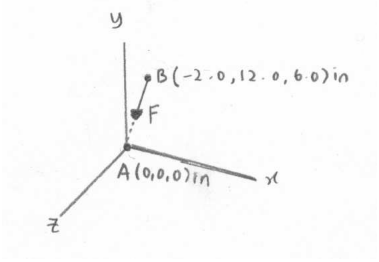
Notorious91/Getty Images

GOAL : Express the force at the shoulder in Cartesian notation.

GIVEN : Magnitude and orientation of non-planar force, a coordinate system.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE**

First we obtain the unit vector $\boldsymbol{u}_{AB}$

$$\begin{aligned}\boldsymbol{BA} &= \sqrt{(0-(-2.0\text{in}))^2+(0-12.0\text{in})^2+(0-6.0\text{in})^2}\\ &= 13.56\text{in}\\ \boldsymbol{u}_{BA} &= \frac{0-(-2.0\text{in})}{13.56\text{in}}\,\hat{\mathbf{i}}+\frac{(0-12.0\text{in})}{13.56\text{in}}\,\hat{\mathbf{j}}+\frac{(0.6.0\text{in})}{13.56\text{in}}\,\hat{\mathbf{k}}\\ &= 0.1475\,\hat{\mathbf{i}}-0.8850\,\hat{\mathbf{j}}-0.4425\,\hat{\mathbf{k}}\end{aligned}$$

To express the force in Cartesian notation, we multiply the unit vector with the magnitude of the force.

$$\boldsymbol{F} = ||\boldsymbol{F}||\boldsymbol{u}_{BA}$$

RESULTS

$$\boxed{\boldsymbol{F} = 28.0\,\text{lb}\,\hat{\mathbf{i}} - 168.2\,\text{lb}\,\hat{\mathbf{j}} - 84.1\,\text{lb}\,\hat{\mathbf{k}}}$$

CHECK : Ensure the magnitude of the unit vector is 1 and that the direction is correct.

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PROBLEM 2.5.58

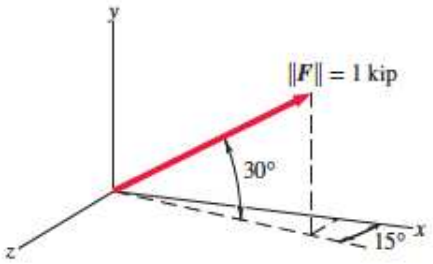
Consider the 1-kip force $\boldsymbol{F}$ shown below. Write this force

a. in terms of a unit vector along the line of action of $\boldsymbol{F}$, and a magnitude

b. in Cartesian vector notation

c. as magnitude and space angles

d. in terms of its magnitude and the angles θ and ϕ.

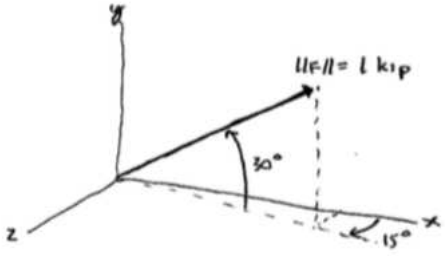


GOAL : Determine (a) the unit vector along $\boldsymbol{F}$, (b) vector notation for $\boldsymbol{F}$, (c) the magnitude and space angles, and (d) the magnitude and angles θ and ϕ.

GIVEN : Magnitude and orientation of non-planar force, a coordinate system.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\hat{\boldsymbol{u}} = \cos 30^\circ \cos 15^\circ \,\hat{\mathbf{i}} + \sin 30^\circ \,\hat{\mathbf{j}} + \cos 30^\circ \sin 15^\circ \,\hat{\mathbf{k}}$$
$$= 0.837\,\hat{\mathbf{i}} + 0.500\,\hat{\mathbf{j}} + 0.224\,\hat{\mathbf{k}}$$

RESULTS (a): The unit vector is:

$$\boxed{\hat{\boldsymbol{u}} = 0.837\,\hat{\mathbf{i}} + 0.500\,\hat{\mathbf{j}} + 0.224\,\hat{\mathbf{k}}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\boldsymbol{F} = \|\boldsymbol{F}\|(\boldsymbol{u}) = (0.837\,\hat{\mathbf{i}} + 0.500\,\hat{\mathbf{j}} + 0.224\,\hat{\mathbf{k}}) \text{ kip}$$

RESULTS (b): The force in vector notation is:

$$\boxed{\boldsymbol{F} = (0.837\,\hat{\mathbf{i}} + 0.500\,\hat{\mathbf{j}} + 0.224\,\hat{\mathbf{k}}) \text{ kip}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$\theta_x = \cos^{-1}(\hat{\boldsymbol{u}}_x) = 33.23^\circ$$
$$\theta_y = 60^\circ$$
$$\theta_z = \cos^{-1}(\hat{\boldsymbol{u}}_z) = 77.05^\circ$$

RESULTS (c): The magnitude and space angles are:

$$\boxed{\begin{aligned} \|\boldsymbol{F}\| &= 1 \text{ kip} \\ \theta_x &= 33.2^\circ \\ \theta_y &= 60.0^\circ \\ \theta_z &= 77.1^\circ \end{aligned}}$$

FORMULATE EQUATIONS and **SOLVE** (d):

Using (7.4B):

$$\theta = \tan^{-1}\left(\frac{\cos\theta_y}{\cos\theta_x}\right) = \tan^{-1}\left(\frac{\cos 60^\circ}{\cos 33.23^\circ}\right)$$
$$= \tan^{-1}\left(\frac{0.500}{0.837}\right) = 30.87^\circ$$
$$\phi = \theta_z = 77.05^\circ$$

RESULTS (d): The magnitude and angles θ and ϕ are:

$$\boxed{\begin{aligned} \|\boldsymbol{F}\| &= 1 \text{ kip} \\ \theta &= 30.9^\circ \\ \phi &= 77.1^\circ \end{aligned}}$$

CHECK : Verify visually (noting the orientation of axes), and verify magnitudes.

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PROBLEM 2.5.59

The x, y, and z scalar components of a 140-lb force are in the proportion of $3:-2:6$. Determine these components and the space angles between the force and the reference axes.

GOAL : Determine the components and space angles of a given non-planar force.

GIVEN : The x, y, and z scalar components of a 140-lb force are in the proportion 3:-2:6.

ASSUME : None necessary.

DRAW : None necessary

FORMULATE EQUATIONS and **SOLVE** :

$$F_x = ||\boldsymbol{F}|| \frac{3}{\sqrt{3^2+(-2)^2+6^2}} = 60.0\,\text{lb}$$

$$F_y = ||\boldsymbol{F}|| \frac{-2}{\sqrt{3^2+(-2)^2+6^2}} = -40.0\,\text{lb}$$

$$F_z = ||\boldsymbol{F}|| \frac{6}{\sqrt{3^2+(-2)^2+6^2}} = 120\,\text{lb}$$

$$\theta_x = \cos^{-1}\left(\frac{3}{\sqrt{3^2+(-2)^2+6^2}}\right) = 64.62^\circ$$

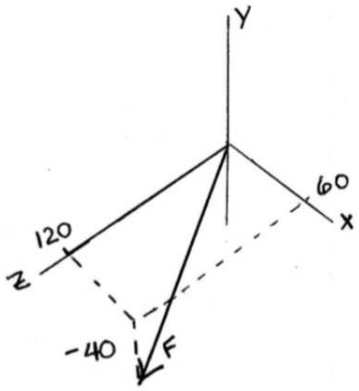
$$\theta_y = \cos^{-1}\left(\frac{-2}{\sqrt{3^2+(-2)^2+6^2}}\right) = 106.6^\circ$$

$$\theta_z = \cos^{-1}\left(\frac{6}{\sqrt{3^2+(-2)^2+6^2}}\right) = 31.0^\circ$$

RESULTS :

$F_x = 60.0\,\text{lb}$	$\theta_x = 64.6^\circ$
$F_y = -40.0\,\text{lb}$	$\theta_y = 106.6^\circ$
$F_z = 120.0\,\text{lb}$	$\theta_z = 31.0^\circ$

CHECK : Verify the magnitude. A simple sketch can also help to verify that the angles are correct.



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PROBLEM 2.5.60

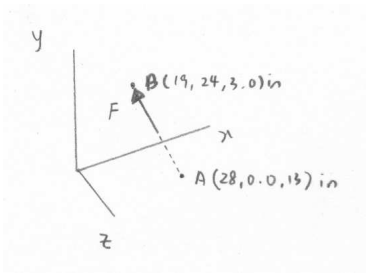
A gold bag filled with clubs leans on two legs as shown. Assume the bag is symmetrical about the xy plane and the force pushing on the bag at B acts along the line of action of leg AB. If the maximum total force each leg can support without failing is 100 lb, determine the maximum vertical force that two legs can exert on the bag.

GOAL : Determine the maximum vertical force that the two legs can exert on a golf bag.

GIVEN : The coordinates and the magnitude of the force along one of the legs.

ASSUME : Both legs are made of the same materials and they are the same geometrical wise.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

We will first obtain the unit vector along the leg.

$$\boldsymbol{AB} = \sqrt{(19\text{in}-28\text{in})^2+(24\text{in}-0)^2+(3\text{in}-13\text{in})^2}$$
$$= 27.51\text{in}$$
$$\boldsymbol{u}_{AB} = \frac{(19\text{in}-28\text{in})}{27.51\text{in}}\,\hat{\mathbf{i}} + \frac{(24\text{in}-0)}{27.51\text{in}}\,\hat{\mathbf{j}} + \frac{(3\text{in}-13\text{in})}{27.51\text{in}}$$
$$= -0.3272\,\text{lb}\,\hat{\mathbf{i}} + 87.24\,\text{lb}\,\hat{\mathbf{j}} - 36.35\,\text{lb}\,\hat{\mathbf{k}}$$

RESULTS : Assuming both legs are the same, and because we are told the golf bag is symmetrical, we can say that the maximum vertical force that the two legs can exert is

$$\boxed{\text{Maximum vertical force} = (87.24\,\text{lb})(2) = 174.5\,\text{lb}}$$

CHECK : Verify the magnitude.

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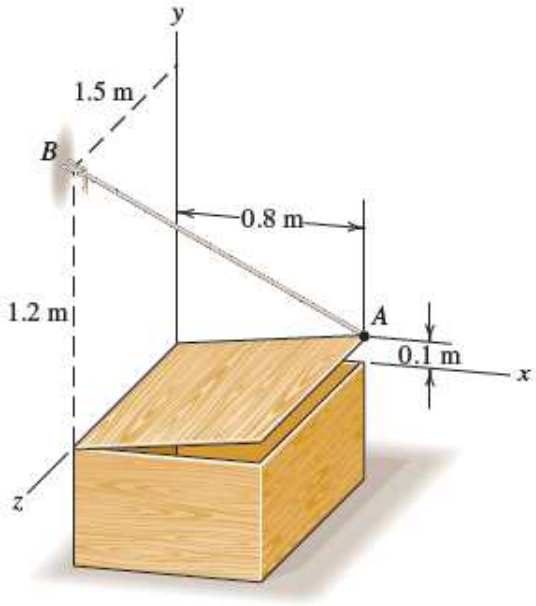
PROBLEM 2.5.61

The lid of the wooden crate below is held open by a rope attached at corner A and hooked to the wall at B. The tension in the rope is 30 N.

a. Write an expression for the rope force pulling on the lid at A. Call this force $\boldsymbol{F_1}$.

b. Write an expression for the rope force pulling on the wall at B. Call this force $\boldsymbol{F_2}$.

c. Show that $\boldsymbol{F_1} = -\boldsymbol{F_2}$.



GOAL : (a) Write an expression for the rope force $\boldsymbol{F}_1$ pulling on the lid at A, (b) write and expression for the rope force $\boldsymbol{F}_2$ pulling on the wall at B, and (c) show that $\boldsymbol{F}_1$ = -$\boldsymbol{F}_2$.

GIVEN : Dimensions of the wooden crate and rope, a coordinate system, the tension in the rope (30 N).

ASSUME : None necessary.

DRAW :

FORMULATE EQUATIONS and **SOLVE** (a):

$$\begin{aligned}\boldsymbol{F}_1 &= ||\boldsymbol{F}_{AB}||\hat{\boldsymbol{u}}_{AB} \\ &= (30\,\text{N})\frac{[(0-0.8)\,\hat{\mathbf{i}}+(1.2-0.1)\,\hat{\mathbf{j}}+(1.5-0)\,\hat{\mathbf{k}}]}{\sqrt{(0-0.8)^2+(1.2-0.1)^2+(1.5-0)^2}} \\ &= (-11.85\,\hat{\mathbf{i}}+16.30\,\hat{\mathbf{j}}+22.22\,\hat{\mathbf{k}})\,\text{N}\end{aligned}$$

RESULTS (a):

$$\boxed{\boldsymbol{F}_1 = (-11.9\,\hat{\mathbf{i}}+16.3\,\hat{\mathbf{j}}+22.2\,\hat{\mathbf{k}})\,\text{N}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}\boldsymbol{F}_2 &= ||\boldsymbol{F}_{BA}||\hat{\boldsymbol{u}}_{BA} \\ &= (30\,\text{N})\frac{[(0.8-0)\,\hat{\mathbf{i}}+(0.1-1.2)\,\hat{\mathbf{j}}+(0-1.5)\,\hat{\mathbf{k}}]}{\sqrt{(0.8-0)^2+(0.1-1.2)^2+(0-1.5)^2}} \\ &= (11.85\,\hat{\mathbf{i}}-16.30\,\hat{\mathbf{j}}-22.22\,\hat{\mathbf{k}})\,\text{N}\end{aligned}$$

RESULTS (b):

$$\boxed{\boldsymbol{F}_2 = (11.9\,\hat{\mathbf{i}}-16.3\,\hat{\mathbf{j}}-22.2\,\hat{\mathbf{k}})\,\text{N}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

None necessary.

RESULTS (c):

$$\boxed{\boldsymbol{F}_1 = -\boldsymbol{F}_2 \text{ by comparing results from (a) and (b)}}$$

CHECK : Verify calculations and ensure that the magnitudes of the forces are correct.

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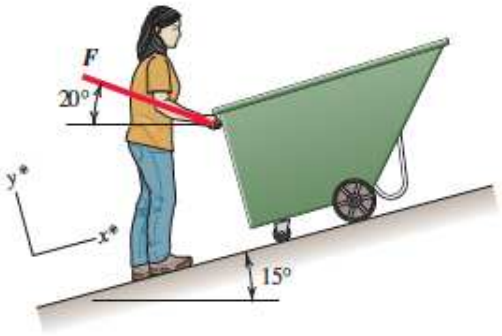
PROBLEM 2.5.62

A worker applies a 250N force $\boldsymbol{F}$ to push a refuse container up a ramp. For the worker and refuse container to move at constant velocity up the ramp, the magnitude of the component of $\boldsymbol{F}$ parallel to the ramp must be equal to the magnitude of the component of the weight of the container parallel to the ramp. What is the weight of the container?

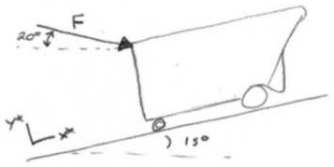


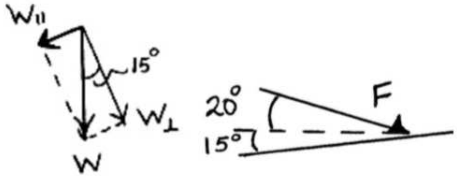
GOAL : Determine the weight of the container to move at constant speed.

GIVEN : F = 250 lb (in exercise 4.5.57), slope of incline.

ASSUME : Planar. Wheels rotate on frictionless axles.

DRAW :





FORMULATE EQUATIONS and **SOLVE** :

$$F_{\parallel} = (250\,\text{N})\cos(20^\circ + 15^\circ) = 204.8\,\text{N}$$

$$W_{\parallel} = W\sin 15^\circ$$

$$W = \frac{W_{\parallel}}{\sin 15^\circ} = \frac{F_{\parallel}}{\sin 15^\circ} = \frac{204.8\,\text{N}}{\sin 15^\circ} = 791.2\,\text{N}$$

RESULTS :

$$\boxed{W = 791\,\text{N}}$$

CHECK : Check equations, and whether the solution is reasonable. The solutions is reasonable because the incline is not very steep so the component of the weight parallel to the slope is relatively small. In the limit, if the cart were on a horizontal surface and there was no friction anywhere in the system, you could apply a tiny horizontal force to a very heavy cart and it would zoom across the floor.

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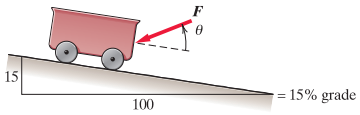
PROBLEM 2.5.63

A cart weighing 400 N is pushed up a 15% grade by the force $\boldsymbol{F}$ shown below. If $\boldsymbol{F}$ has magnitude of 200 N, determine the angle θ such that the scalar component of $\boldsymbol{F}$ parallel to the slope is equal in magnitude but opposite in direction to the component of the cart weight that is parallel to the slope.

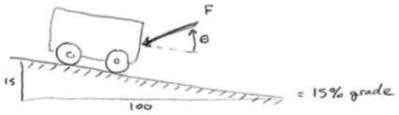


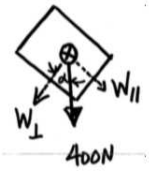
GOAL : determine the angle θ such that the scalar component of $\boldsymbol{F}$ parallel to the slope is equal in magnitude but opposite in direction to the component of the cart weight that is parallel to the slope.

GIVEN : The magnitude of $\boldsymbol{F} = 200\,\text{N}$. From Exercise 2.5.53, the parallel component of the weight is 59.3 N.

ASSUME : Planar.

DRAW :





FORMULATE EQUATIONS and **SOLVE** :

$$F_{\parallel} = F\cos\theta = W_{\parallel}$$

$$(200\,\text{N})\cos\theta = 59.3\,\text{N}$$

$$\theta = \cos^{-1}\left(\frac{59.3\,\text{N}}{200\,\text{N}}\right) = 72.75^{\circ}$$

RESULTS :

$$\boxed{\theta = 72.8^{\circ}}$$

CHECK : Check that $(200\ \text{N})\cos 72.8^{\circ} = 59.3\ \text{N}$. The parallel component of 59.3 N is about 30% of 200 N. Therefore the angle needs to be fairly large so that $\cos\theta$ is 0.30. The answer seems reasonable.

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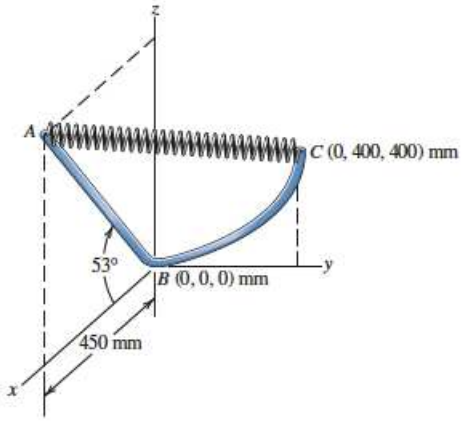
PROBLEM 2.5.64

A spring whose stiffness is 250 N/m and whose unstretched length is 400 mm (0.400 m) is stretched between ends A and C of a bent rod ABC, as shown. If the magnitude of the spring force is the product of the spring stiffness and the stretch, determine the force exerted by the spring on end C of the rod. Write your answer in Cartesian vector notation.

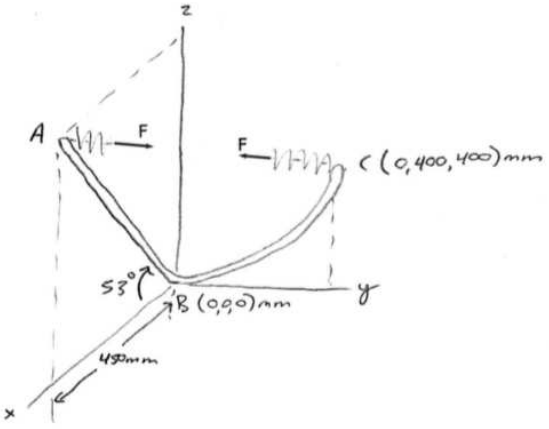


GOAL : Determine the force exerted by the spring on end C of the rod, expressed in vector notation.

GIVEN : The spring stiffness is 250 N/m with an unstretched length of 400 mm. The spring force is the product of the stiffness and displacement.

ASSUME : The spring is weightless and therefore does not sag.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$A = (450,\ 0,\ 450\tan 53^\circ)\ \text{mm} = (450,\ 0,\ 597.2)\ \text{mm}$$

$$C = (0,\ 400,\ 400)$$

d is the distance between A and C.

$$d = \sqrt{(450-0)^2 + (0-400)^2 + (597.2-400)^2}\ \text{mm}$$
$$\Rightarrow \quad d = 633.6\ \text{mm}$$

$$||\boldsymbol{F}|| = (0.250\ \text{N/mm})(\text{spring stretch})$$
$$||\boldsymbol{F}|| = (0.250\ \text{N/mm})(d - 400\ \text{mm}) = 58.4\ \text{N}$$

$$\hat{\boldsymbol{u}} = \frac{450}{633.6}\,\hat{\mathbf{i}} - \frac{400}{633.6}\,\hat{\mathbf{j}} + \frac{197.2}{633.6}\,\hat{\mathbf{k}}$$
$$\Rightarrow \quad \hat{\boldsymbol{u}} = 0.710\,\hat{\mathbf{i}} - 0.631\,\hat{\mathbf{j}} + 0.311\,\hat{\mathbf{k}}$$

$$\boldsymbol{F} = ||\boldsymbol{F}||\hat{\boldsymbol{u}} = (41.46\,\hat{\mathbf{i}} - 36.84\,\hat{\mathbf{j}} + 18.16\,\hat{\mathbf{k}})\ \text{N}$$

RESULTS :

$$\boxed{\boldsymbol{F} = (41.5\,\hat{\mathbf{i}} - 36.8\,\hat{\mathbf{j}} + 18.2\,\hat{\mathbf{k}})\ \text{N}}$$

CHECK : Ensure the magnitude of $\boldsymbol{F}$ is 58.4 N. Also check the directions of the unit vector components visually with the figure.

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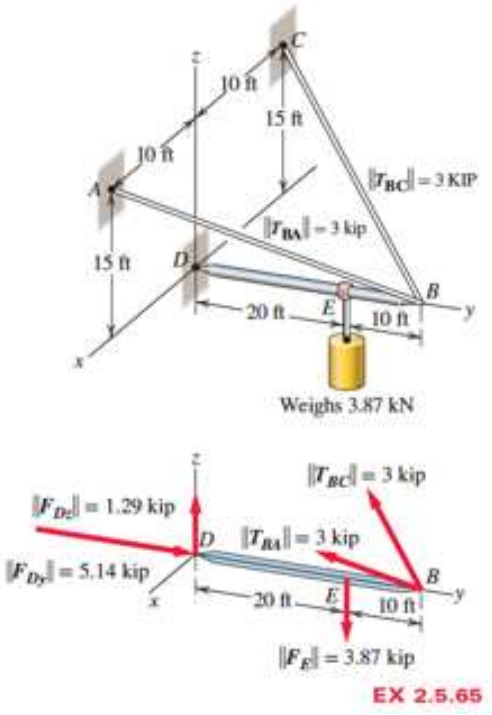
PROBLEM 2.5.65

The forces acting on member *BD* are shown in the free-body diagram. Express each force shown below in terms of rectangular component vectors.

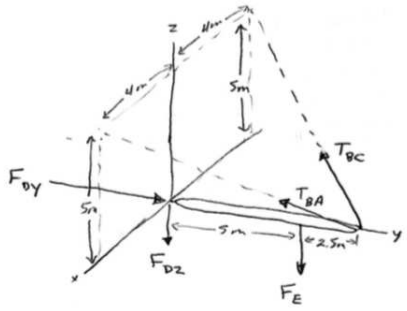


GOAL : Express each of the given forces in terms of its rectangular component vectors.

GIVEN : Free-body diagram of beam suspended by cables.

ASSUME : The beam is massless.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\boldsymbol{T}_{BA} = \|\boldsymbol{T}_{BA}\| \left(\frac{(4\,\text{m}\,\hat{\mathbf{i}} - 7.5\,\text{m}\,\hat{\mathbf{j}} + 5\,\text{m}\,\hat{\mathbf{k}})}{\sqrt{(4\,\text{m})^2 + (-7.5\,\text{m})^2 + (5\,\text{m})^2}} \right)$$
$$= (10\,\text{kN})(0.406\,\hat{\mathbf{i}} - 0.761\,\hat{\mathbf{j}} + 0.507\,\hat{\mathbf{k}})$$
$$= (4.06\,\hat{\mathbf{i}} - 7.61\,\hat{\mathbf{j}} + 5.07\,\hat{\mathbf{k}})\,\text{kN}$$

$$\boldsymbol{T}_{BC} = \|\boldsymbol{T}_{BC}\| \left(\frac{(-4\,\text{m}\,\hat{\mathbf{i}} - 7.5\,\text{m}\,\hat{\mathbf{j}} + 5\,\text{m}\,\hat{\mathbf{k}})}{\sqrt{(-4\,\text{m})^2 + (-7.5\,\text{m})^2 + (5\,\text{m})^2}} \right)$$
$$= (10\,\text{kN})(-0.406\,\hat{\mathbf{i}} - 0.761\,\hat{\mathbf{j}} + 0.507\,\hat{\mathbf{k}})$$
$$= (-4.06\,\hat{\mathbf{i}} - 7.61\,\hat{\mathbf{j}} + 5.07\,\hat{\mathbf{k}})\,\text{kN}$$

RESULTS :

$$\boldsymbol{T}_{BA} = (4.06\,\hat{\mathbf{i}} - 7.61\,\hat{\mathbf{j}} + 5.07\,\hat{\mathbf{k}})\,\text{kN}$$
$$\boldsymbol{T}_{BC} = (-4.06\,\hat{\mathbf{i}} - 7.61\,\hat{\mathbf{j}} + 5.07\,\hat{\mathbf{k}})\,\text{kN}$$
$$\boldsymbol{F}_E = -5.0\,\text{kN}\,\hat{\mathbf{k}}$$
$$\boldsymbol{F}_D = (15.2\,\hat{\mathbf{j}} - 5.14\,\hat{\mathbf{k}})\,\text{kN}$$

CHECK : Verify that the magnitudes of the forces are preserved.

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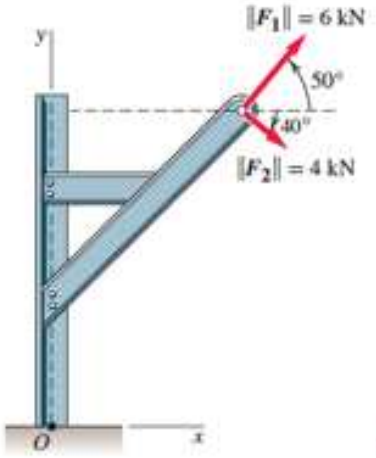
PROBLEM 2.6.1

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to the bracket as shown. Write the resultant $\boldsymbol{F_R}$ (where $\boldsymbol{F_R} = \boldsymbol{F_1} + \boldsymbol{F_2}$) in terms of $\boldsymbol{i}$ and $\boldsymbol{j}$. Use graphical force addition



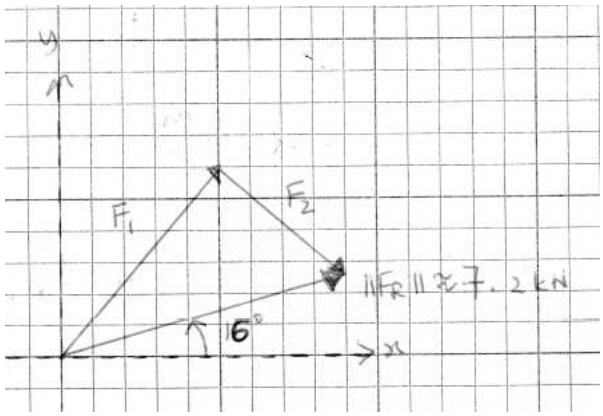
EX 2.6.1

GOAL : To determine the resultant force by graphical component

GIVEN : The magnitude and orientation of two forces applied to the bracket.

ASSUME : The system is planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** : None necessary

RESULTS :
We can measure the $\boldsymbol{F_R}$ drawn and measured the angle using a protractor. They turn out to be

$$\boldsymbol{F_R} = (6.95\,\hat{\mathbf{i}} + 1.98\,\hat{\mathbf{j}})\ \text{kN}$$
$$\theta_x = 16^\circ$$

CHECK : Use geometric techniques to verify the result (Problem 2.6.2).

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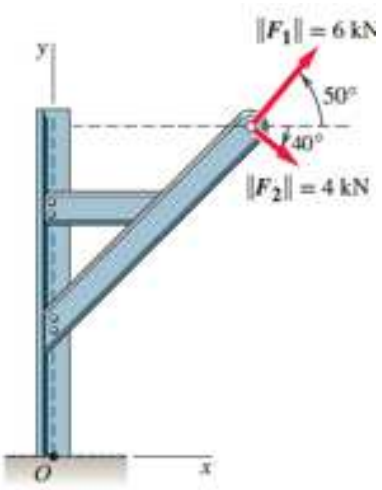
PROBLEM 2.6.2

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to the bracket as shown. Write the resultant $\boldsymbol{F_R}$ (where $\boldsymbol{F_R} = \boldsymbol{F_1} + \boldsymbol{F_2}$) in terms of $\boldsymbol{i}$ and $\boldsymbol{j}$. Use geometric/trigonometric force addition.

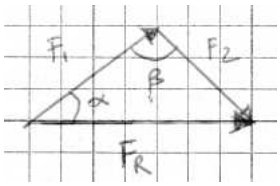


GOAL : To determine the resultant force by geometric/trigonometric additions.

GIVEN : The magnitude and orientation of two forces applied to the bracket.

ASSUME : The system is planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

We can say the following from the drawing.

$$\theta_{xF_1} = 50^\circ$$
$$\theta_{yF_1} = 40^\circ$$
$$\theta_{xF_2} = 40^\circ$$
$$\theta_{yF_2} = 130^\circ$$

We can then obtain β.

$$\beta = 180^\circ - (50^\circ + 40^\circ) = 90^\circ$$

With that, we can use the cosine rule to obtain $\boldsymbol{F_R}$.

$$\begin{aligned} ||\boldsymbol{F_R}|| &= ||\boldsymbol{F_1}||^2 + ||\boldsymbol{F_2}||^2 - 2||\boldsymbol{F_1}||||\boldsymbol{F_2}||\cos\beta \\ &= 36 + 16 - 2(6)(4)\cos 90^\circ \\ &= 7.21kN \end{aligned}$$

We can then use the sine rule to obtain the angle α.

$$\frac{\sin\alpha}{||\boldsymbol{F_2}||} = \frac{\sin\beta}{||\boldsymbol{F_R}||}$$
$$\sin\alpha = \frac{\sin 90^\circ ||\boldsymbol{F_2}||}{||\boldsymbol{F_R}||}$$
$$\alpha = 33.7^\circ$$

With this, we can then obtain the space angles for $\boldsymbol{F_R}$.

$$\theta_x = 50^\circ - 33.7^\circ = 16.3^\circ$$
$$\theta_y = 90^\circ - 16.3^\circ = 73.7^\circ$$

RESULTS :
With the results, we can write the forces in rectangular component and it is

$$\boxed{\boldsymbol{F_R} = (6.92\,\hat{\mathbf{i}} + 2.02\,\hat{\mathbf{j}})\text{ kN}}$$

CHECK : Use graphical or component force addition to check.

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PROBLEM 2.6.3

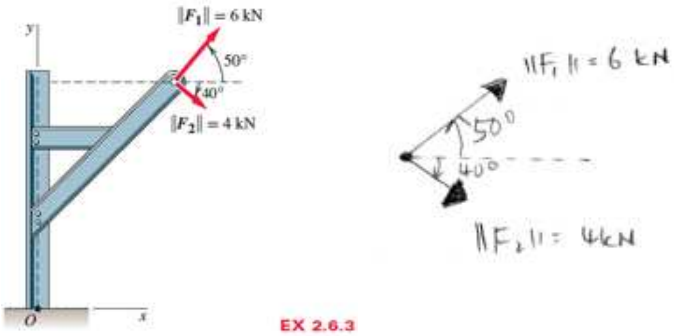
Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to the bracket as shown. Write the resultant $\boldsymbol{F_R}$ (where $\boldsymbol{F_R = F_1 + F_2}$) in terms of $\boldsymbol{i}$ and $\boldsymbol{j}$. Use component force addition.

GOAL : To determine the resultant force by component addition.

GIVEN : The magnitude and orientation of two forces applied to the bracket.

ASSUME : The system is planar.

DRAW :



EX 2.6.3

FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_1 &= ||\boldsymbol{F}_1||(\cos 50^\circ\,\hat{\mathbf{i}} + \sin 50^\circ\,\hat{\mathbf{j}}) \\ &= (3.86\,\hat{\mathbf{i}} + 3.06\,\hat{\mathbf{j}})\ \text{kN}\end{aligned}$$

$$\begin{aligned}\boldsymbol{F}_2 &= ||\boldsymbol{F}_2||(\cos 40^\circ\,\hat{\mathbf{i}} - \sin 40^\circ\,\hat{\mathbf{j}}) \\ &= (3.06\,\hat{\mathbf{i}} - 2.57\,\hat{\mathbf{j}})\ \text{kN}\end{aligned}$$

$$\begin{aligned}\boldsymbol{F}_R &= \boldsymbol{F}_1 + \boldsymbol{F}_2 \\ &= (6.92\,\hat{\mathbf{i}} + 2.03\,\hat{\mathbf{j}})\ \text{kN}\end{aligned}$$

RESULTS :

$$\boxed{\boldsymbol{F}_R = (6.92\,\hat{\mathbf{i}} + 2.03\,\hat{\mathbf{j}})\ \text{kN}}$$

CHECK : Use graphical or geometric techniques to verify the result (Problem 2.6.1 and 2.6.2).

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PROBLEM 2.6.4

If $\boldsymbol{F}_A$ = 1.00 kN $\boldsymbol{i}$ – 4.5 kN $\boldsymbol{j}$ and $\boldsymbol{F}_B$ = –2 kN$\boldsymbol{i}$ – 2 kN$\boldsymbol{j}$, what is the magnitude of $\boldsymbol{F} = 6\boldsymbol{F}_A + 4\boldsymbol{F}_B$?

GOAL : To determine the magnitude of $\boldsymbol{F} = 6\boldsymbol{F}_A + 4\boldsymbol{F}_B$.

GIVEN : $\boldsymbol{F}_A = 1.00\,\text{kN}\,\hat{\mathbf{i}} - 4.5\,\text{kN}\,\hat{\mathbf{j}}$ and $\boldsymbol{F}_B = -2\,\text{kN}\,\hat{\mathbf{i}} - 2\,\text{kN}\,\hat{\mathbf{j}}$.

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F} &= 6\boldsymbol{F}_A + 4\boldsymbol{F}_B \\ &= (6\,\text{kN}\,\hat{\mathbf{i}} - 27\,\text{kN}\,\hat{\mathbf{j}}) + (-8\,\text{kN}\,\hat{\mathbf{i}} - 8\,\text{kN}\,\hat{\mathbf{j}}) \\ &= -2\,\text{kN}\,\hat{\mathbf{i}} - 35\,\text{kN}\,\hat{\mathbf{j}}\end{aligned}$$

$$\begin{aligned}||\boldsymbol{F}|| &= \sqrt{(F_x)^2 + (F_y)^2} \\ &= \sqrt{(-2\,\text{kN})^2 + (-35\,\text{kN})^2} = 35.06\,\text{kN}\end{aligned}$$

RESULTS :

$$\boxed{||\boldsymbol{F}|| = 35.1\,\text{kN}}$$

CHECK : Use graphical addition techniques.

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PROBLEM 2.6.5

Find the magnitude of $\boldsymbol{F} = 3\boldsymbol{F}_A - 2\boldsymbol{F}_B$ for the two forces $\boldsymbol{F}_A = -11.0\,\text{kip}\ \boldsymbol{i} - 15.0\,\text{kip}\ \boldsymbol{j}$ and $\boldsymbol{F}_B = 8.0\,\text{kip}\ \boldsymbol{i} - 8.0\,\text{kip}\,\boldsymbol{j}$.

GOAL : To determine the magnitude of $\boldsymbol{F} = 3\boldsymbol{F}_A - 2\boldsymbol{F}_B$.

GIVEN : $\boldsymbol{F} = 3\boldsymbol{F}_A - 2\boldsymbol{F}_B$; $\boldsymbol{F}_A = -11.0\,\text{kip}\,\boldsymbol{i} - 15.0\,\text{kip}\,\boldsymbol{j}$ and $\boldsymbol{F}_B = 8.0\,\text{kip}\,\boldsymbol{i} - 8.0\,\text{kip}\,\boldsymbol{j}$

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F} &= 3\boldsymbol{F}_A - 2\boldsymbol{F}_B \\ &= (-11.0\,\text{kip}\,\hat{\mathbf{i}} - 15.0\,\text{kip}\,\hat{\mathbf{j}}) + (-8.0\,\text{kip}\,\hat{\mathbf{i}} - 8.0\,\text{kip}\,\hat{\mathbf{j}}) \\ &= -49.0\,\text{kip}\,\hat{\mathbf{i}} - 29.0\,\text{kip}\,\hat{\mathbf{j}}\end{aligned}$$

$$\begin{aligned}||\boldsymbol{F}|| &= \sqrt{(F_x)^2 + (F_y)^2} \\ &= \sqrt{(-49.0\,\text{kip})^2 + (-29.0\,\text{kip})^2} = 56.9\,\text{kip}\end{aligned}$$

RESULTS :

$$\boxed{||\boldsymbol{F}|| = 56.9\,\text{kip}}$$

CHECK : Use graphical addition techniques.

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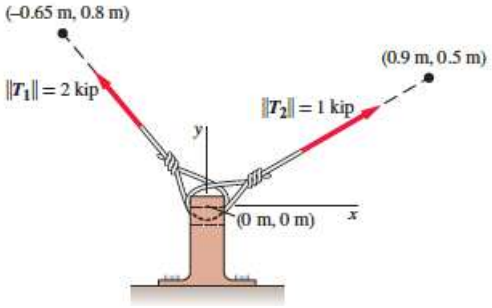
PROBLEM 2.6.6

Two support cables are tethered to the ground. The tensions in the cables are shown as well as points on the lines of action of $\boldsymbol{T_1}$ and $\boldsymbol{T_2}$.

a. Write the resultant $\boldsymbol{T}_R$ (where $\boldsymbol{T}_R = \boldsymbol{T_1} + \boldsymbol{T_2}$) in vector notation.

b. Determine the magnitude of $\boldsymbol{T}_R$ and its space angles.

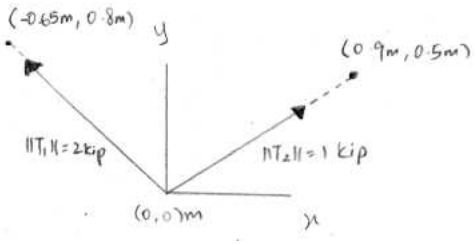


GOAL : Determine the magnitude, space angles and the vector notation of the resultant force.

GIVEN : Magnitude and orientation of two forces applied to a support.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Obtaining the unit vectors and force vectors:

$$\begin{aligned}
\|\boldsymbol{u_1}\| &= \sqrt{(0.9-0)\,\text{m}^2 + (0.5-0)\,\text{m}^2} \\
&= 1.0296\,\text{m} \\
\boldsymbol{u_1} &= \frac{(0.9-0)m}{1.0296m}\,\hat{\mathbf{i}} + \frac{(0.5-0)m}{1.0296m}\,\hat{\mathbf{j}} \\
&= 0.8741\,\hat{\mathbf{i}} + 0.4856\,\hat{\mathbf{j}} \\
\boldsymbol{T_1} &= 2\,\text{kip}(0.8741\,\hat{\mathbf{i}} + 0.4856\,\hat{\mathbf{j}}) \\
&= 1.748\,\text{kip}\,\hat{\mathbf{i}} + 0.971\,\text{kip}\,\hat{\mathbf{j}}
\end{aligned}$$

$$\begin{aligned}
\|\boldsymbol{u_2}\| &= \sqrt{(-0.65-0)\,\text{m}^2 + (0.8-0)\,\text{m}^2} \\
&= 1.0309\,\text{m} \\
\boldsymbol{u_2} &= \frac{(-0.65-0)m}{1.0309m}\,\hat{\mathbf{i}} + \frac{(0.8-0)m}{1.0309m}\,\hat{\mathbf{j}} \\
&= -0.8306\,\hat{\mathbf{i}} + 0.7761\,\hat{\mathbf{j}} \\
\boldsymbol{T_2} &= 1\,\text{kip}(-0.8306\,\hat{\mathbf{i}} + 0.7761\,\hat{\mathbf{j}}) \\
&= -0.631\,\text{kip}\,\hat{\mathbf{i}} + 0.776\,\text{kip}\,\hat{\mathbf{j}}
\end{aligned}$$

Using component addition:

$$\begin{aligned}
\boldsymbol{T}_R &= (1.748\,\text{kip}\,\hat{\mathbf{i}} + 0.971\,\text{kip}\,\hat{\mathbf{j}}) \\
&\quad + (-0.631\,\text{kip}\,\hat{\mathbf{i}} + 0.776\,\text{kip}\,\hat{\mathbf{j}}) \\
&= (1.118\,\hat{\mathbf{i}} + 1.747\,\hat{\mathbf{j}})\,\text{kip}
\end{aligned}$$

$$\begin{aligned}
\|\boldsymbol{T}_R\| &= \sqrt{(1.118\,\text{kip})^2 + (1.747\,\text{kip})^2} \\
&= 2.074\,\text{kip}
\end{aligned}$$

$$\begin{aligned}
\theta_x &= \cos^{-1}\left(\frac{T_{Rx}}{\|\boldsymbol{T}_R\|}\right) \\
&= \cos^{-1}\left(\frac{1.118\,\text{kip}}{2.074\,\text{kip}}\right) = 57.4°
\end{aligned}$$

$$\theta_y = \theta_x - 90° = 32.6°$$

RESULTS (a): $\boldsymbol{T}_R$ in vector notation is:

$$\boxed{\boldsymbol{T}_R = (1.748\,\text{kip}\,\hat{\mathbf{i}} + 0.971\,\text{kip}\,\hat{\mathbf{j}})}$$

RESULTS (b): The magnitude and space angles are:

$$\boxed{\begin{aligned}
\|\boldsymbol{T}_R\| &= 2.07\,\text{kip} \\
\theta_x &= 57.4° \\
\theta_y &= 32.6° \\
\theta_z &= 90°
\end{aligned}}$$

CHECK : Check your intuition on the resultant. Do the magnitude and orientation seem reasonable?.
You could also use graphical or geometric techniques to verify the result.

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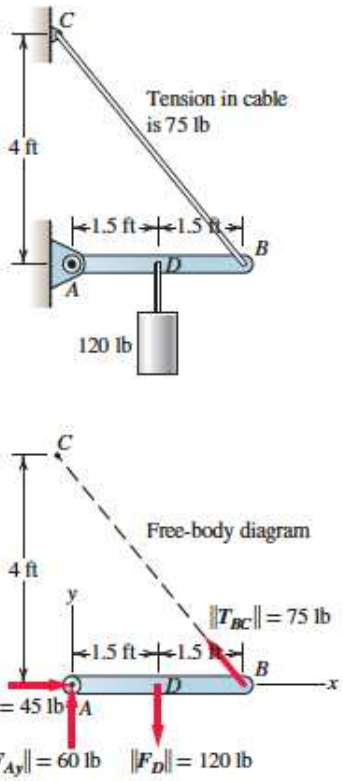
PROBLEM 2.6.7

Redraw the free-body diagram of member AB to show $\boldsymbol{F_A}$ as a single force acting at A. Indicate the magnitude and space angle that define $\boldsymbol{F_A}$.



GOAL : To redraw the free-body diagram with combined forces at points A.

GIVEN : A free body diagram.

ASSUME : Planar.

DRAW : None necessary since it is given.

FORMULATE EQUATIONS and **SOLVE** :

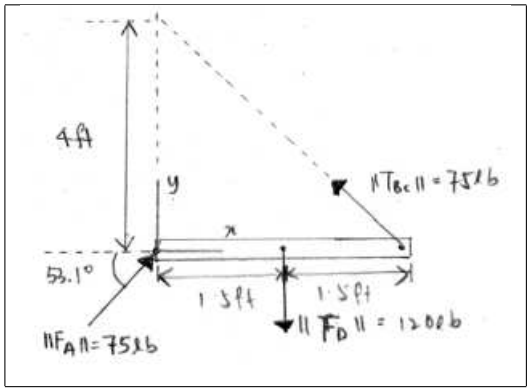
At A:

$$\boldsymbol{F}_A = (45ii)\text{ lb} + (60\,\hat{\mathbf{j}})\text{ lb}$$

$$||\boldsymbol{F}_A|| = \sqrt{45^2 + 60^2} = 75\text{ lb}$$

$$\theta_x = \cos^{-1}\left(\frac{F_{Ax}}{||\boldsymbol{F}_A||}\right) = \cos^{-1}\left(\frac{45\text{ lb}}{75\text{ lb}}\right) = 53.1^\circ$$

RESULTS :



CHECK : Check the original free-body diagram to make sure forces appear correct.

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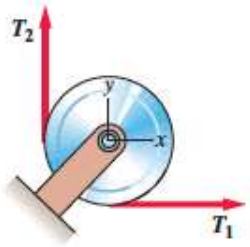
PROBLEM 2.6.8

Consider the frictionless pulley shown. Because the pulley is frictionless, $\|\boldsymbol{T_1}\| = \|\boldsymbol{T_2}\|$ and $\|\boldsymbol{T_3}\| = \|\boldsymbol{T_4}\|$. Express the resultant $\boldsymbol{R_a}$ of $\boldsymbol{T_1} + \boldsymbol{T_2}$ in terms of rectangular components. Also show that the line of action of $\boldsymbol{R_a}$ bisects the angle between $\boldsymbol{T_1}$ and $\boldsymbol{T_2}$.

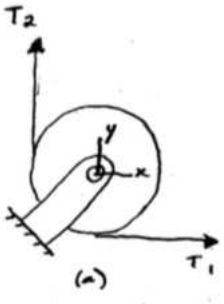


GOAL : Determine the resultant $\boldsymbol{R}_a = \boldsymbol{T}_1 + \boldsymbol{T}_2$ and show that the line of action bisects the angle between the two vectors.

GIVEN : The direction of the forces pulling on the pulley. The pulleys are frictionless ($||\boldsymbol{T}_1|| = ||\boldsymbol{T}_2||$).

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$||\boldsymbol{T}_a|| = ||\boldsymbol{T}_1|| = ||\boldsymbol{T}_2||$$

$$\begin{aligned}
\boldsymbol{R}_a &= \boldsymbol{T}_1 + \boldsymbol{T}_2 = ||\boldsymbol{T}_1||\,\hat{\mathbf{i}} + ||\boldsymbol{T}_2||\,\hat{\mathbf{j}} \\
&= ||\boldsymbol{T}_a||\,\hat{\mathbf{i}} + ||\boldsymbol{T}_a||\,\hat{\mathbf{j}} \\
||\boldsymbol{R}_a|| &= \sqrt{||\boldsymbol{T}_a||^2 + ||\boldsymbol{T}_a||^2} \\
&= \sqrt{2}||\boldsymbol{T}_a|| \\
\theta_x &= \cos^{-1}\left(\frac{\boldsymbol{R}_{ax}}{||\boldsymbol{R}_a||}\right) = \cos^{-1}\left(\frac{||\boldsymbol{T}_a||}{\sqrt{2}||\boldsymbol{T}_a||}\right) \\
&= 45.0^\circ
\end{aligned}$$

RESULTS : The resultant, $\boldsymbol{R}_a$ is

$$\boxed{\begin{array}{c} \boldsymbol{R}_a = ||\boldsymbol{T}_a||\,\hat{\mathbf{i}} + ||\boldsymbol{T}_a||\,\hat{\mathbf{j}} \\ \theta_x = 45^\circ, \text{ which bisects the angles of } \boldsymbol{T}_1 \text{ and } \boldsymbol{T}_2 \end{array}}$$

CHECK : Verify calculations and note that the bisecting angle is a good check.

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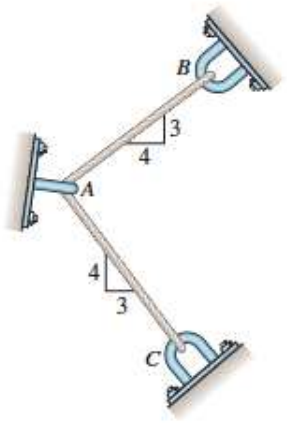
PROBLEM 2.6.9

The tension in each of the two supporting cables *AB* and *AC* is 10 lb. Determine the resultant force acting at *A* due to the two cables.

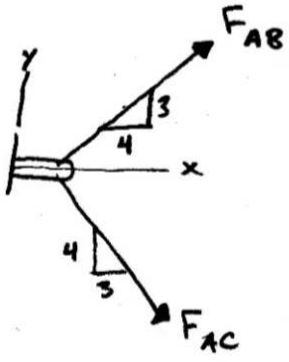


GOAL : To determine the magnitude of the resultant force.

GIVEN : The geometry of a system of two cables attached to supports *a*, *B*, and *C*. The tension in each cable is 10 lb.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_A &= \boldsymbol{F}_{AB} + \boldsymbol{F}_{AC} \\ &= (10\,\text{lb})\left(\frac{4}{5}\,\hat{\mathbf{i}} + \frac{3}{5}\,\hat{\mathbf{j}}\right) + (10\,\text{lb})\left(\frac{3}{5}\,\hat{\mathbf{i}} - \frac{4}{5}\,\hat{\mathbf{j}}\right) \\ &= (14\,\hat{\mathbf{i}} - 2\,\hat{\mathbf{j}})\,\text{lb}\end{aligned}$$

RESULTS :

$$\boxed{\boldsymbol{F}_R = (14\,\hat{\mathbf{i}} - 2\,\hat{\mathbf{j}})\,\text{lb}}$$

CHECK : Since the cables are both exerting forces in the positive *x* direction but nearly mirrored about the axis, it follows that the $\hat{\mathbf{i}}$ component of the resultant would be positive and large and that the $\hat{\mathbf{j}}$ component would be close to zero.

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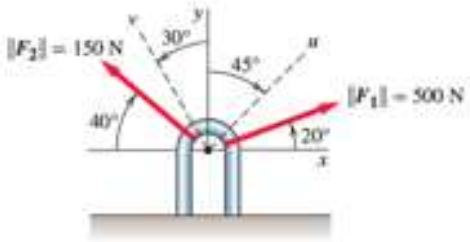
PROBLEM 2.6.10

Two forces act on a u-bolt as shown.

a. Find the resultant of the two forces and express it in vector notation. .

b. Find the space angles associated with the resultant.

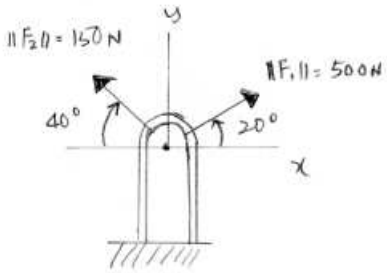


GOAL : To determine (a) the vector notation, and (b) magnitude and space angles of the resultant fore.

GIVEN : Magnitude and orientation of two forces acting on the u-bolt.

ASSUME : Planar, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\begin{aligned}\boldsymbol{F}_R &= (500\,\text{N})(\cos 20°\,\hat{\mathbf{i}} + \sin 20°\,\hat{\mathbf{j}}) \\ &\quad + (150\,\text{N})(-\cos 40°\,\hat{\mathbf{i}} + \sin 40°\,\hat{\mathbf{j}}) \\ &= (269.0\,\hat{\mathbf{i}} + 267.0\,\hat{\mathbf{j}})\,\text{N}\end{aligned}$$

$$||\boldsymbol{F}_R|| = \sqrt{(269.0\,\text{N})^2 + (267.0\,\text{N})^2} = 379.4\,\text{N}$$

$$\theta_x = \cos^{-1}\left(\frac{F_{Rx}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{269.0\,\text{N}}{379.4\,\text{N}}\right) = 44.8°$$

$$\theta_y = 90° - \theta_x = 45.2°$$

RESULTS (a):

$$\boxed{\begin{aligned}\boldsymbol{F}_R &= (269.0\,\hat{\mathbf{i}} + 267.0\,\hat{\mathbf{j}})\,\text{N} \\ ||\boldsymbol{F}_R|| &= 379.0\,\text{N} \\ \theta_x &= 44.8° \\ \theta_y &= 45.2° \\ \theta_z &= 90.0°\end{aligned}}$$

CHECK : Part (a) and (b) can be checked using geometric relations.

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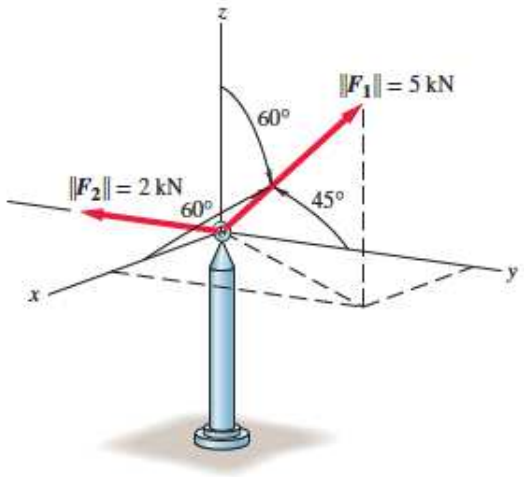
PROBLEM 2.6.11

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to a post as shown below. Write the resultant $\boldsymbol{F_R}\,(=\boldsymbol{F_1}+\boldsymbol{F_2})$ in terms of vector notation.

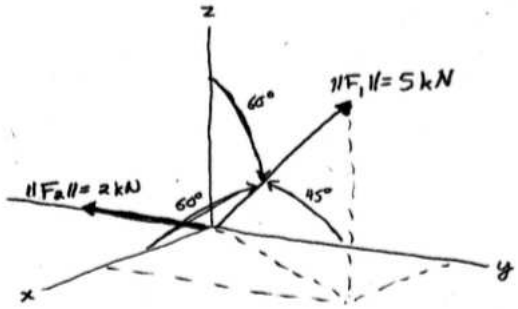


GOAL : Determine the resultant force in vector notation.

GIVEN : The magnitude and orientation of two forces applied to a post.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F_R} &= \boldsymbol{F}_1 + \boldsymbol{F}_2 \\ &= 5\,\text{kN}(\cos 60^\circ\,\hat{\mathbf{i}} + \cos 45^\circ\,\hat{\mathbf{j}} + \cos 60^\circ\,\hat{\mathbf{k}}) + 2\,\text{kN}(-\hat{\mathbf{j}}) \\ &= (2.5\,\hat{\mathbf{i}} + 1.536\,\hat{\mathbf{j}} + 2.5\,\hat{\mathbf{k}})\,\text{kN}\end{aligned}$$

RESULTS :

$$\boxed{\boldsymbol{F_R} = (2.5\,\hat{\mathbf{i}} + 1.54\,\hat{\mathbf{j}} + 2.5\,\hat{\mathbf{k}})\,\text{kN}}$$

CHECK : The x and z component are positive, which can be verified visually. One could use geometric techniques as a check, but geometric techniques are difficult to use for nonplanar problems.

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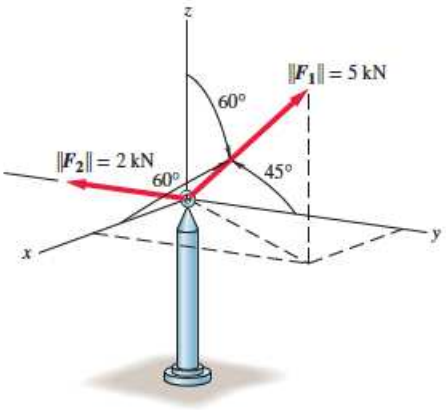
PROBLEM 2.6.12

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to a post as shown below. Write the resultant $\boldsymbol{F}_R\,(=\boldsymbol{F_1}+\boldsymbol{F_2})$ in terms of magnitude and space angles.

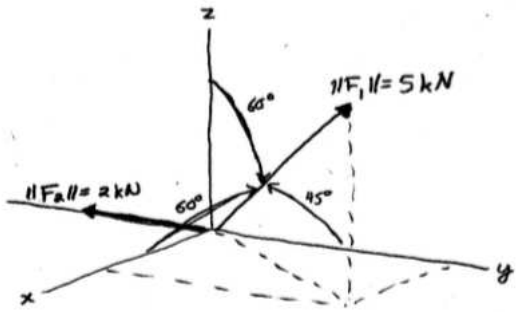


GOAL : Determine the resultant force in terms of magnitude and space angles.

GIVEN : The magnitude and orientation of two forces applied to a post.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

First, use component addition:

$$\begin{aligned}\boldsymbol{F}_R &= \boldsymbol{F}_1 + \boldsymbol{F}_2 \\ &= 5\,\text{kN}(\cos 60^\circ\,\hat{\mathbf{i}} + \cos 45^\circ\,\hat{\mathbf{j}} + \cos 60^\circ\,\hat{\mathbf{k}}) + 2\,\text{kN}(-\hat{\mathbf{j}}) \\ &= (2.5\,\hat{\mathbf{i}} + 1.536\,\hat{\mathbf{j}} + 2.5\,\hat{\mathbf{k}})\,\text{kN}\end{aligned}$$

Then calculate the magnitude and space angles:

$$\|\boldsymbol{F}_R\| = \sqrt{(2.5\,\text{kN})^2 + (1.536\,\text{kN})^2 + (2.5\,\text{kN})^2} = 3.86\,\text{kN}$$

$$\theta_x = \cos^{-1}\left(\frac{F_{Rx}}{\|\boldsymbol{F}_R\|}\right) = \cos^{-1}\left(\frac{2.5\,\text{kN}}{3.86\,\text{kN}}\right) = 49.6^\circ$$

$$\theta_y = \cos^{-1}\left(\frac{F_{Ry}}{\|\boldsymbol{F}_R\|}\right) = \cos^{-1}\left(\frac{1.536\,\text{kN}}{3.86\,\text{kN}}\right) = 66.5^\circ$$

$$\theta_z = \cos^{-1}\left(\frac{F_{Rz}}{\|\boldsymbol{F}_R\|}\right) = \cos^{-1}\left(\frac{2.5\,\text{kN}}{3.86\,\text{kN}}\right) = 49.6^\circ$$

RESULTS :

$$\boxed{\begin{aligned}\|\boldsymbol{F}_R\| &= 3.86\,\text{kN} \\ \theta_x &= 49.6^\circ \\ \theta_y &= 66.5^\circ \\ \theta_z &= 49.6^\circ\end{aligned}}$$

CHECK : The x and z component are positive, which can be verified visually. One could use geometric techniques as a check, but geometric techniques are difficult to use for nonplanar problems.

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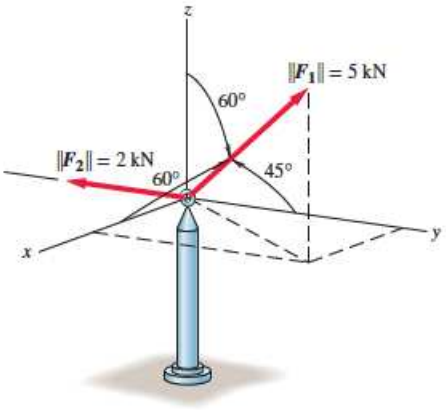
PROBLEM 2.6.13

Two forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are applied to a post as shown. Write the vector expression for the unit vector along the line of action of $\boldsymbol{F}_R\,(=\boldsymbol{F_1}+\boldsymbol{F_2})$.

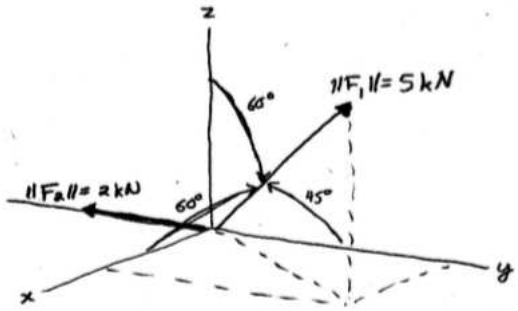


GOAL : Determine the an expression for the unit vector along the line of action of the resultant.

GIVEN : The magnitude and orientation of two forces applied to a post.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

First, find the resultant:

$$\begin{aligned}\boldsymbol{F}_R &= \boldsymbol{F}_1 + \boldsymbol{F}_2 \\ &= 5\,\text{kN}(\cos 60^\circ\,\hat{\mathbf{i}} + \cos 45^\circ\,\hat{\mathbf{j}} + \cos 60^\circ\,\hat{\mathbf{k}}) + 2\,\text{kN}(-\hat{\mathbf{j}}) \\ &= (2.5\,\hat{\mathbf{i}} + 1.536\,\hat{\mathbf{j}} + 2.5\,\hat{\mathbf{k}})\,\text{kN}\end{aligned}$$

Then find the unit vector:

$$\begin{aligned}\hat{\boldsymbol{u}}_R &= \frac{1}{\|\boldsymbol{F}_R\|}\boldsymbol{F}_R \\ &= \frac{(2.5\,\hat{\mathbf{i}} + 1.536\,\hat{\mathbf{j}} + 2.5\,\hat{\mathbf{k}}\,\text{kN})}{\sqrt{(2.5\,\text{kN})^2 + (1.536\,\text{kN})^2 + (2.5\,\text{kN})^2}} \\ &= 0.649\,\hat{\mathbf{i}} + 0.398\,\hat{\mathbf{j}} + 0.649\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS :

$$\boxed{\hat{\boldsymbol{u}}_R = 0.649\,\hat{\mathbf{i}} + 0.398\,\hat{\mathbf{j}} + 0.649\,\hat{\mathbf{k}}}$$

CHECK : Check that the magnitude of the unit vector is 1. The x and z component are positive, which can be verified visually.

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PROBLEM 2.6.14

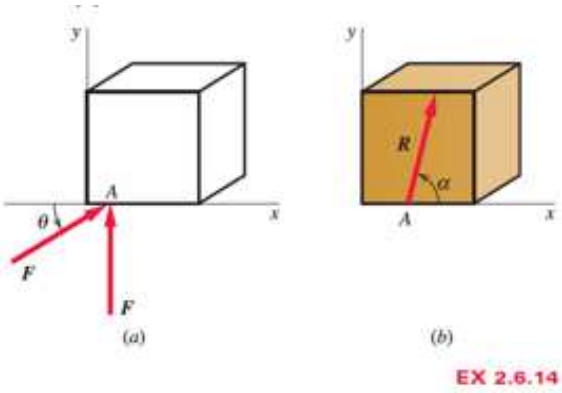
Two forces of equal magnitude are applied to a bloack in the *xy* plane at point *A* as shown in (a). If the magnitude of F remains constant and the angle θ is reduced, what will happen to the magnitude of the resultant force R as shown in (b)?

a. R will get smaller

b. R will remain the same

c. R will get larger

Justify your answer.



GOAL : To determine whether the magnitude of the resultant force changes when one of the component forces is altered.

GIVEN : Magnitude and orientation of two forces acting on the block.

ASSUME : Planar.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** (a):

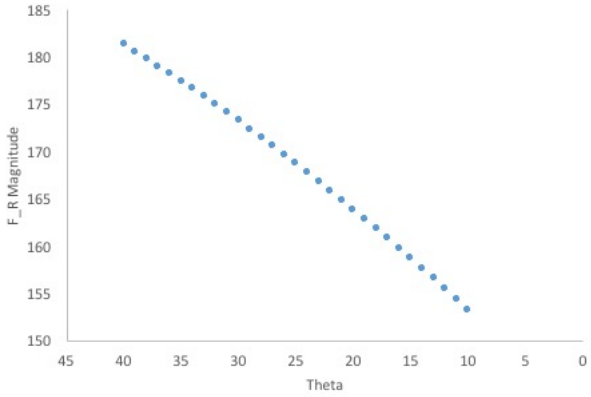
We begin by solving for the resultant force from the two forces.

$$\begin{aligned} \boldsymbol{F}_R &= F\cos\theta\,\hat{\mathbf{i}} + F\sin\theta\,\hat{\mathbf{j}} + F\,\hat{\mathbf{j}} \\ &= F[\cos\theta\,\hat{\mathbf{i}} + (\sin\theta + 1)\,\hat{\mathbf{j}}] \end{aligned}$$

Then, we can get the magnitude with the following equation.

$$||\boldsymbol{F}_R|| = F\sqrt{\cos^2\theta + (\sin\theta + 1)^2}$$

Plotting this between $10^\circ < \theta < 40^\circ$ shows the following.



RESULTS

Based on the plot, we can see that when θ decreases,

R will get smaller.

CHECK : The formulation could be double checked and the plotting should be done to ensure no minor mistakes are done.

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PROBLEM 2.6.15

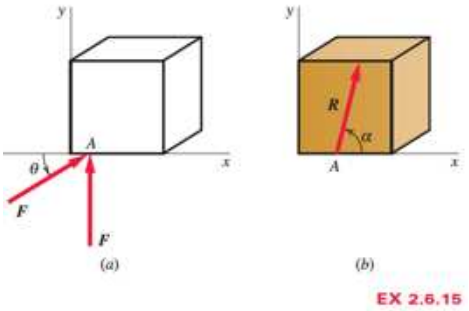
Two forces of equal magnitude are applied to a bloack in the xy plane at point A as shown in (a). If the magnitude of F remains constant and the angle θ is reduced, what will happen to the angle α that the resultant force R makes with x-axis?

a. α will get smaller

b. α will remain the same

c. α will get larger

Justify your answer.



EX 2.6.15

GOAL : To determine whether the angle α of the resultant force changes when one of the component forces is altered.

GIVEN : Magnitude and orientation of two forces acting on the block.

ASSUME : Planar.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** (a):

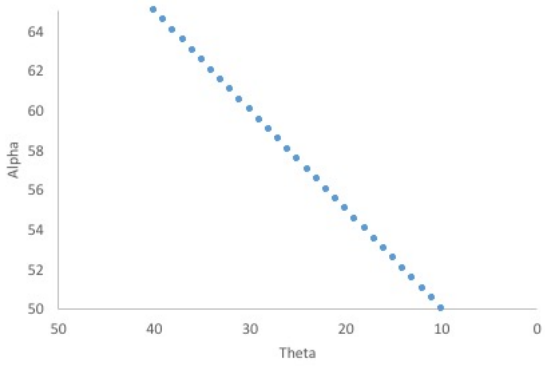
We begin by solving for the resultant force from the two forces.

$$\begin{aligned} \boldsymbol{F}_R &= F\cos\theta\,\hat{\mathbf{i}} + F\sin\theta\,\hat{\mathbf{j}} + F\,\hat{\mathbf{j}} \\ &= F[\cos\theta\,\hat{\mathbf{i}} + (\sin\theta + 1)\,\hat{\mathbf{j}}] \end{aligned}$$

We know that $\alpha = \theta_x$, which means

$$\cos\alpha = \frac{\cos\theta}{\sqrt{\cos^2\theta + (\sin^2\theta + 1)}}$$

Plotting this between $10^\circ < \theta < 40^\circ$ shows the following.



RESULTS

Based on the plot, we can see that when θ decreases,

α will get smaller.

CHECK : The formulation could be double checked and the plotting should be done to ensure no minor mistakes are done.

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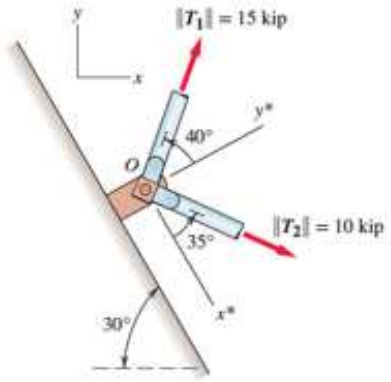
PROBLEM 2.6.16

Two structural members are pinned to the support at O. Tension forces $\boldsymbol{T_1}$ and $\boldsymbol{T_2}$ act on the members as shown below.

a. Write $\boldsymbol{T}_R = \boldsymbol{T_1} + \boldsymbol{T_2}$ in vector notation based on the x and y axes shown.

b. Write $\boldsymbol{T}_R^* = \boldsymbol{T_1} + \boldsymbol{T_2}$ in vector notation based on the x^* and y^* axes shown. (Call the unit vector aligned with x^*, i^*, and the unit vector aligned with y^*, j^*.)

c. Determine the magnitude of $\boldsymbol{T}_R$ and the magnitude of $\boldsymbol{T}_R^*$. Are they equal?



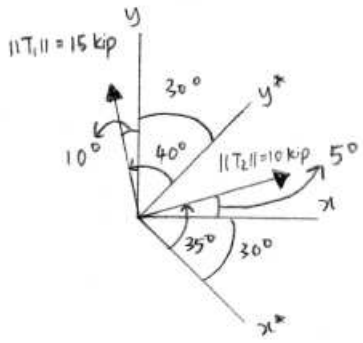
EX 2.6.16

GOAL : Determine (a) the resultant force in vector notation in the xy coordinates, (b) the resultant force in vector notation in the x^*y^* coordinates, (c) magnitudes of $||\boldsymbol{T}_R|| = ||\boldsymbol{T}_{R^*}||$ and whether they are equal.

GIVEN : Magnitude and orientation of two forces pulling on a support.

ASSUME : Planar system.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{T}_R &= (15\,\text{kip})(-\sin 10^\circ\,\hat{\mathbf{i}} + \cos 10^\circ\,\hat{\mathbf{j}}) \\ &+ (10\,\text{kip})(\cos 5^\circ\,\hat{\mathbf{i}} + \sin 5^\circ)\,\hat{\mathbf{j}}) \\ &= (7.36\,\hat{\mathbf{i}} + 15.64\,\hat{\mathbf{j}})\,\text{kip}\end{aligned}$$

RESULTS (a):

$$\boxed{\boldsymbol{T}_R = (7.36\,\hat{\mathbf{i}} + 15.64\,\hat{\mathbf{j}})\,\text{kip}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}\boldsymbol{T}_{R^*} &= (-15\,\text{kip})(-\sin 40^\circ\,\hat{\mathbf{i}}^* + \cos 40^\circ\,\hat{\mathbf{j}}^*) \\ &+ (10\,\text{kip})(\cos 35^\circ\,\hat{\mathbf{i}}^* + \sin 35^\circ\,\hat{\mathbf{j}}^*) \\ &= (-1.450\,\hat{\mathbf{i}}^* + 17.23\,\hat{\mathbf{j}}^*)\,\text{kip}\end{aligned}$$

RESULTS (b):

$$\boxed{\boldsymbol{T}_{R^*} = (-1.450\,\hat{\mathbf{i}} + 17.23\,\hat{\mathbf{j}})\,\text{kip}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$||\boldsymbol{T}_R|| = \sqrt{(7.36\,\text{kip})^2 + (15.64\,\text{kip})^2} = 17.29\,\text{kip}$$

$$||\boldsymbol{T}_{R^*}|| = \sqrt{(-1.450\,\text{kip})^2 + (17.23\,\text{kip})^2} = 17.29\,\text{kip}$$

RESULTS (c):

$$\boxed{||\boldsymbol{T}_R|| = ||\boldsymbol{T}_{R^*}||}$$

CHECK : Part (c) serves as a good self-check.

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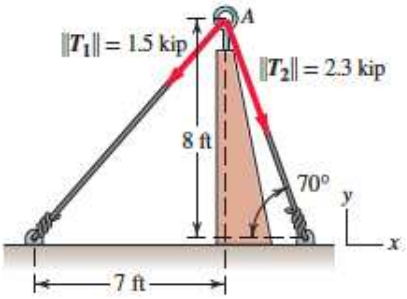
PROBLEM 2.6.17

The tensions of two cables ($\boldsymbol{T_1}$ and $\boldsymbol{T_2}$) act on the top of a wall at A, as shown below. What is their resultant $\boldsymbol{R}$?

a. Express $\boldsymbol{R}$ in terms of its components along the x and y axes shown. Include a sketch of the components.

b. Express $\boldsymbol{R}$ in terms of its magnitude and space angles. Include a sketch that shows the space angles.

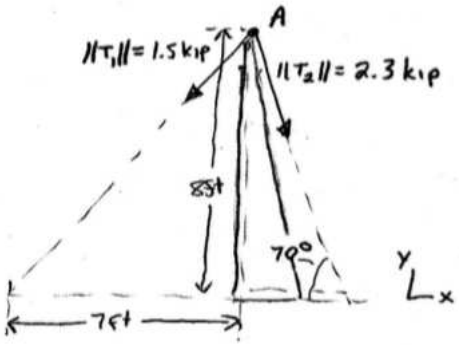


GOAL : Determine the magnitude, space angles and the vector notation of the resultant.

GIVEN : Wall with known dimensions and loads.

ASSUME : Can treat as a planar system, thus $\theta_z = 90°$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{R} &= \boldsymbol{T}_1 + \boldsymbol{T}_2 \\ &= (1.5\,\text{kip})\left(-\frac{7}{\sqrt{7^2+8^2}}\,\hat{\mathbf{i}} - \frac{8}{\sqrt{7^2+8^2}}\,\hat{\mathbf{j}}\right) \\ &+ (2.3\,\text{kip})\left(\sin 20°\,\hat{\mathbf{i}} - \cos 20°\,\hat{\mathbf{j}}\right) \\ &= (-0.201\,\hat{\mathbf{i}} - 3.29\,\hat{\mathbf{j}})\,\text{kip}\end{aligned}$$

RESULTS (a): The components of $\boldsymbol{R}$ are:

$$\boxed{\begin{aligned}R_x &= -0.20\,\text{kip} \\ R_y &= -3.29\,\text{kip}\end{aligned}}$$

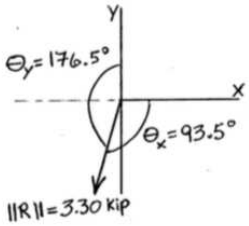
FORMULATE EQUATIONS and **SOLVE** :

$$\|\boldsymbol{R}\| = \sqrt{(-0.201\,\text{kip})^2 + (-3.29\,\text{kip})^2} = 3.30\,\text{kip}$$

$$\theta_x = \cos^{-1}\left(\frac{R_x}{\|\boldsymbol{R}\|}\right) = \cos^{-1}\left(\frac{-0.201\,\text{kip}}{3.30\,\text{kip}}\right) = 93.5°$$

$$\theta_y = \cos^{-1}\left(\frac{R_y}{\|\boldsymbol{R}\|}\right) = \cos^{-1}\left(\frac{-3.29\,\text{kip}}{3.30\,\text{kip}}\right) = 176.5°$$

RESULTS :



$$\boxed{\begin{aligned}\|\boldsymbol{R}\| &= 3.30\,\text{kip} \\ \theta_x &= 93.5° \\ \theta_y &= 176.5° \\ \theta_z &= 90°\end{aligned}}$$

CHECK : Check your intuition on the resultant. Do the magnitude and space angles seem reasonable? You could also use graphical or geometric techniques to verify the result.

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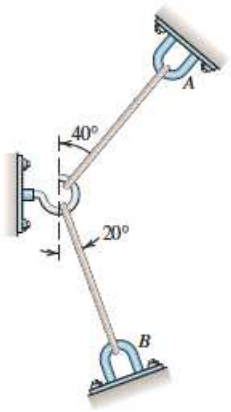
PROBLEM 2.6.18

The cables A and B exert forces $\boldsymbol{F}_A$ and $\boldsymbol{F}_B$ on the hook. The magnitude of $\boldsymbol{F}_A$ is 100 N. The tension in cable B has been adjusted so that the resultant force $(\boldsymbol{F}_A + \boldsymbol{F}_B)$ is perpendicular to the wall to which the hook is attached.

a. Find the magnitude of $\boldsymbol{F}_B$.

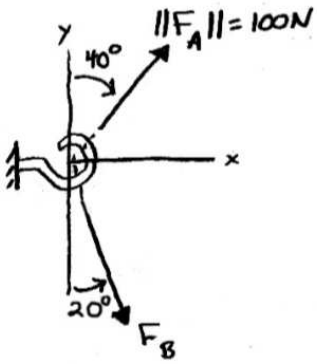
b. Specify the resultant force $\boldsymbol{F}_R$ in vector notation.



GOAL : To: (a) find the magnitude of $\boldsymbol{F}_B$ and (b) express the resultant in vector notation.

GIVEN : The tension in cable B has been adjusted so that the resultant force is perpendicular to the wall when $||\boldsymbol{F}_A|| = 100\,\text{N}$.

ASSUME : Planar. **DRAW** :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\begin{aligned}\boldsymbol{F}_R &= ||\boldsymbol{F}_A||(\sin 40^\circ\,\hat{\mathbf{i}} + \cos 40^\circ\,\hat{\mathbf{j}}) \\ &\quad + ||\boldsymbol{F}_B||(\sin 20^\circ\,\hat{\mathbf{i}} - \cos 20^\circ\,\hat{\mathbf{j}})\end{aligned}$$

Setting the $\hat{\mathbf{j}}$ component of the resultant equal to zero:

$$F_{Ry} = (100\,\text{N})\cos 40^\circ - ||\boldsymbol{F}_B||\cos 20^\circ = 0$$

$$||\boldsymbol{F}_B|| = 81.5\,\text{N}$$

RESULTS (a): The tension in cable B must be:

$$\boxed{||\boldsymbol{F}_B|| = 81.5\,\text{N}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}\boldsymbol{F}_R &= (100\,\text{N})(\sin 40^\circ\,\hat{\mathbf{i}} + \cos 40^\circ\,\hat{\mathbf{j}}) \\ &\quad + (81.5\,\text{N})(\sin 20^\circ\,\hat{\mathbf{i}} - \cos 20^\circ\,\hat{\mathbf{j}}) \\ &= (92.2\,\hat{\mathbf{i}} + 0.0\,\hat{\mathbf{j}})\,\text{N}\end{aligned}$$

RESULTS (b): The resultant force is:

$$\boxed{\boldsymbol{F}_R = (92.2\,\hat{\mathbf{i}})\,\text{N}}$$

CHECK : Part (b) is a good check for part (a). Check calculations.

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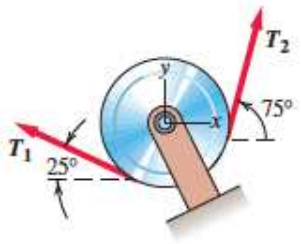
PROBLEM 2.6.19

Consider the frictionless pulley shown below. Because the pulley is frictionless, $\|\boldsymbol{T_1}\| = \|\boldsymbol{T_2}\|$.Express the resultant $\boldsymbol{R}$ of $\boldsymbol{T_1} + \boldsymbol{T_2}$ in terms of rectangular components. Also show that the line of action of $\boldsymbol{R}$ bisects the angle between $\boldsymbol{T_1}$ and $\boldsymbol{T_2}$.

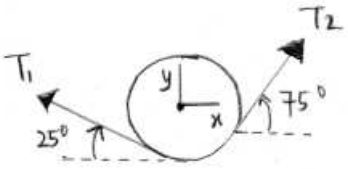


GOAL : Determine: (a) the resultant $\boldsymbol{R}_a = \boldsymbol{T}_1 + \boldsymbol{T}_2$ and show that the line of action bisects the angle between the two vectors.

GIVEN : The direction of the forces pulling on the pulley. The pulley is frictionless ($||\boldsymbol{T}_1|| = ||\boldsymbol{T}_2||$).

ASSUME : Planar.

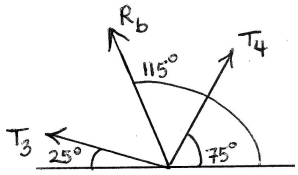
DRAW :



FORMULATE EQUATIONS and **SOLVE**

$$||\boldsymbol{T}|| = ||\boldsymbol{T}_1|| = ||\boldsymbol{T}_2||$$

$$\begin{aligned}
\boldsymbol{R} &= \boldsymbol{T}_1 + \boldsymbol{T}_2 \\
&= ||\boldsymbol{T}_1||(-\cos 25^\circ\,\hat{\mathbf{i}} + \sin 25^\circ\,\hat{\mathbf{j}}) \\
&+ ||\boldsymbol{T}_2||(\cos 75^\circ\,\hat{\mathbf{i}} + \sin 75^\circ\,\hat{\mathbf{j}}) \\
&= ||\boldsymbol{T}_b||(-0.647\,\hat{\mathbf{i}} + 1.389\,\hat{\mathbf{j}}) \\
||\boldsymbol{R}|| &= \sqrt{(-0.647||\boldsymbol{T}_b||)^2 + (1.389||\boldsymbol{T}_b||)^2} \\
&= 1.532||\boldsymbol{T}_b|| \\
\theta_x &= \cos^{-1}\left(\frac{\boldsymbol{R}_x}{||\boldsymbol{R}||}\right) = \cos^{-1}\left(\frac{-0.647||\boldsymbol{T}||}{1.532||\boldsymbol{T}||}\right) \\
&= 115.0^\circ
\end{aligned}$$



RESULTS (b): The resultant, $\boldsymbol{R}$ is

$$\boldsymbol{R} = ||\boldsymbol{T}||(-0.647\,\hat{\mathbf{i}} + 1.389\,\hat{\mathbf{j}})$$

$\theta_x = 115.0^\circ$, which bisects the angles of $\boldsymbol{T}_1$ and $\boldsymbol{T}_2$

CHECK : Verify calculations and note that the bisecting angle is a good check.

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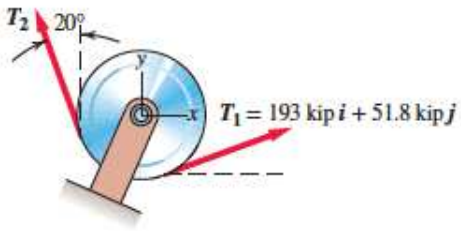
PROBLEM 2.6.20

The frictionless pulley shown below is such that the magnitude of $\boldsymbol{T_1}$ is equal to the magnitude of $\boldsymbol{T_2}$. Based on the information given in the figure, what are the scalar components of $\boldsymbol{T_2}$?

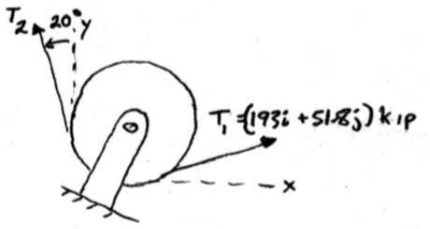


GOAL : To determine the scalar components of $\boldsymbol{T}_2$

GIVEN : Two forces pulling on a pulley in terms of their x and y components. The pulley is frictionless.

ASSUME : Planar system.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$||\boldsymbol{T}_1|| = \sqrt{(193\,\text{kip})^2 + (51.8\,\text{kip})^2} = 199.8\,\text{kip}$$

$$||\boldsymbol{T}_2|| = ||\boldsymbol{T}_1||$$

$$\begin{aligned}\boldsymbol{T}_{2x} &= ||\boldsymbol{T}_2||(-\sin 20^\circ) \\ &= 199.8\,\text{kip}(-\sin 20^\circ) = -68.3\,\text{kip}\end{aligned}$$

$$\begin{aligned}\boldsymbol{T}_{2y} &= ||\boldsymbol{T}_2||(\cos 20^\circ) \\ &= 199.8\,\text{kip}(\cos 20^\circ) = 187.8\,\text{kip}\end{aligned}$$

RESULTS :

$$\boxed{\begin{aligned}\boldsymbol{T}_{2x} &= -68.3\,\text{kip} \\ \boldsymbol{T}_{2y} &= 187.8\,\text{kip}\end{aligned}}$$

CHECK : Find the magnitude of $\boldsymbol{T}_2$ to make sure it is equal to $\|\boldsymbol{T}_1\|$:

$$\begin{aligned}||\boldsymbol{T}_2|| &= \sqrt{(-68.3\,\text{kip})^2 + (187.8\,\text{kip})^2} \\ &= 199.8\,\text{kip} = ||\boldsymbol{T}_1||\end{aligned}$$

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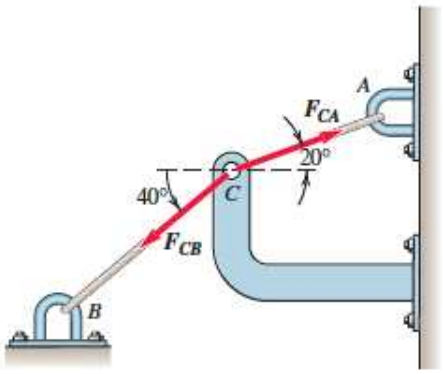
PROBLEM 2.6.21

An angle bracket is bolted to a wall as shown below. The cables A and B exert forces $\boldsymbol{F}_A$ and $\boldsymbol{F}_B$ on the bracket. The magnitude of $\boldsymbol{F}_A$ is 200 lb. The tension in cable BC has been adjusted so that the resultant force $(\boldsymbol{F}_{CA}+\boldsymbol{F}_{CB})$ is parallel to the wall to which the bracket is attached.

a. Find the magnitude of $\boldsymbol{F}_{CB}$.

b. Specify the resultant force $\boldsymbol{F}_R$ in vector notation.

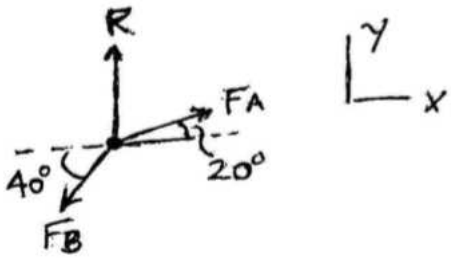


GOAL : To (a) find the magnitude of $\boldsymbol{F}_B$ and (b) express the resultant in vector notation.

GIVEN : Geometry of system, $||\boldsymbol{F}_A|| = 200$ lb, the tension in cable B has been adjusted so that the resultant force is vertical.

ASSUME : Planar.

DRAW : The diagram helps understand the problem. It is not a free-body diagram.



FORMULATE EQUATIONS and **SOLVE** (a):

$$\boldsymbol{F}_R = ||\boldsymbol{F}_A||(\cos 20^\circ\,\hat{\mathbf{i}} + \sin 20^\circ\,\hat{\mathbf{j}}) + ||\boldsymbol{F}_B||(-\cos 40^\circ\,\hat{\mathbf{i}} - \sin 40^\circ\,\hat{\mathbf{j}})$$

Setting the $\hat{\mathbf{i}}$ component of the resultant equal to zero:

$$F_{Rx} = (200\,\text{lb})\cos 20^\circ - ||\boldsymbol{F}_B||\cos 40^\circ = 0$$

$$||\boldsymbol{F}_B|| = 245.3\,\text{lb}$$

RESULTS (a): The tension in cable B must be:

$$\boxed{||\boldsymbol{F}_B|| = 245\,\text{lb}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}\boldsymbol{F}_R &= (200\,\text{lb})(\cos 20^\circ\,\hat{\mathbf{i}} + \sin 20^\circ\,\hat{\mathbf{j}}) \\ &\quad + (245.3\,\text{lb})(-\cos 40^\circ\,\hat{\mathbf{i}} - \sin 40^\circ\,\hat{\mathbf{j}}) \\ &= (0.0\,\hat{\mathbf{i}} - 89.3\,\hat{\mathbf{k}})\,\text{lb}\end{aligned}$$

RESULTS (b): The resultant force is:

$$\boxed{\boldsymbol{F}_R = (-89.3\,\hat{\mathbf{j}})\,\text{lb}}$$

CHECK : Part (b) is a good check for part (a). Check calculations.

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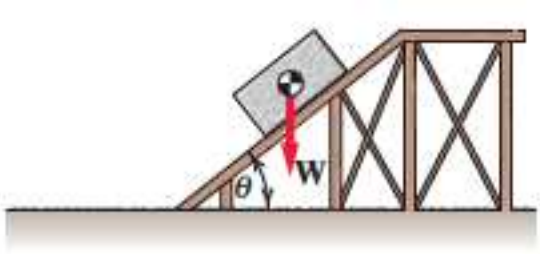
PROBLEM 2.6.22

A block of weight W sits on an inclined surface. The block will slide down the surface if the magnitude of $\boldsymbol{F}_{\text{friction}}$ (the friction force between the block and the surface) exceeds $1/3$ of the magnitude of the normal force. What is the maximum value of the incline angle θ at which the block will not slide down the surface?

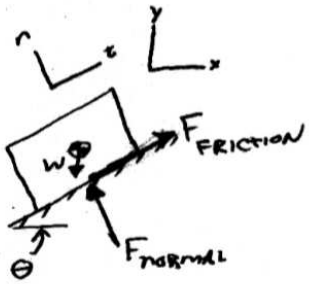


GOAL : Determine the maximum value of the angle of incline before block starts to slide.

GIVEN : The block weight, **W**. Sliding occurs if the friction force exceeds 1/3 of the normal force.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

When the block is not sliding, the normal force must balance the normal component of the weight, and the friction force must balance the parallel component of the weight:

$$\boldsymbol{F}_{\text{normal}} = W\cos\theta \tag{1}$$

$$\boldsymbol{F}_{\text{friction}} = W\sin\theta \tag{2}$$

$$\boldsymbol{F}_{\text{friction}} < \frac{1}{3}\boldsymbol{F}_{\text{normal}} \tag{3}$$

Substitute (1) and (2) into (3)

$$W\sin\theta < \frac{W}{3}\cos\theta$$

$$\tan\theta < \frac{1}{3}$$

$$\theta < \tan^{-1}\left(\frac{1}{3}\right) = 18.4^\circ$$

RESULTS :

$$\boxed{\theta < 18.4^\circ}$$

CHECK : Substitute the value for θ back into equations (1), (2), and (3) to check that the friction force is less than $1/3$ the normal force.

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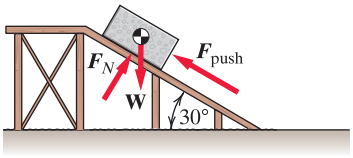
PROBLEM 2.6.23

The forces acting on a block are gravity ($\boldsymbol{W}$, magnitude 10 lb), a normal contact force ($\boldsymbol{F}_N$), and a push force ($\boldsymbol{F}_{\text{push}}$), as shown. The surface on which the block rests is smooth, so there is no friction force. If the sum of the forces acting on the block is zero, use component force addition to determine the magnitudes of $\boldsymbol{F}_N$ and $\boldsymbol{F}_{\text{push}}$?

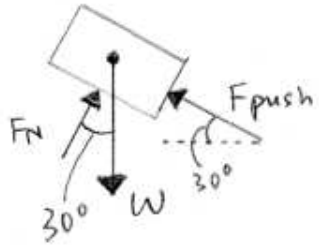


GOAL : Determine, using component force addition, the normal and the push forces so that the resultant force acting on the block is zero.

GIVEN : The resultant force on the block is zero, **W** = 10 lb, and the surface is smooth.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

From the free-body diagram, we can obtain the resultant force by adding all the forces.

$$\begin{aligned}\boldsymbol{F}_R &= -\boldsymbol{W}\,\hat{\mathbf{j}} - \boldsymbol{F}_{\text{push}}\cos 30^\circ\,\hat{\mathbf{i}} + \boldsymbol{F}_{\text{push}}\sin 30^\circ\,\hat{\mathbf{j}} \\ &\quad + \boldsymbol{F}_{\text{N}}\sin 30^\circ\,\hat{\mathbf{i}} + \boldsymbol{F}_{\text{N}}\cos 30^\circ\,\hat{\mathbf{j}} \\ \boldsymbol{F}_R &= (-\boldsymbol{F}_{\text{push}}\cos 30^\circ + \boldsymbol{F}_{\text{N}}\sin 30^\circ)\,\hat{\mathbf{i}} \\ &\quad + (-\boldsymbol{W} + \boldsymbol{F}_{\text{push}}\sin 30^\circ + \boldsymbol{F}_{\text{N}}\cos 30^\circ)\,\hat{\mathbf{j}}\end{aligned}$$

We know that the sum of forces is zero. This means

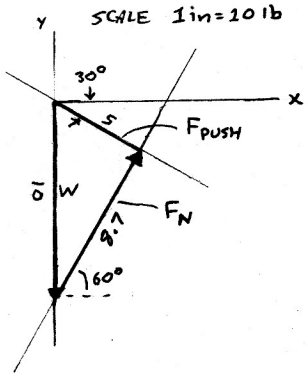
$$\begin{aligned}-\boldsymbol{F}_{\text{push}}\cos 30^\circ + \boldsymbol{F}_{\text{N}}\sin 30^\circ &= 0 \\ \boldsymbol{F}_{\text{push}}\sin 30^\circ + \boldsymbol{F}_{\text{N}}\cos 30^\circ &= \boldsymbol{W}\end{aligned}$$

Solving this simultaneously will give $\boldsymbol{F}_{\text{push}}$ and $\boldsymbol{F}_{\text{N}}$.

RESULTS :
With the equations, we get

$$\boxed{F_N = 8.66\,\text{lb}, \quad F_{push} = 5\,\text{lb}}$$

CHECK : Use graphical method as shown below.



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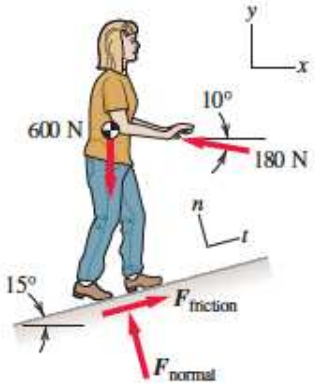
PROBLEM 2.6.24

A person who weighs 600 N is pushing a refuse container up a 15° incline. The forces acting on the person are shown. if the resultant force in direction n is zero, what is the magnitude of $\mathbf{F}_{normal}$?

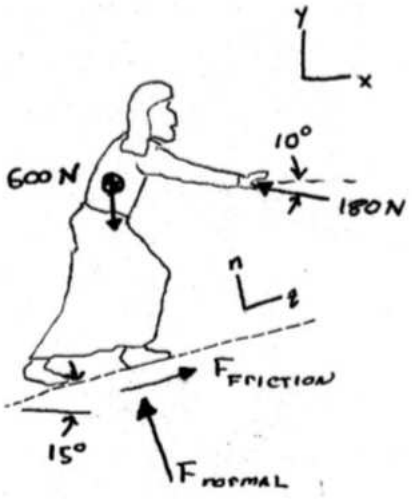


GOAL : To determine the normal force.

GIVEN : Forces acting on a woman pushing a refuse container up a 15° incline.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Sum force normal to slope.

$$\sum \boldsymbol{F}_n = \boldsymbol{F}_{\text{normal}} - (600\,\text{N})\cos 15^\circ + (180\,\text{N})\sin 25^\circ = 0$$

$$\boldsymbol{F}_{\text{normal}} = 503\,\text{N}$$

RESULTS (b): The normal force is:

$$\boxed{\boldsymbol{F}_{\text{normal}} = 503\,\text{N}}$$

CHECK : A thorough check would be to find the sum of the vertical and horizontal forces and ensure that each sum is zero.

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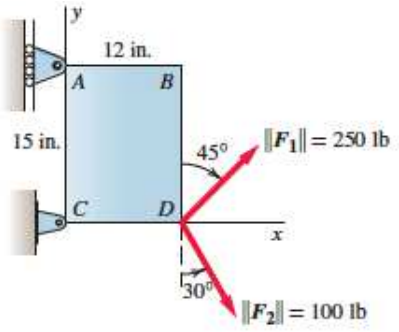
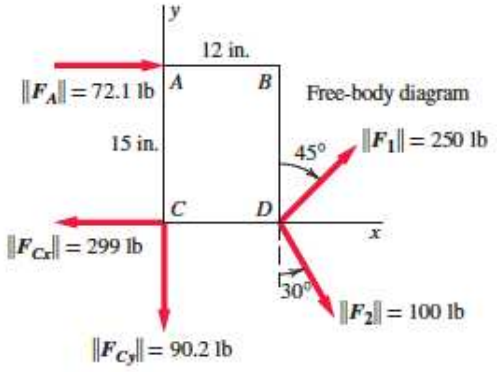
PROBLEM 2.6.25

Redraw the free-body diagram shown to represent $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ as a single force $\boldsymbol{F}_R$ acting at D and $\boldsymbol{F}_{Cx}$ and $\boldsymbol{F}_{Cy}$ as a single force $\boldsymbol{F}_C$ acting at C. Write $\boldsymbol{F}_R$ and $\boldsymbol{F}_C$ in terms of $\boldsymbol{i}$ and $\boldsymbol{j}$.





GOAL : To redraw the free body diagram with $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ as a single force $\boldsymbol{F}_R$ acting at D and $\boldsymbol{F}_{Cx}$ and $\boldsymbol{F}_{Cy}$ as a single force $\boldsymbol{F}_C$ acting at C.

GIVEN : The free-body diagram of the system.

ASSUME : Planar.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

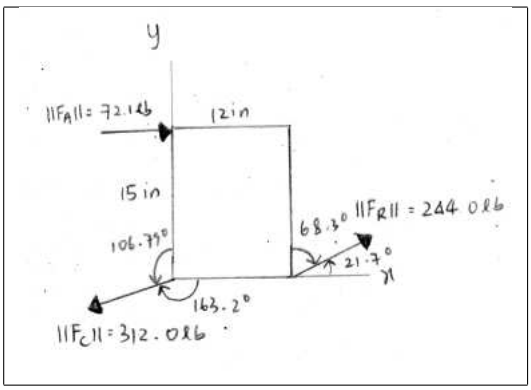
For $\boldsymbol{F}_C$,

$$\begin{aligned}
\boldsymbol{F}_C &= -299\,\text{lb}\,\hat{\mathbf{i}} - 90.2\,\text{lb}\,\hat{\mathbf{j}} \\
||\boldsymbol{F}_C|| &= \sqrt{(-299\,\text{lb})^2 + (-90.2\,\text{lb})^2} \\
&= 312.31\,\text{lb} \\
\theta_x &= \cos^{-1}\left(\frac{F_{Cx}}{||\boldsymbol{F}_C||}\right) = cos^{-1}\left(\frac{-299}{312.31}\right) \\
&= 163.2^\circ \\
\theta_y &= \cos^{-1}\left(\frac{F_{Cy}}{||\boldsymbol{F}_C||}\right) = cos^{-1}\left(\frac{-90.2}{312.31}\right) \\
&= 106.8^\circ
\end{aligned}$$

For $\boldsymbol{F}_R$,

$$\begin{aligned}
\boldsymbol{F}_R &= 250\,\text{lb}\sin 45^\circ\,\hat{\mathbf{i}} + 250\,\text{lb}\cos 45^\circ\,\hat{\mathbf{j}} \\
&\quad + 100\,\text{lb}\sin 30^\circ\,\hat{\mathbf{i}} - 100\,\text{lb}\cos 30^\circ\,\hat{\mathbf{j}} \\
&= 226.78\,\hat{\mathbf{i}} + 90.17\,\hat{\mathbf{j}} \\
||\boldsymbol{F}_R|| &= \sqrt{(226.78\,\text{lb})^2 + (90.17\,\text{lb})^2} \\
&= 244.05\,\text{lb} \\
\theta_x &= \cos^{-1}\left(\frac{F_{Rx}}{||\boldsymbol{F}_R||}\right) = cos^{-1}\left(\frac{226.78}{244.05}\right) \\
&= 21.7^\circ \\
\theta_y &= \cos^{-1}\left(\frac{F_{Cy}}{||\boldsymbol{F}_C||}\right) = cos^{-1}\left(\frac{90.17}{244.05}\right) \\
&= 68.3^\circ
\end{aligned}$$

RESULTS (b): The redrawn free-body diagram looks like:



CHECK : Check the original free-body diagram to make sure forces appear correct.

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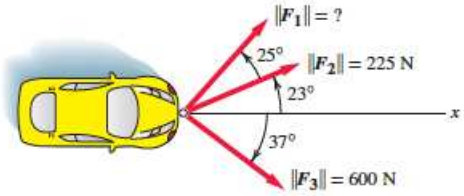
PROBLEM 2.6.26

Three ropes attached to a stalled car apply the forces shown. Determine the magnitude of $\boldsymbol{F_1}$ and the magnitude of the resultant $\boldsymbol{F_R}$ if the line of action of the resultant is along the x axis.

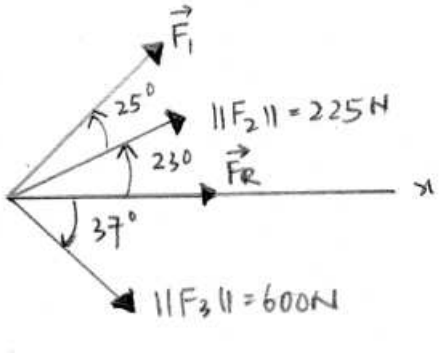


GOAL : To determine the magnitudes of $\boldsymbol{F}_1$ and $\boldsymbol{F}_R$ so that the resultant lies along the x axis.

GIVEN : Magnitude and orientation of the forces on a stalled car.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_R = &||\boldsymbol{F_1}||(\cos 48^\circ\,\hat{\mathbf{i}} + \sin 48^\circ\,\hat{\mathbf{j}}) \\ &+ 225\,\text{N}(\cos 23^\circ\,\hat{\mathbf{i}} + \sin 23^\circ\,\hat{\mathbf{j}}) \\ &+ 600\,\text{N}(\cos 37^\circ\,\hat{\mathbf{i}} - \sin 37^\circ\,\hat{\mathbf{j}})\end{aligned} \tag{1}$$

The y component of $\boldsymbol{F}_R$ must be zero if the line of action of the resultant is along the x axis:

$$\begin{aligned}\boldsymbol{F}_{Ry} &= ||\boldsymbol{F_1}||\sin 48^\circ + 87.9\,\text{N} - 361.1\,\text{N} = 0 \\ &= ||\boldsymbol{F_1}||\sin 48^\circ - 273.2\,\text{N} = 0\end{aligned}$$

$$||\boldsymbol{F}_1|| = 367.6\,\text{N}$$

Substituting back into (1) to find $\boldsymbol{F}_R$:

$$\boldsymbol{F}_R = (932.3\,\hat{\mathbf{i}} + 0\,\hat{\mathbf{j}})\,\text{N}$$

$$||\boldsymbol{F}_R|| = 932.3\,\text{N}$$

RESULTS :

$$\boxed{\begin{aligned}||\boldsymbol{F}_3|| &= 368\,\text{N} \\ ||\boldsymbol{F}_R|| &= 932\,\text{N}\end{aligned}}$$

CHECK : Solving for $||\boldsymbol{F}_R||$ checked that the value for $||\boldsymbol{F}_1||$ produced a zero y component of $\boldsymbol{F}_R$. Additional checks of calculations are recommended.

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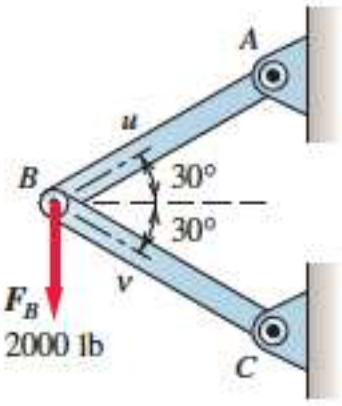
PROBLEM 2.6.27

A 2000-lb force is resisted by two pipe struts as shown below. Three forces act on the pin at B (the applied load, $\boldsymbol{F}_u$, and $\boldsymbol{F}_v$). Given the resultant force acting on the pin is zero, determine

a. the projection $\boldsymbol{F}_u$ of the force along the axis of strut AB

b. the projection $\boldsymbol{F}_v$ of the force along the axis of strut BC

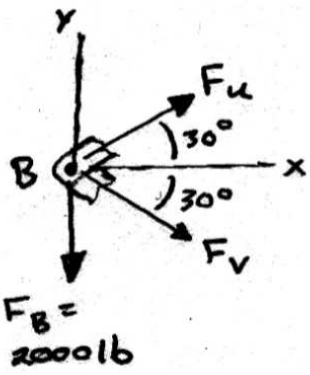


GOAL : Determine the components of force along line AB and line BC.

GIVEN : Magnitude of vertical force, angles of orientation of pipe struts.

ASSUME : Planar.

DRAW : Free-body diagram of point B



FORMULATE EQUATIONS and **SOLVE** :

Call $\mathbf{R}_B$ the resultant of the forces applied at B.

$$\mathbf{R}_B = -2000\,\text{lb}\,\hat{\mathbf{j}} + ||\boldsymbol{F}_u||(\cos 30^\circ\,\hat{\mathbf{i}} + \sin 30^\circ\,\hat{\mathbf{j}}) + ||\boldsymbol{F}_v||(\cos 30^\circ\,\hat{\mathbf{i}} - \sin 30^\circ\,\hat{\mathbf{j}}) = 0$$

Examining the $\hat{\mathbf{i}}$ components:

$$0 = ||\boldsymbol{F}_u||\cos 30^\circ + ||\boldsymbol{F}_v||\cos 30^\circ$$

$$||\boldsymbol{F}_u|| = -||\boldsymbol{F}_v|| \tag{1}$$

Examining the $\hat{\mathbf{j}}$ components:

$$0 = -2000\,\text{lb} + ||\boldsymbol{F}_u||\sin 30^\circ - ||\boldsymbol{F}_v||\sin 30^\circ$$

Substitute from (1)

$$0 = -2000\,\text{lb} + 2||\boldsymbol{F}_u||\sin 30^\circ$$

$$||\boldsymbol{F}_u|| = \frac{2000\,\text{lb}}{2\sin 30^\circ} = 2000\,\text{lb}$$

Substitute $||\boldsymbol{F}_u||$ into (1)

$$||\boldsymbol{F}_v|| = -||\boldsymbol{F}_u|| = -2000\,\text{lb}$$

RESULTS :

$$\boxed{\begin{aligned} ||\boldsymbol{F}_u|| &= 2000\,\text{lb} \\ ||\boldsymbol{F}_v|| &= -2000\,\text{lb} \end{aligned}}$$

CHECK : Ensure that the resultant force at B is zero:

$$\sum \boldsymbol{F} = -2000\,\text{lb}\,\hat{\mathbf{j}} + 2000\,\text{lb}(\cos 30^\circ\,\hat{\mathbf{i}} + \sin 30^\circ\,\hat{\mathbf{j}}) + (-2000\,\text{lb})(\cos 30^\circ\,\hat{\mathbf{i}} - \sin 30^\circ\,\hat{\mathbf{j}}) = 0$$

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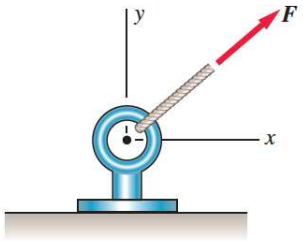
PROBLEM 2.6.28

You have designed a bracket to support a force $\boldsymbol{F} = F_x\boldsymbol{i} + F_y\boldsymbol{j}$. The design is such that the magnitude of $\boldsymbol{F}$ should not exceed 1000 N. If F_x ranges from –750 N $\leq F_x \leq$ 500 N, what is the range of F_y that can be safely supported by the bracket? (Assume that F_x and F_y are independent of each other.)

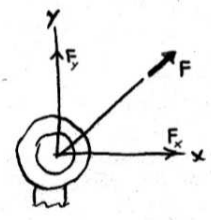


GOAL : To determine the range of F_y that can be supported by the bracket.

GIVEN : $||\boldsymbol{F}|| < 1000\,\text{N}$, $-750\,\text{N} < F_x < 500\,\text{N}$.

ASSUME : Planar and that F_x and F_y are independent. Also assume $F_y > 0$.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$||\boldsymbol{F}|| = \sqrt{(F_x)^2 + (F_y)^2} < 1000\,\text{N}$$

$$F_y < \sqrt{(1000\,\text{N})^2 - (F_x)^2}$$

Check the limiting case (largest $F_x = -750\,\text{N}$):

$$F_{y,\max} = \sqrt{(1000\,\text{N})^2 - (-750\,\text{N})^2} = 661.4\,\text{N}$$

RESULTS :

$$\boxed{0\,\text{N} < F_y < 661\,\text{N}}$$

CHECK : Ensure the magnitude of $\boldsymbol{F}$ with $F_{y,\max}$ is less than the maximum.

$$||\boldsymbol{F}|| = \sqrt{(-750\,\text{N})^2 + (661\,\text{N})^2} = 999.7 < 1000\,\text{N}$$

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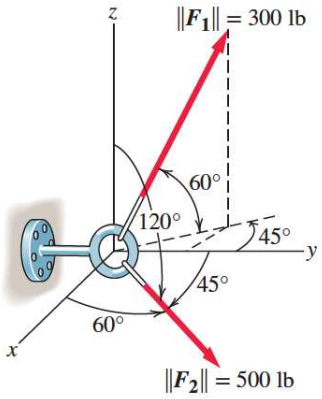
PROBLEM 2.6.29

Two forces $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ are applied to an eyelet as shown below. Determine the resultant $\boldsymbol{T}_R\,(=\boldsymbol{F_1}+\boldsymbol{F_2})$, and write it in vector notation.

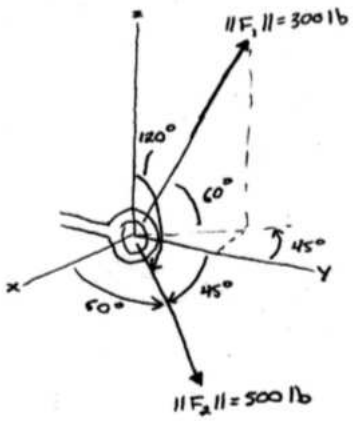


GOAL : Determine the resultant force in vector notation.

GIVEN : Magnitude and orientation of two forces applied to an eyelet.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\boldsymbol{F}_1 = (300\,\text{lb})((\cos 60^\circ \cos 135^\circ)\,\hat{\mathbf{i}} + (\cos 60^\circ \sin 135^\circ)\,\hat{\mathbf{j}} + \sin 60^\circ\,\hat{\mathbf{k}})$$

$$\boldsymbol{F}_2 = (500\,\text{lb})(\cos 60^\circ\,\hat{\mathbf{i}} + \cos 45^\circ\,\hat{\mathbf{j}} + \cos 120^\circ\,\hat{\mathbf{k}})$$

$$\boldsymbol{F}_R = \boldsymbol{F}_1 + \boldsymbol{F}_2$$
$$= (143.9\,\hat{\mathbf{i}} + 459.6\,\hat{\mathbf{j}} + 9.81\,\hat{\mathbf{k}})\,\text{lb}$$

RESULTS :

$$\boxed{\boldsymbol{F}_R = (143.9\,\hat{\mathbf{i}} + 460.\,\hat{\mathbf{j}} + 9.81\,\hat{\mathbf{k}})\,\text{lb}}$$

CHECK : Visual inspection shows that the y component of the resultant must be positive since both forces are in the positive y direction. There is not another good check.

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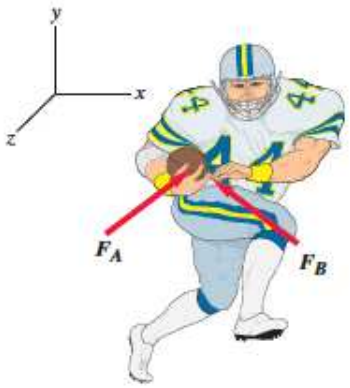
PROBLEM 2.6.30

A football player is tackled simultaneously by two players as shown. Tackler A exerts a force $\boldsymbol{F_A}$ on the player of 1000 N along a line of action described by $\boldsymbol{u}_A = 0.216\boldsymbol{i} + 0.108\boldsymbol{j} - 0.970\boldsymbol{k}$. If the resultant force on the player is 1980 N acting along $\boldsymbol{u}_R = -0.139\,\boldsymbol{i} + 0.096\boldsymbol{j} - 0.986\,\boldsymbol{k}$, find the magnitude of $\boldsymbol{F_B}$ and write the force in vector notation.



GOAL : Determine the magnitude of $\boldsymbol{F_B}$ and write it in vector notation.

GIVEN : The unit vectors and forces of tackler A and the resultant force.

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F_A} &= 1000\,\text{N}(0.216\,\hat{\mathbf{i}} + 0.108\,\hat{\mathbf{j}} - 0.970\,\hat{\mathbf{k}}) \\ &= 216\,\text{N}\,\hat{\mathbf{i}} + 108\,\text{N}\,\hat{\mathbf{j}} - 970\,\text{N}\,\hat{\mathbf{k}} \\ \boldsymbol{F_R} &= 1000\,\text{N}(-0.139\,\hat{\mathbf{i}} + 0.096\,\hat{\mathbf{j}} - 0.986\,\hat{\mathbf{k}}) \\ &= -275.22\,\text{N}\,\hat{\mathbf{i}} + 190.08\,\text{N}\,\hat{\mathbf{j}} - 1952.28\,\text{N}\,\hat{\mathbf{k}}\end{aligned}$$

We know that $\boldsymbol{F_B} = \boldsymbol{F_R} - \boldsymbol{F_A}$, and this means,

$$\boldsymbol{F_B} = -491.22\,\text{N}\,\hat{\mathbf{i}} + 82.08\,\text{N}\,\hat{\mathbf{j}} - 2922.28\,\text{N}\,\hat{\mathbf{k}}$$

RESULTS :
With the equation above, we get,

$$\boxed{\begin{aligned}\boldsymbol{F_B} &= -491.2\,\text{N}\,\hat{\mathbf{i}} + 82.1\,\text{N}\,\hat{\mathbf{j}} - 2922.3\,\text{N}\,\hat{\mathbf{k}} \\ ||\boldsymbol{F_B}|| &= 2964\,\text{N}\end{aligned}}$$

CHECK : Double checking the calculations of both $\boldsymbol{F_A}$ and $\boldsymbol{F_B}$.

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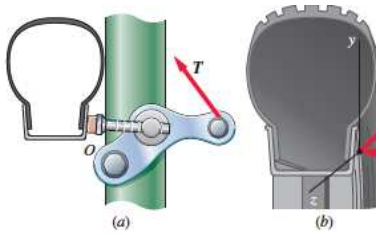
PROBLEM 2.6.30

When the brake is applied to the bicycle wheel in (a) it generates a force $\boldsymbol{F}_{\text{brake}}$ normal to the rim and a force $\boldsymbol{F}_{\text{friction}}$ parallel to the rim (b). Due to the slight slant of the rim flange, $||\boldsymbol{F}_{\text{brake}}||$ is oriented 3° below the x-axis in the xy plane. If $||\boldsymbol{F}_{\text{brake}}||$ is 15 lb and $||\text{F}_{\text{friction}}||$ is 8.25 lb, determine the resultant $\boldsymbol{R}$ force action on the rim and write it in vector notation.

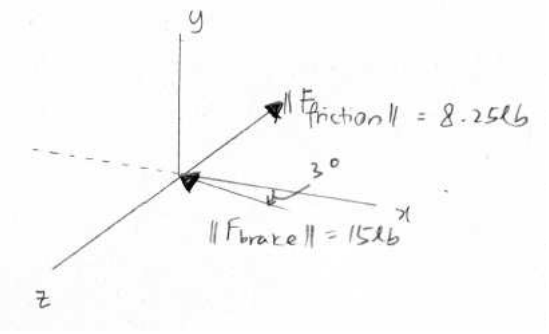


GOAL : Determine the magnitude of the resultant force ,$\boldsymbol{R}$.

GIVEN : The magnitude and the orientation of the both forces.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

We will write each of the forces in vector notation.

$$\boldsymbol{F}_{\text{friction}} = -||\boldsymbol{F}_{\text{friction}}||\hat{\mathbf{k}}$$
$$\boldsymbol{F}_{\text{brake}} = -||\boldsymbol{F}_{\text{brake}}||\cos 3^\circ\,\hat{\mathbf{i}} - ||\boldsymbol{F}_{\text{brake}}||\sin 3^\circ\;\boldsymbol{j}$$

We then sum both to to obtain $\boldsymbol{R}$.

$$\boldsymbol{R} = \boldsymbol{F}_{\text{friction}} + \boldsymbol{F}_{\text{brake}}$$
$$= -||\boldsymbol{F}_{\text{brake}}||\cos 3^\circ\,\hat{\mathbf{i}} - ||\boldsymbol{F}_{\text{friction}}||\;\boldsymbol{k}\;\;||\boldsymbol{F}_{\text{brake}}||\sin 3^\circ)\;\hat{\mathbf{k}}$$

RESULTS :
With the equation above, we substitute the magnitudes and we get,

$$\boldsymbol{R} = -\boxed{14.98\text{ lb}\,\hat{\mathbf{i}} + .785\text{ lb j} - 8.25\text{ lb}\,\boldsymbol{k}}$$

CHECK : Double checking the calculations.

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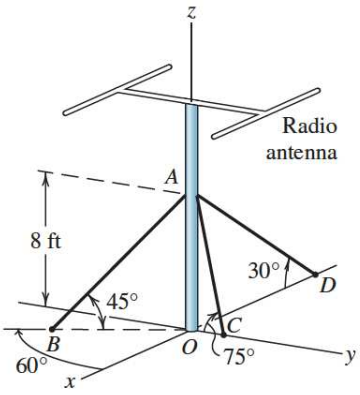
PROBLEM 2.6.32

A radio antenna is supported by three guy wires. The tensile force in wires AB, AC, and AD are 20 kN, 25 kN, and 30 kN, respectively. Determine the resultant $\boldsymbol{T}_R\,(=\boldsymbol{T}_{\mathbf{AB}}+\boldsymbol{T}_{\mathbf{AC}}+\boldsymbol{T}_{\mathbf{AD}})$ acting at A, and write it in vector notation.

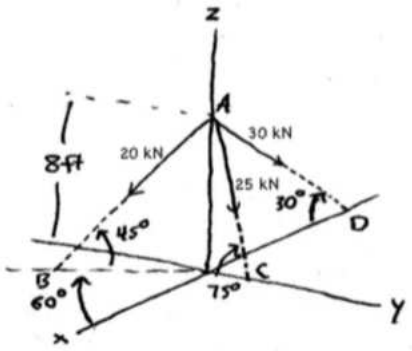


GOAL : Find the resultant force, $\boldsymbol{T}_R$, acting at A and write in vector notation.

GIVEN : The tensile forces in the cables AB, AC and AD are 20 kN, 25 kN, and 30 kN. The dimensions of the antenna and locations of the points B, C, and D are given in the figure.

ASSUME : The antenna is in equilibrium.

DRAW : the forces acting at point A:



FORMULATE EQUATIONS : Decompose the forces in cablesAB, AC and AD into their components in the x, y, and z directions.

By inspection, the components of cable AB are:

$$||\mathbf{T}_{AB}|| = 20\,\text{kN}$$

$$T_{AB,x} = (||\mathbf{T}_{AB}||\cos 45^\circ)(\cos 60^\circ) = 7.07\,\text{kN}$$

$$T_{AB,y} = -(||\mathbf{T}_{AB}||\cos 45^\circ)(\sin 60^\circ) = -12.2\,\text{kN}$$

$$T_{AB,z} = -||\mathbf{T}_{AB}||\sin 45^\circ = -14.1\,\text{kN}$$

Cable AC lies in the yz plane, and by inspection the components are:

$$||\mathbf{T}_{AB}|| = 25\,\text{kN}$$

$$T_{AC,x} = 0\,\text{kN}$$

$$T_{AC,y} = ||\mathbf{T}_{AC}||\cos 75^\circ = 6.47\,\text{kN}$$

$$T_{AC,z} = -||\mathbf{T}_{AC}||\sin 75^\circ = -24.1\,\text{kN}$$

Cable AD lies in the xz plane, and by inspection the components are:

$$||\mathbf{T}_{AB}|| = 30\,\text{kN}$$

$$T_{AD,x} = -||\mathbf{T}_{AD}||\cos 30^\circ = -26.0\,\text{kN}$$

$$T_{AD,y} = 0\,\text{kN}$$

$$T_{AD,z} = -||\mathbf{T}_{AD}||\sin 30^\circ = -15.0\,\text{kN}$$

SOLVE : The resultant force at A can be found by summing the components from the three cable tensions:

$$T_{A,x} = T_{AB,x} + T_{AC,x} + T_{AD,x} = -18.9\,\text{kN}$$

$$T_{A,y} = T_{AB,y} + T_{AC,y} + T_{AD,y} = -5.70\,\text{kN}$$

$$T_{A,z} = T_{AB,z} + T_{AC,z} + T_{AD,z} = -53.2\,\text{kN}$$

Which can be expressed in vector form as:

$$\boxed{\mathbf{T}_A = -18.9\,\text{kN}i - 5.70\,\text{kN}j - 53.2\,\text{kN}k}$$

CHECK : The z-component of our answer is relatively large and negative, as all three cable forces have negative z-components. By picturing a top view of the system, looking down on the xy plane, we can also see that the x- and y- components should be negative, as we computed.

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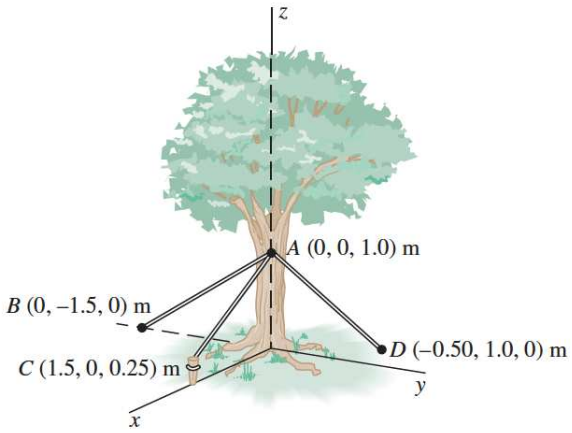
PROBLEM 2.6.33

Three cables brace a newly planted tree as shown. Each cable has a tension of 250 N. Determine the resultant force $\boldsymbol{F}_R$ acting on the tree as a result of the three cables. Express $\boldsymbol{F}_R$ in terms of the right-handed orthogonal unit vectors $\boldsymbol{i}, \boldsymbol{j}$, and $\boldsymbol{k}$.

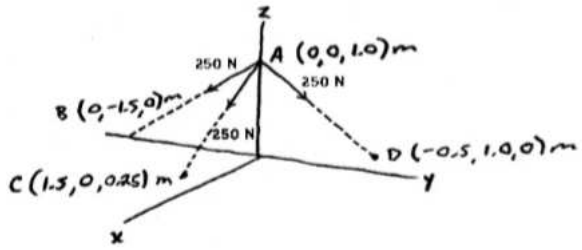


GOAL : To determine the resultant force, $\boldsymbol{F}_R$, acting on the tree.

GIVEN : End points of three cables supporting a newly planted tree. Each cable has a tension of 250 N.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\hat{\boldsymbol{u}}_{AB} = \frac{(0\,\hat{\mathbf{i}} - 1.5\,\hat{\mathbf{j}} - 1.0\,\hat{\mathbf{k}})}{\sqrt{(0)^2 + (-1.5)^2 + (-1.0)^2}}$$

$$= (0\,\hat{\mathbf{i}} - 0.832\,\hat{\mathbf{j}} - 0.555\,\hat{\mathbf{k}})$$

$$\hat{\boldsymbol{u}}_{AC} = \frac{(1.5\,\hat{\mathbf{i}} + 0\,\hat{\mathbf{j}} - 0.75\,\hat{\mathbf{k}})}{\sqrt{(1.5)^2 + (0)^2 + (-0.75)^2}}$$

$$= (0.894\,\hat{\mathbf{i}} + 0\,\hat{\mathbf{j}} - 0.447\,\hat{\mathbf{k}})$$

$$\hat{\boldsymbol{u}}_{AD} = \frac{(-0.5\,\hat{\mathbf{i}} + 1.0\,\hat{\mathbf{j}} - 1.0\,\hat{\mathbf{k}})}{\sqrt{(-0.5)^2 + (1.0)^2 + (-1.0)^2}}$$

$$= (-0.333\,\hat{\mathbf{i}} + 0.667\,\hat{\mathbf{j}} - 0.667\,\hat{\mathbf{k}})$$

$$\boldsymbol{T}_{AB} = ||\boldsymbol{T}_{AB}||\hat{\boldsymbol{u}}_{AB} = (-208\,\hat{\mathbf{j}} - 138.7\,\hat{\mathbf{k}})\ \text{N}$$

$$\boldsymbol{T}_{AC} = ||\boldsymbol{T}_{AC}||\hat{\boldsymbol{u}}_{AC} = (224\,\hat{\mathbf{i}} - 111.8\,\hat{\mathbf{k}})\ \text{N}$$

$$\boldsymbol{T}_{AD} = ||\boldsymbol{T}_{AD}||\hat{\boldsymbol{u}}_{AD} = (-83.3\,\hat{\mathbf{i}} + 166.7\,\hat{\mathbf{j}} - 166.7\,\hat{\mathbf{k}})\ \text{N}$$

$$\boldsymbol{T}_R = \boldsymbol{T}_{AD} + \boldsymbol{T}_{AB} + \boldsymbol{T}_{AC} = (140.7\,\hat{\mathbf{i}} - 41.3\,\hat{\mathbf{j}} - 417\,\hat{\mathbf{k}})\ \text{N}$$

RESULTS :

$$\boxed{\boldsymbol{T}_R = (140.7\,\hat{\mathbf{i}} - 41.3\,\hat{\mathbf{j}} - 417\,\hat{\mathbf{k}})\ \text{N}}$$

CHECK : Check of the results are reasonable. Visual inspection shows that the x component should be positive, the y component negative but close to zero, and the z component large and negative.

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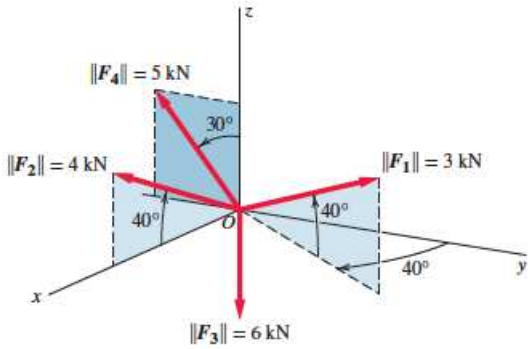
PROBLEM 2.6.34

Four forces applied to an object are concurrent at O as shown. Determine the magnitude of the resultant $\boldsymbol{F}_R$ of the four forces.

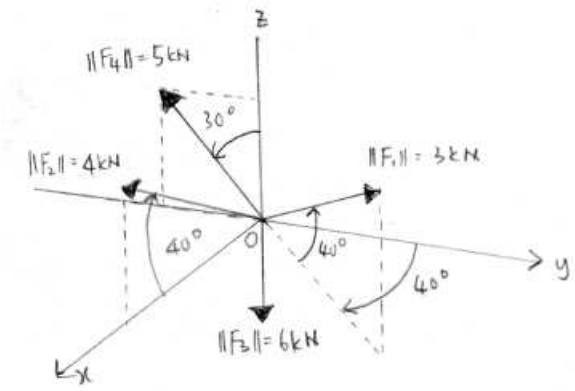


GOAL : To determine the magnitude of the resultant force.

GIVEN : Magnitude and orientation of four forces.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_R &= [(3\cos 40^\circ \sin 40^\circ + 4\cos 40^\circ)\,\hat{\mathbf{i}} \\ &\quad + (3\cos 40^\circ \cos 40^\circ - 5\sin 30^\circ)\,\hat{\mathbf{j}} \\ &\quad + (3\sin 40^\circ + 4\sin 40^\circ - 6 + 5\cos 30^\circ)\,\hat{\mathbf{k}}]\ \text{kN} \\ &= (4.54\,\hat{\mathbf{i}} - 0.740\,\hat{\mathbf{j}} + 2.83\,\hat{\mathbf{k}})\ \text{kN}\end{aligned}$$

$$\begin{aligned}||\boldsymbol{F}_R|| &= \sqrt{(4.54\,\text{kN})^2 + (-0.740\,\text{kN})^2 + (2.83\,\text{kN})^2} \\ &= 5.40\,\text{kN}\end{aligned}$$

RESULTS :

$$\boxed{||\boldsymbol{F}_R|| = 5.40\,\text{kN}}$$

CHECK : Ensure magnitude seems reasonable and check calculations.

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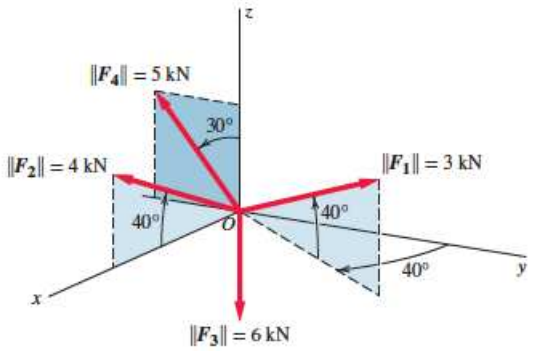
PROBLEM 2.6.35

Four forces applied to an object are concurrent at O as shown. Determine the space angles θ_x, θ_y, and θ_z between the line of action of the resultant and the positive x, y, and z coordinate axes.

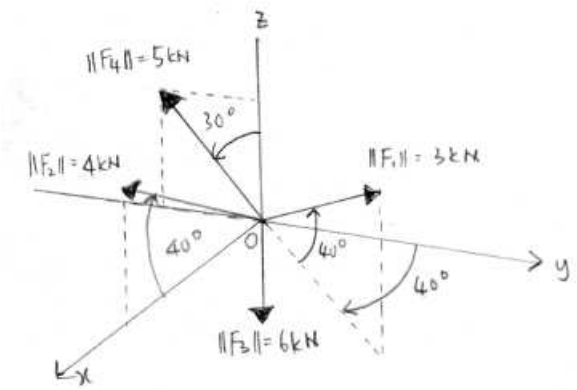


GOAL : To determine the magnitude of the resultant force and the space angles.

GIVEN : Magnitude and orientation of four forces.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_R &= [(3\cos 40^\circ \sin 40^\circ + 4\cos 40^\circ)\,\hat{\mathbf{i}} \\ &\quad + (3\cos 40^\circ \cos 40^\circ - 5\sin 30^\circ)\,\hat{\mathbf{j}} \\ &\quad + (3\sin 40^\circ + 4\sin 40^\circ - 6 + 5\cos 30^\circ)\,\hat{\mathbf{k}}]\ \text{kN} \\ &= (4.54\,\hat{\mathbf{i}} - 0.740\,\hat{\mathbf{j}} + 2.83\,\hat{\mathbf{k}})\ \text{kN}\end{aligned}$$

$$\begin{aligned}||\boldsymbol{F}_R|| &= \sqrt{(4.54\,\text{kN})^2 + (-0.740\,\text{kN})^2 + (2.83\,\text{kN})^2} \\ &= 5.40\,\text{kN}\end{aligned}$$

The space angles can be calculated as such.

$$\begin{aligned}\theta_x &= \cos^{-1}\left(\frac{F_{Rx}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{4.54}{5.40}\right) \\ &= 32.8^\circ \\ \theta_y &= \cos^{-1}\left(\frac{F_{Ry}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{-0.74}{5.40}\right) \\ &= 97.9^\circ \\ \theta_z &= \cos^{-1}\left(\frac{F_{Rz}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{2.83}{5.40}\right) \\ &= 58.4^\circ\end{aligned}$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 32.8^\circ \\ \theta_y &= 97.9^\circ \\ \theta_z &= 58.4^\circ\end{aligned}}$$

CHECK : Ensure the space angles seem reasonable and check calculations.

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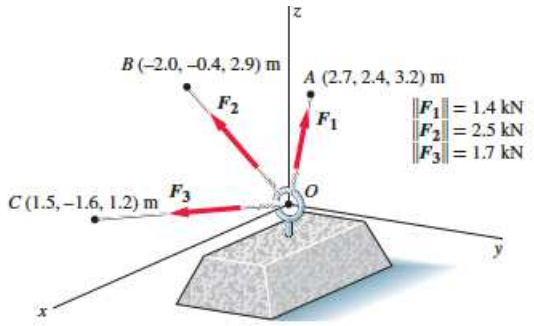
PROBLEM 2.6.36

Three forces are applied with cables to the anchor block shown below. Determine

a. the resultant $\boldsymbol{F}_R$ in terms of its rectangular components

b. the magnitude of the force that tends to pull the block upward (in the z direction)

c. the magnitude of the force that tends to slide the block along the ground (in the xy plane)

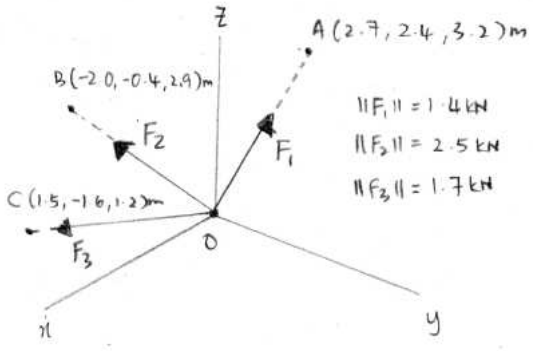


GOAL : Determine (a) the resultant in vector notation, (b) the magnitude of the upward (along z axis) force, (c) the magnitude of the sliding force (in the xy plane).

GIVEN : Magnitude and line of action forces applied to an anchor block.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\boldsymbol{F}_1 = \frac{(1.4\,\text{kN})\left[(2.7\,\text{m})\,\hat{\mathbf{i}} + (2.4\,\text{m})\,\hat{\mathbf{j}} + (3.2\,\text{m})\,\hat{\mathbf{k}}\right]}{\sqrt{(2.7\,\text{m})^2 + (2.4\,\text{m})^2 + (3.2\,\text{m})^2}}$$
$$= (0.78\,\hat{\mathbf{i}} + 0.70\,\hat{\mathbf{j}} + 0.93\,\hat{\mathbf{k}})\,\text{kN}$$

$$\boldsymbol{F}_2 = \frac{(2.5\,\text{kN})\left[(-2.0\,\text{m})\,\hat{\mathbf{i}} + (-0.4\,\text{m})\,\hat{\mathbf{j}} + (2.9\,\text{m})\,\hat{\mathbf{k}}\right]}{\sqrt{(-2.0\,\text{m})^2 + (-0.4\,\text{m})^2 + (2.9\,\text{m})^2}}$$
$$= (-1.41\,\hat{\mathbf{i}} - 0.28\,\hat{\mathbf{j}} + 2.05\,\hat{\mathbf{k}})\,\text{kN}$$

$$\boldsymbol{F}_3 = \frac{(1.7\,\text{kN})\left[(1.5\,\text{m})\,\hat{\mathbf{i}} + (-1.6\,\text{m})\,\hat{\mathbf{j}} + (1.2\,\text{m})\,\hat{\mathbf{k}}\right]}{\sqrt{(1.5\,\text{m})^2 + (-1.6\,\text{m})^2 + (1.2\,\text{m})^2}}$$
$$= (1.02\,\hat{\mathbf{i}} - 1.09\,\hat{\mathbf{j}} + 0.82\,\hat{\mathbf{k}})\,\text{kN}$$

$$\boldsymbol{F}_R = \boldsymbol{F}_1 + \boldsymbol{F}_2 + \boldsymbol{F}_3$$
$$= (0.39\,\hat{\mathbf{i}} - 0.67\,\hat{\mathbf{j}} + 3.79\,\hat{\mathbf{k}})\,\text{kN}$$

RESULTS (a): The resultant force is:

$$\boxed{\boldsymbol{F}_R = (0.39\,\hat{\mathbf{i}} - 0.67\,\hat{\mathbf{j}} + 3.79\,\hat{\mathbf{k}})\,\text{kN}}$$

FORMULATE EQUATIONS and **SOLVE** (b): None necessary

RESULTS (b): The upward force is:

$$\boxed{\boldsymbol{F}_{\text{upward}} = 3.79\,\text{kN}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$\boldsymbol{F}_{\text{sliding}} = \sqrt{(\boldsymbol{F}_{Rx})^2 + (\boldsymbol{F}_{Ry})^2}$$
$$= \sqrt{(40.39\,\text{kN})^2 + (0.67\,\text{kN})^2} = 0.78\,\text{kN}$$

RESULTS (c): The sliding force is:

$$\boxed{\boldsymbol{F}_{\text{sliding}} = 0.78\,\text{kN}}$$

CHECK : Check calculations, and visually check that the resultant force is in the proper direction.

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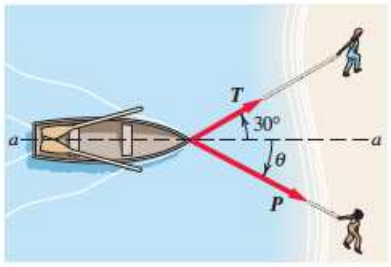
PROBLEM 2.6.38

Two ropes are used to pull a boat to shore, as shown in Figure 1. The resultant forces $\boldsymbol{T}$ and $\boldsymbol{P}$ has a magnitude of 300 lb and is directed along the keel line a-a. Plot magnitude $||\boldsymbol{T}||$ as a function of the angle θ. Where is $||\boldsymbol{T}||$ a minimum? Compared your results with Figure 2.

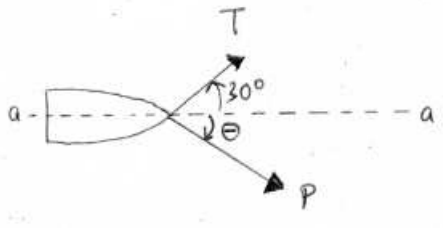


GOAL : To determine the minimum
vvT.

GIVEN : Magnitude and orientation of the four forces, resultant force only acts in the line a–a.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

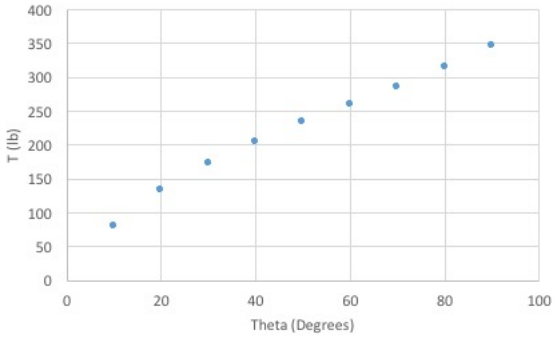
Since we know that the resultant force is directed along the keel line a-a, we know that the sum of the x components to be 300 lb and the sum of y-components to be zero. These two conditions give the following two equations.

$$||\boldsymbol{T}|\cos 30^\circ + ||\boldsymbol{P}||\cos\theta = 300\,\text{lb}$$
$$||\boldsymbol{T}|\sin 30^\circ + ||\boldsymbol{P}||\sin\theta = 0$$

Solving for simultaneously both equations for $||\boldsymbol{T}||$, we get,

$$||\boldsymbol{T}|| = \frac{300\,\text{lb}}{\left(\frac{\sin 30^\circ}{\sin\theta}\cos\theta\right) + \cos 30^\circ}$$

Plotting this gives



RESULTS :
Based on the plot, $||\boldsymbol{T}||$ is a minimum when $\theta = 10^\circ$.

$$\boxed{\text{Minimum } ||\boldsymbol{T}|| \approx 81.0\,\text{lb}}$$

which is the same results obtained shown in Example 2.6.7.

CHECK : The minimum could be obtained by using the method shown in Example 2.6.7 for checking.

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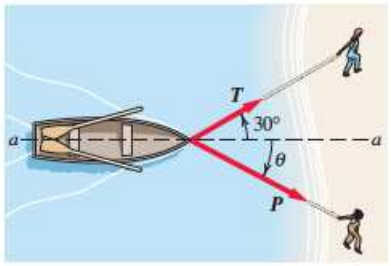
PROBLEM 2.6.38

For the boat shown write P as a function of θ and use calculus to find θ so that P is minimized. Compare your results with Example 2.6.7.

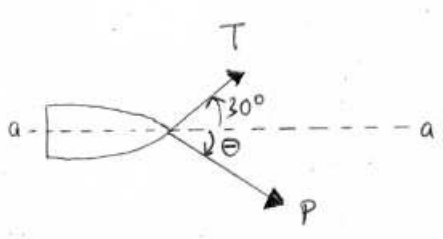


GOAL : To determine the minimum P using calculus.

GIVEN : Magnitude and orientation of the four forces, resultant force only acts in the line a–a.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

From problem 2.6.37 and example, we obtain the following function.

$$||\boldsymbol{P}|| = \frac{300\,\text{lb}}{(\frac{\sin\theta}{\tan 30^\circ} + \cos\theta)} \tag{1}$$

If the function (1) has a local minimum (or maximum) for θ in the range of $0^\circ < \theta \leq 90^\circ$, the derivative of the function will be zero at this minimum (or maximum). Take the derivative of (1) with respect to θ and set it equal to zero (because the derivative of function is zero at a minimum or maximum).

$$\frac{d\boldsymbol{P}}{d\theta} = \frac{-300\,\text{lb}(\frac{\cos\theta}{\tan 30^\circ} - \sin\theta)}{(\frac{\sin\theta}{\tan 30^\circ} + \cos\theta)^2} \tag{2}$$

Multiplying both sides of (2) by

$$(\frac{\sin\theta}{\tan 30^\circ} + \cos\theta)^2$$

and dividing 300 lb, we have

$$\frac{\cos\theta}{\tan 30^\circ} - \sin\theta = 0$$

Next we can divide both sides by $\cos\theta$ to get

$$\frac{1}{\tan 30^\circ} - \tan\theta = 0$$

which means

$$\tan\theta = \frac{1}{\tan 30^\circ} \tag{3}$$

RESULTS :
Solving for θ from (3), we find that $\theta = 60^\circ$. This is substituted back into (1). The final answers are

$$\boxed{\begin{aligned}\theta &= 60^\circ \\ \boldsymbol{P} &= 150\,\text{lb}\end{aligned}}$$

which is the same results obtained shown in Example 2.6.7.

CHECK : The minimum could be obtained by using the method shown in Example 2.6.7 for checking.

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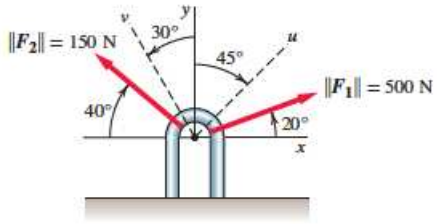
PROBLEM 2.6.39

The two forces acting on a u-bolt have a resultant $\boldsymbol{F}_R = \boldsymbol{F}_1 + \boldsymbol{F}_2$. Find the magnitudes of two other forces $\boldsymbol{F}_u$ and $\boldsymbol{F}_v$ acting in the direction of the u and v axes respectively, which wold have the same resultant $\boldsymbol{F}_R$.

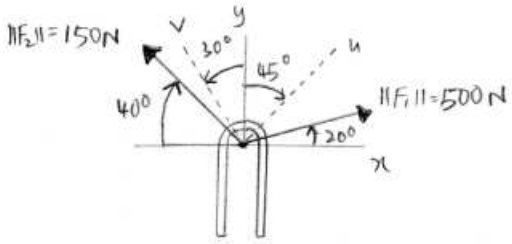


GOAL : To determine the magnitudes of $\boldsymbol{F}_u$ and $\boldsymbol{F}_v$

GIVEN : Magnitude and orientation of $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$, the fact that $\boldsymbol{F}_R = \boldsymbol{F}_1 + \boldsymbol{F}_2$=$\boldsymbol{F}_u + \boldsymbol{F}_v$.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

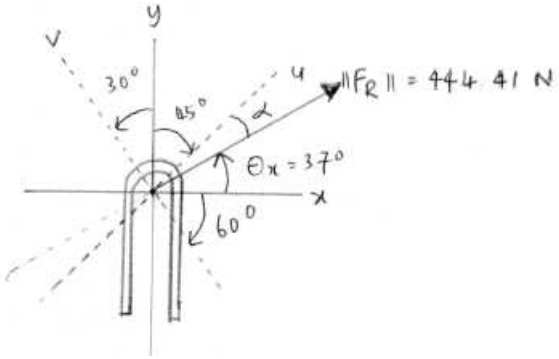
We first find $\boldsymbol{F}_R$ with given $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$.

$$\begin{aligned}\boldsymbol{F}_R &= \boldsymbol{F}_1 + \boldsymbol{F}_2 \\ &= 500\,\text{N}(\cos 20^\circ\,\hat{\mathbf{i}} + \sin 20^\circ\,\hat{\mathbf{j}}) + \\ &\quad 50\,\text{N}(-\cos 40^\circ\,\hat{\mathbf{i}} + \sin 40^\circ\,\hat{\mathbf{j}}) \\ &= 354.94\,\text{N}\,\hat{\mathbf{i}} + 267.43\,\text{N}\,\hat{\mathbf{j}}\end{aligned}$$

We then find the space angles.

$$\begin{aligned}||\boldsymbol{F}_R|| &= \sqrt{(354.94\,\text{N})^2 + (267.43\,\text{N})^2} = 444.41\,\text{N} \\ \boldsymbol{u}_R &= \frac{354.94\,\text{N}}{444.41\,\text{N}}\,\hat{\mathbf{i}} + \frac{267.43}{444.41}\,\hat{\mathbf{j}} \\ &= 0.7987\,\hat{\mathbf{i}} + 0.6018\,\hat{\mathbf{j}} \\ \theta_x &= \cos^{-1} 0.7987 = 36.99^\circ \approx 37^\circ \\ \theta_y &= 90^\circ - 37^\circ = 53^\circ\end{aligned}$$

With that, we draw $\boldsymbol{F}_R$ on the FBD.



With that, we will resolve $\boldsymbol{F}_R$ into u and v axes. Knowing that $\alpha = 90^\circ - (45^\circ + 37^\circ)$,

$$\begin{aligned}\boldsymbol{F}_u &= ||\boldsymbol{F}_R|| \cos\alpha = 440.09\,\text{N} \\ \boldsymbol{F}_v &= ||\boldsymbol{F}_R|| \cos(60^\circ + 37^\circ) = 54.16\,\text{N}\end{aligned}$$

RESULTS :
The final results are

$$\boxed{\begin{aligned}\boldsymbol{F}_u &= 440\,\text{N} \\ \boldsymbol{F}_v &= 54.2\,\text{N}\end{aligned}}$$

CHECK : The calculations and should be checked.

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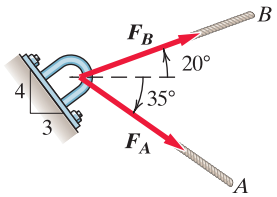
PROBLEM 2.6.40

Cables A and B act on a bracket as shown. The tension in cable A is 500 N. The orientation of $\boldsymbol{F}_B$ is at $\theta = 20^\circ$.

a. Write an expression (in vector notation) for the resultant force $\boldsymbol{F}_R$ acting on the bracket. Use a coordinate system perpendicular and parallel to the inclined surface.

b. If the bracket will pull away from the wall when the component of $\boldsymbol{F}_R$ parallel to the wall is greater than or equal to 550 N and the component of $\boldsymbol{F}_R$ perpendicular to the wall is greater than or equal to 600 N, how large can the magnitude of $\boldsymbol{F}_B$ be?

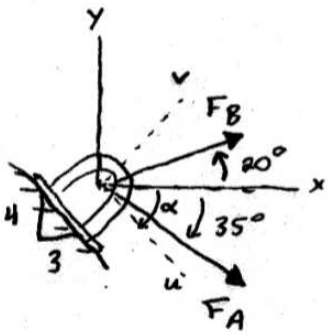


GOAL : To determine (a) an expression for the resultant force in vector notation, and (b) the magnitude of $\boldsymbol{F}_B$ that will cause the bracket to pull away (parallel force > 550 N or perpendicular force > 600 N).

GIVEN : Magnitudes and orientations of two forces acting on a bracket. The tension in cable A is 500 N.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\boldsymbol{F}_R = (500\,\text{N})(\cos 35^\circ\,\hat{\mathbf{i}} - \sin 35^\circ\,\hat{\mathbf{j}}) + ||\boldsymbol{F}_B||(\cos 20^\circ\,\hat{\mathbf{i}} + \sin 20^\circ\,\hat{\mathbf{j}})$$

RESULTS (a):

$$\boxed{\boldsymbol{F}_R = [(500\,\text{N})\cos 35^\circ + ||\boldsymbol{F}_B||\cos 20^\circ]\,\hat{\mathbf{i}} + [(-500\,\text{N})\sin 35^\circ + ||\boldsymbol{F}_B||\sin 20^\circ]\,\hat{\mathbf{j}}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

Let α define the orientation of a uv coordinate system

$$\alpha = \tan^{-1}\left(\frac{4}{3}\right) = 53.13^\circ$$

Find the resultant in the uv coordinate frame (with $\hat{\mathbf{i}}^*$ along the u axis):

$$\begin{aligned}\boldsymbol{F}_{R_{uv}} &= (500\,\text{N})[\cos(\alpha - 35^\circ)\,\hat{\mathbf{i}}^* + \sin(\alpha - 35^\circ)\,\hat{\mathbf{j}}^*] \\ &\quad + ||\boldsymbol{F}_B||[\cos(\alpha + 20^\circ)\,\hat{\mathbf{i}}^* + \sin(\alpha + 20^\circ)\,\hat{\mathbf{j}}^*] \\ &= (500\,\text{N})[\cos(18.13^\circ)\,\hat{\mathbf{i}}^* + \sin(18.13^\circ)\,\hat{\mathbf{j}}^*] \\ &\quad + ||\boldsymbol{F}_B||[\cos(73.13^\circ)\,\hat{\mathbf{i}}^* + \sin(73.13^\circ)\,\hat{\mathbf{j}}^*]\end{aligned}$$

Examining the parallel ($\hat{\mathbf{i}}^*$) component:

$$\begin{aligned}\boldsymbol{F}_{R_u} &= (500\,\text{N})\cos(18.13^\circ) + ||\boldsymbol{F}_B||\cos(73.13^\circ) \\ &= 475.176\,\text{N} + 0.290\,||\boldsymbol{F}_B|| < 550\,\text{N}\end{aligned}$$

$$||\boldsymbol{F}_B|| = \frac{550\,\text{N} - 475.18\,\text{N}}{0.290} = 258\,\text{N}$$

Examining the perpendicular ($\hat{\mathbf{j}}^*$) component:

$$\begin{aligned}\boldsymbol{F}_{R_v} &= (500\,\text{N})\sin(18.13^\circ) + ||\boldsymbol{F}_B||\sin(73.13^\circ) \\ &= 155.6\,\text{N} + 0.957\,||\boldsymbol{F}_B|| < 600\,\text{N}\end{aligned}$$

$$||\boldsymbol{F}_B|| = \frac{600\,\text{N} - 155.6\,\text{N}}{0.957} = 464\,\text{N}$$

RESULTS (b): The limiting case is the maximum parallel force, which is achieved when:

$$\boxed{||\boldsymbol{F}_B|| = 258\,\text{N}}$$

CHECK : Substitute $||\boldsymbol{F}_B||$ back into equations to check resultant force.

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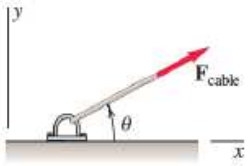
Exercise 2.6.41

Please Note: this solution shows a model solution to th match those in the problem you are working on.

A bracket is glued to the floor, and a cable is attached, as shown. If F_{shear} (the shear force between the bracket and the floor) is not to exceed 50 N, and $F_{tension}$ (the tension force between the bracket and the floor) is not to exceed 100 N, what is the maximum allowable tension in the cable? (*Hint:* Graphical addition of F_{shear}, $F_{tension}$, and F_{cable} should result in a triangle.)

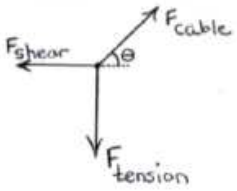


GOAL : To determine the maximum allowable tension in the cable.

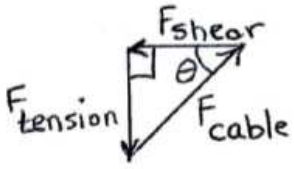
GIVEN : $F_{shear} < 50\,\text{N}$ and $F_{tension} < 100\,\text{N}$

ASSUME : Planar, and $0° < \theta < 90°$.

DRAW : The three forces on the bracket can be represented as three forces acting on a particle



The three forces form a force triangle



FORMULATE EQUATIONS and SOLVE :

Two conditions must be satisfied

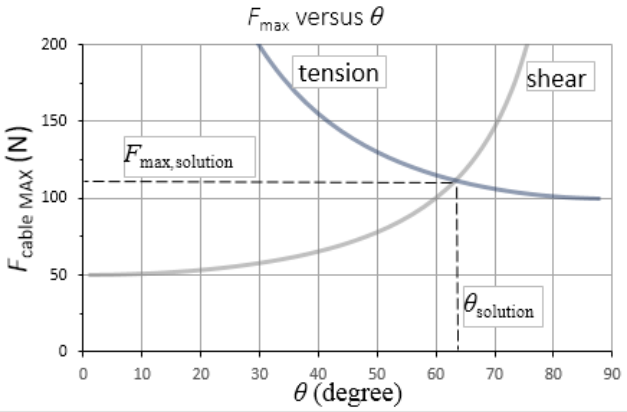
$F_{\text{shear}} = F_{\text{cable}} \cos\theta \le 50\ \text{N}$

$F_{\text{cable max}} \le \dfrac{50\ \text{N}}{\cos\theta}$ due to the shear condition (1)

$F_{\text{tension}} = F_{\text{cable}} \sin\theta \le 100\ \text{N}$

$F_{\text{cable max}} \le \dfrac{100\ \text{N}}{\sin\theta}$ due to the tension condition (2)

Plot the two functions for $F_{\text{cable max}}$



The two conditions will be satisfied at only one point, the point of intersection of the curves defined by (1) and (2).

$$\frac{50\ \text{N}}{\cos\theta} = \frac{100\ \text{N}}{\sin\theta}$$

Solving for θ gives $\theta_{\text{solution}} = 63.4°$

At $\theta_{\text{solution}} = 63.4°$ $F_{\text{max, solution}} = 111.8$ N

RESULTS:

$F_{\text{cable}} \le 111.8$ N

CHECK:

Substitute values of θ greater and less than 63.4° into equations (1) and (2) to ensure that this is the only case for with both conditions are satisfied.

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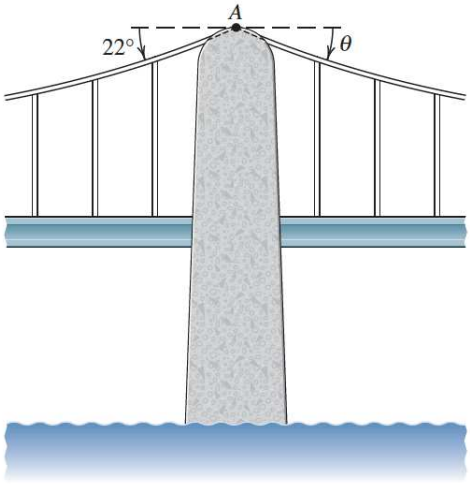
PROBLEM 2.6.42

A net downward force of 150 MN acts on a suspension bridge tower as a result of the main cable passing over the top of the tower at A. If the tension in the cable just to the left of the tower is 220 MN, determine the tension in the cable just to the right of the tower as well as the angle of the cable relative to horizontal.

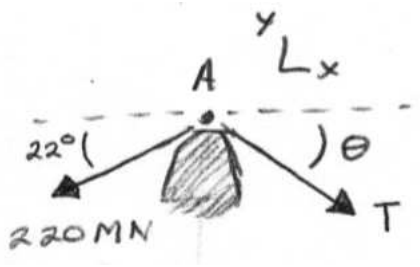


GOAL : Determine the $\|\mathbf{T}\|$ in the right cable and the angle the cable makes with the horizontal.

GIVEN : The left cable has a tension of 220 MN and pulls down at 22° relative to horizontal. The two cables result in a downward force of 150 MN at A.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_R &= 220\text{ MN}(-\cos 22^\circ\,\hat{\mathbf{i}} - \sin 22^\circ\,\hat{\mathbf{j}}) \\ &\quad + ||\boldsymbol{T}||(\cos\theta\,\hat{\mathbf{i}} - \sin\theta\,\hat{\mathbf{j}}) \\ &= (0\,\hat{\mathbf{i}} - 150\,\hat{\mathbf{j}})\text{ MN}\end{aligned}$$

Examining the $\hat{\mathbf{i}}$ components:

$$-(220\text{ MN})\cos 22^\circ + ||\boldsymbol{T}||\cos\theta = 0$$

$$||\boldsymbol{T}|| = \frac{(220\text{ MN})\cos 22^\circ}{\cos\theta} \qquad (1)$$

Examining the $\hat{\mathbf{j}}$ components:

$$-(220\text{ MN})\sin 22^\circ - ||\boldsymbol{T}||\sin\theta = -150\,\text{kN}$$

Substitute from (1)

$$-(220\text{ MN})\sin 22^\circ - \frac{(220\text{ MN})\cos 22^\circ}{\cos\theta}\sin\theta = -150\,\text{kN}$$

$$\theta = \tan^{-1}\left(\frac{-150\text{ MN} + (220\text{ MN})\sin 22^\circ}{-(220\text{ MN})\cos 22^\circ}\right) = 18.33^\circ$$

Substitute θ into (1)

$$||\boldsymbol{T}|| = \frac{(220\text{ MN})\cos 22^\circ}{\cos 18.33^\circ} = 214.9\text{ MN}$$

RESULTS :

$$\boxed{\begin{aligned}||\boldsymbol{T}|| &= 215\,\text{kN} \\ \theta &= 18.3^\circ\end{aligned}}$$

CHECK : Confirm the resultant:

$$\begin{aligned}\boldsymbol{F}_R &= 220\text{ MN}(-\cos 22^\circ\,\hat{\mathbf{i}} - \sin 22^\circ\,\hat{\mathbf{j}}) \\ &\quad + 215\text{ MN}(\cos 18.3^\circ\,\hat{\mathbf{i}} - \sin 18.3^\circ\,\hat{\mathbf{j}}) \\ &\approx (0\,\hat{\mathbf{i}} - 150\,\hat{\mathbf{j}})\text{ MN}\end{aligned}$$

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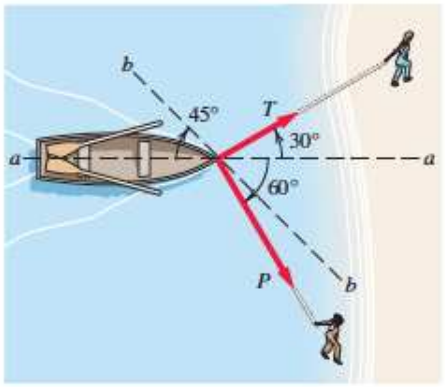
PROBLEM 2.6.43

The boat tenders want to turn the boat towards its starboard side by pulling the boat with a resultant force of 300 lb directed along the line *b*-*b* that is 45° clockwise from *a*-*a*. Find the required forces, $||\mathbf{T}||$ and $||\mathbf{P}||$ to produce this resultant.

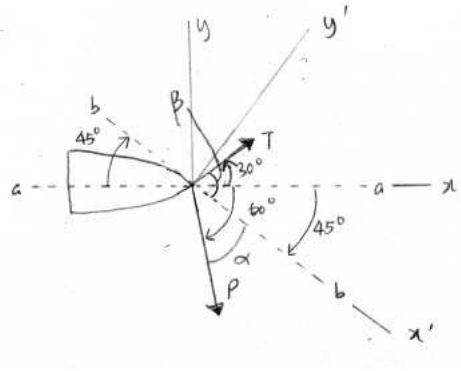


GOAL : Determine $||\mathbf{T}||$ and $||\mathbf{P}||$.

GIVEN : The resultant force of 300 lb and the line of action of the resultant force.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Based on the diagram drawn above, we can calculate that

$$\alpha = 60^\circ - 45^\circ = 15^\circ$$
$$\beta = 45^\circ + 30^\circ = 75^\circ$$

We set a new coordinate system in which the x-axis is parallel to line *b*-*b*. We then write the resultant force in with the new coordinate system. The unit vectors in this coordinated system is represented by $\boldsymbol{i}^*$ and $\boldsymbol{j}^*$.

$$\boldsymbol{F}_R = ||\boldsymbol{T}||\cos\beta\,\hat{\mathbf{i}}^* + ||\boldsymbol{T}\sin\beta\,\hat{\mathbf{j}}^*$$
$$+ ||\boldsymbol{P}||\cos\alpha\,\hat{\mathbf{i}}^* + ||\boldsymbol{P}\sin\alpha\,\hat{\mathbf{j}}^*$$

We can get two equations as shown below.

$$||\boldsymbol{T}||\cos\beta + ||\boldsymbol{P}||\cos\alpha = 300\,\text{lb}$$
$$||\boldsymbol{T}||\sin\beta + ||\boldsymbol{P}||\sin\alpha = 0$$

RESULTS :
Solving the two equations give us

$$\boxed{\begin{aligned} ||\boldsymbol{T}|| &= 77.6\,\text{lb} \\ ||\boldsymbol{P}|| &= 290\,\text{lb} \end{aligned}}$$

CHECK : Check the calculations and the directions of the vectors.

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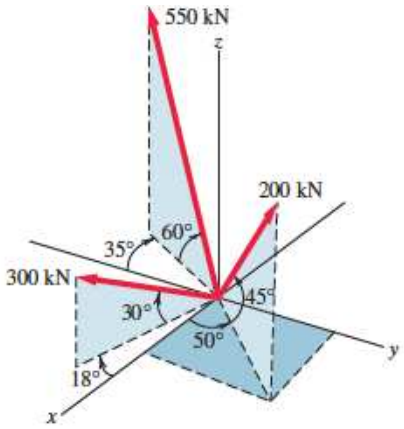
PROBLEM 2.6.44

Three forces act as shown below. Use rectangular component addition to determine the magnitude of the resultant $\boldsymbol{F}_R$ of the three forces.

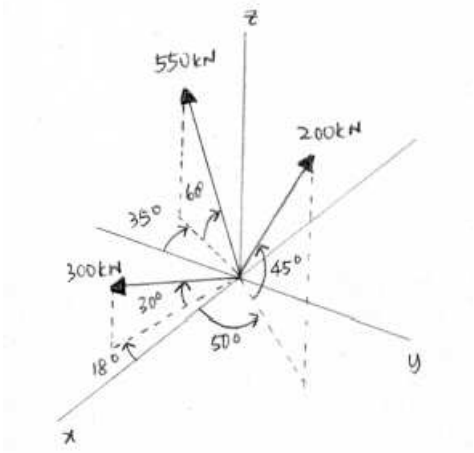


GOAL : Determine the magnitude of the resultant force.

GIVEN : Magnitudes and angles defining orientation of three forces, and a coordinate system.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_R &= [(200\cos 45^\circ \cos 50^\circ + 300\cos 18^\circ \cos 30^\circ \\ &\quad + (-550\cos 60^\circ \sin 35^\circ))\,\hat{\mathbf{i}} \\ &\quad + (200\cos 45^\circ \sin 50^\circ - 300\cos 30^\circ \sin 18^\circ \\ &\quad + (-550\cos 60^\circ \cos 35^\circ)\,\hat{\mathbf{j}} \\ &\quad + (200\sin 45^\circ + 300\sin 30^\circ + 550\sin 60^\circ)\,\hat{\mathbf{k}}]\ \text{kN} \\ &= (180.26\,\hat{\mathbf{i}} - 197.22\,\hat{\mathbf{j}} + 767.74\,\hat{\mathbf{k}})\ \text{kN}\end{aligned}$$

$$\begin{aligned}||\boldsymbol{F}_R|| &= \sqrt{(180.26\,\text{kN})^2 + (-197.22\,\text{kN})^2 + (767.74\,\text{kN})^2} \\ &= 813\,\text{kN}\end{aligned}$$

RESULTS :

$$\boxed{||\boldsymbol{F}_R|| = 813\,\text{kN}}$$

CHECK : Double-check angles and calculations.

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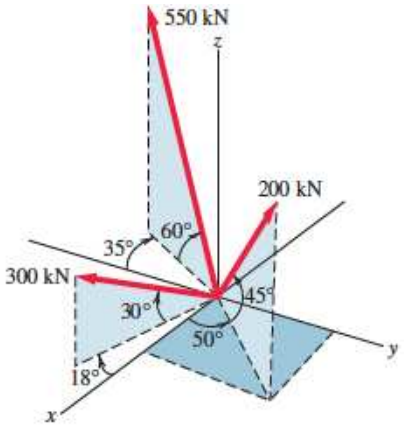
PROBLEM 2.6.45

Three forces act as shown. Determine the space angles θ_x, θ_y, and θ_z between the line of action of the resultant and the positive x, y, and z coordinate axes.

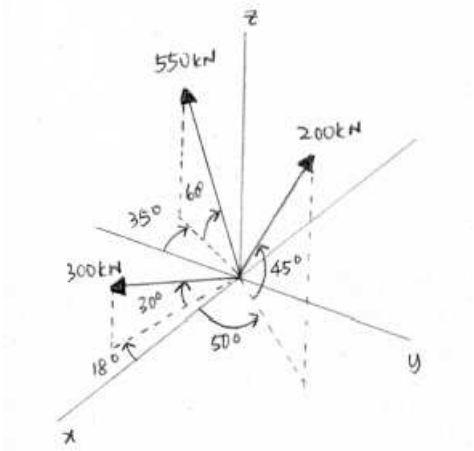


GOAL : Determine the magnitude of the resultant force.

GIVEN : Magnitudes and angles defining orientation of three forces, and a coordinate system.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}\boldsymbol{F}_R &= [(200\cos 45^\circ \cos 50^\circ + 300\cos 18^\circ \cos 30^\circ \\ &\quad + (-550\cos 60^\circ \sin 35^\circ))\,\hat{\mathbf{i}} \\ &\quad + (200\cos 45^\circ \sin 50^\circ - 300\cos 30^\circ \sin 18^\circ \\ &\quad + (-550\cos 60^\circ \cos 35^\circ)\,\hat{\mathbf{j}} \\ &\quad + (200\sin 45^\circ + 300\sin 30^\circ + 550\sin 60^\circ)\,\hat{\mathbf{k}}]\ \text{kN} \\ &= (180.26\,\hat{\mathbf{i}} - 197.22\,\hat{\mathbf{j}} + 767.74\,\hat{\mathbf{k}})\ \text{kN}\end{aligned}$$

$$\theta_x = \cos^{-1}\left(\frac{F_{Rx}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{180.26\ \text{kN}}{813\ \text{kN}}\right) = 77.2^\circ$$

$$\theta_y = \cos^{-1}\left(\frac{F_{Ry}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{-197.22\ \text{kN}}{813\ \text{kip}}\right) = 104.0^\circ$$

$$\theta_z = \cos^{-1}\left(\frac{F_{Rz}}{||\boldsymbol{F}_R||}\right) = \cos^{-1}\left(\frac{767.74\ \text{kN}}{813\ \text{kip}}\right) = 19.2^\circ$$

RESULTS :

$$\boxed{\begin{aligned}\theta_x &= 77.2^\circ \\ \theta_y &= 104.0^\circ \\ \theta_z &= 19.2^\circ\end{aligned}}$$

CHECK : Double-check angles and calculations.

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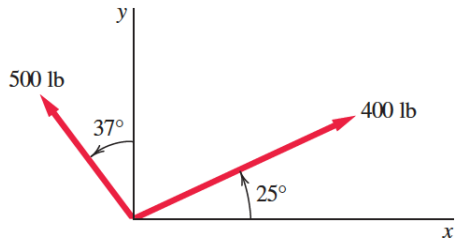
PROBLEM 2.7.1

Determine the dot product of the two forces shown below by

a. using the definition given in (2.26)

b. using the definition given in (2.29)

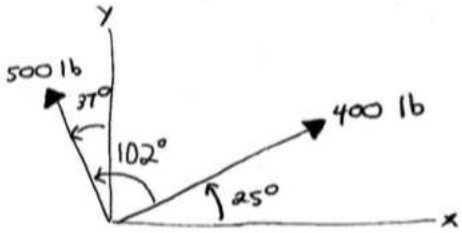


GOAL : Determine the dot products of two forces using (a) equation (2.26), and (b) equation (2.29).

GIVEN : Magnitude and orientation of two forces.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = ||\boldsymbol{V}_1||\,||\boldsymbol{V}_2|| \cos\theta \qquad (4.20)$$

$$\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = (400\,\text{lb})(500\,\text{lb})\cos 102^\circ = -41582\,\text{lb}^2$$

RESULTS (a): Using (2.26):

$$\boxed{\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = -41582\,\text{lb}^2}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = V_{1_x} V_{2_x} + V_{1_y} V_{2_y} \qquad (4.23)$$

$$\begin{aligned} \boldsymbol{V}_1 \cdot \boldsymbol{V}_2 &= [(400\,\text{lb})\cos 25^\circ][(500\,\text{lb})\cos 127^\circ] \\ &\quad + [(400\,\text{lb})\sin 25^\circ][(500\,\text{lb})\sin 127^\circ] \\ &= -41582\,\text{lb}^2 \end{aligned}$$

RESULTS (b): Using (2.29):

$$\boxed{\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = -41582\,\text{lb}^2}$$

CHECK : The two parts of the problem form an excellent self-check.

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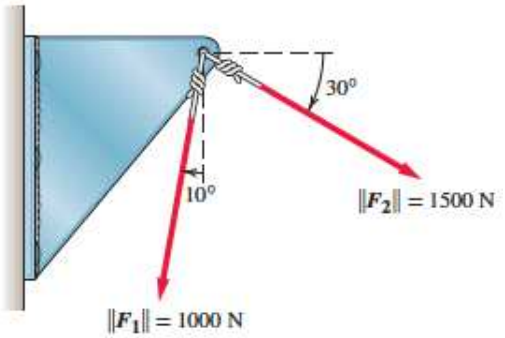
PROBLEM 2.7.2

Determine the dot product of the two forces $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ applied to the bracket. Use this dot product to show that the angle between the two forces is 70°.

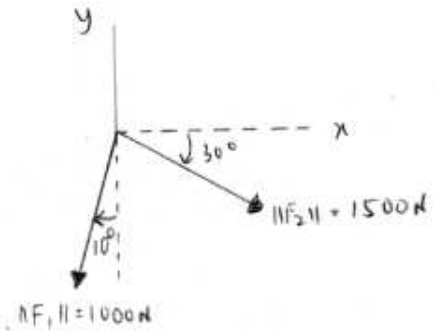


GOAL : Determine the dot products of two forces and show that the angle between the two forces is 70°.

GIVEN : Magnitude and orientation of two forces.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE**

We first get the forces in vector notation.

$$\begin{aligned}\boldsymbol{F}_1 &= -1000\,\text{N}\sin 10^\circ\,\hat{\mathbf{i}} - 1000\,\text{N}\cos 10^\circ\,\hat{\mathbf{j}}\\ &= -173.65\,\text{N}\,\hat{\mathbf{i}} - 984.81\,\text{N}\,\hat{\mathbf{j}}\\ \boldsymbol{F}_2 &= 1500\,\text{N}\cos 30^\circ\,\hat{\mathbf{i}} - 1500\,\text{N}\sin 30^\circ\,\hat{\mathbf{j}}\\ &= 1299.04\,\text{N}\,\hat{\mathbf{i}} - 750\,\text{N}\,\hat{\mathbf{j}}\end{aligned}$$

Dotting both of these give

$$\begin{aligned}\boldsymbol{F}_1\cdot\boldsymbol{F}_2 &= (-173.65\,\text{N})(1299.04\,\text{N}) + (-984.81\,\text{N})(-750\,\text{N})\\ &= 513029\,\text{N}^2\end{aligned}$$

We know that

$$\boldsymbol{F}_1\cdot\boldsymbol{F}_2 = ||\boldsymbol{F}_1||\,||\boldsymbol{F}_2||\cos\theta$$

which means

$$\cos\theta = \frac{\boldsymbol{F}_1\cdot\boldsymbol{F}_2}{||\boldsymbol{F}_1||\,||\boldsymbol{F}_2||}$$

And this gives us

$$\theta \approx 70^\circ$$

RESULTS

$$\boxed{\boldsymbol{F}_1\cdot\boldsymbol{F}_2 = 513029\,\text{N}^2}$$

CHECK : Check the calculations and the dot product performed.

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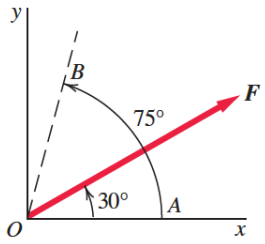
PROBLEM 2.7.3

Consider the 800-lb force $\boldsymbol{F}$.

a. Write an expression for the projection of $\boldsymbol{F}$ in the direction OA. Use this expression to determine the value of the projection.

b. Write an expression for the projection of $\boldsymbol{F}$ in the direction OB. Use this expression to determine the value of the projection.

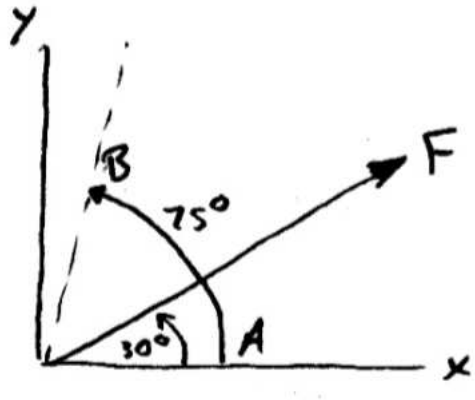


GOAL : Write expressions for the projections of $\boldsymbol{F}$ in the directions of OA and OB and determine their value for the given magnitude of $\boldsymbol{F}$.

GIVEN : Orientation of $\boldsymbol{F}$, and $||\boldsymbol{F}|| = 800\,\text{lb}$.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\boldsymbol{F}_{OA} = ||\boldsymbol{F}||\cos 30^\circ = (800\,\text{lb})\cos 30^\circ = 692.8\,\text{lb}$$

Alternatively

$$\begin{aligned}\boldsymbol{F}_{OA} &= \boldsymbol{F}\cdot\boldsymbol{u}_{OA} = (||\boldsymbol{F}||\cos 30^\circ\,\hat{\mathbf{i}} + ||\boldsymbol{F}||\sin 30^\circ\,\hat{\mathbf{j}})\cdot\hat{\mathbf{i}} \\ &= ||\boldsymbol{F}||\cos 30^\circ\end{aligned}$$

RESULTS (a): The projection onto OA:

$$\boxed{\begin{aligned}\boldsymbol{F}_{OA} &= ||\boldsymbol{F}||\cos 30^\circ \\ \boldsymbol{F}_{OA} &= 693\,\text{lb}\end{aligned}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\boldsymbol{F}_{OB} = ||\boldsymbol{F}||\cos(75^\circ - 30^\circ) = (800\,\text{lb})\cos 45^\circ = 565.7\,\text{lb}$$

Alternatively

$$\begin{aligned}\boldsymbol{F}_{OB} &= \boldsymbol{F}\cdot\boldsymbol{u}_{OB} = (||\boldsymbol{F}||\cos 30^\circ\,\hat{\mathbf{i}} + ||\boldsymbol{F}||\sin 30^\circ\,\hat{\mathbf{j}})\cdot(\cos 75^\circ\,\hat{\mathbf{i}} + \sin 75^\circ\,\hat{\mathbf{j}}) \\ &= ||\boldsymbol{F}||(\cos 30^\circ\cos 75^\circ + \sin 30^\circ\sin 75^\circ) = 800\,\text{lb}(0.707)\end{aligned}$$

RESULTS (b): The projection onto OB:

$$\boxed{\begin{aligned}\boldsymbol{F}_{OB} &= ||\boldsymbol{F}||\cos 45^\circ \\ \boldsymbol{F}_{OB} &= 566\,\text{lb}\end{aligned}}$$

CHECK : Ensure the angles are correct and check calculations.

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PROBLEM 2.7.04

Let $\boldsymbol{A} = t\boldsymbol{i} - 3\boldsymbol{j}$ and $\boldsymbol{B} = 5\boldsymbol{i} + 7\boldsymbol{j}$, where t is a scalar. Find t so that $\boldsymbol{A}$ and $\boldsymbol{B}$ are perpendicular to each other.

GOAL : Determine t so that the two vectors are perpendicular to each other.

GIVEN : Two different forces in vector notation:

$$\boldsymbol{A} = t\,\hat{\mathbf{i}} - 3\,\hat{\mathbf{j}}$$

$$\boldsymbol{B} = 5\,\hat{\mathbf{i}} + 7\,\hat{\mathbf{j}}$$

ASSUME : Planar.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

For the two vectors to be perpendicular, the dot product must be zero:

$$A \cdot B = 0 = 5t - (3)(7) = 5t - 21$$

$$t = \frac{21}{5} = 4.2$$

RESULTS :

$$\boxed{t = 4.2}$$

CHECK : Verify math by substituting the value for t back into $\boldsymbol{A}$ and ensuring the dot product is zero.

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PROBLEM 2.7.5

Let $\boldsymbol{A} = 3\boldsymbol{i} + 6\boldsymbol{j} - 2\boldsymbol{k}$, $\boldsymbol{B} = -3\boldsymbol{j} + 4\boldsymbol{k}$, and $\boldsymbol{C} = 1\boldsymbol{i} - 7\boldsymbol{j} + 4\boldsymbol{k}$. Determine

a. $(\boldsymbol{A} \cdot \boldsymbol{B})\,\boldsymbol{C}$

b. $\boldsymbol{A} \cdot (\boldsymbol{B} + \boldsymbol{C})\,(-\boldsymbol{A}) \cdot (3\boldsymbol{B} - 5\boldsymbol{C})$

GOAL : Determine (a) $(\boldsymbol{A}\cdot\boldsymbol{B})\boldsymbol{C}$, and (b) $\boldsymbol{A}\cdot(\boldsymbol{B}+\boldsymbol{C})(-\boldsymbol{A})\cdot(3\boldsymbol{B}-5\boldsymbol{C})$.

GIVEN : Three different vectors.

$$\boldsymbol{A} = 3\,\hat{\mathbf{i}} + 6\,\hat{\mathbf{j}} - 2\,\hat{\mathbf{k}}$$

$$\boldsymbol{B} = -3\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}}$$

$$\boldsymbol{C} = 1\,\hat{\mathbf{i}} - 7\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}}$$

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** (a):

$$\begin{aligned}(\boldsymbol{A}\cdot\boldsymbol{B}) &= (3)(0) + (6)(-3) + (-2)(4) = -26\\ (\boldsymbol{A}\cdot\boldsymbol{B})\,\boldsymbol{C} &= (-26)(1\,\hat{\mathbf{i}} - 7\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}})\\ &= -26\,\hat{\mathbf{i}} + 182\,\hat{\mathbf{j}} - 104\,\hat{\mathbf{k}}\end{aligned}$$

RESULTS (a):

$$\boxed{(\boldsymbol{A}\cdot\boldsymbol{B})\,\boldsymbol{C} = -26\,\hat{\mathbf{i}} + 182\,\hat{\mathbf{j}} - 104\,\hat{\mathbf{k}}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}(\boldsymbol{B}+\boldsymbol{C}) &= (-3\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}}) + (1\,\hat{\mathbf{i}} - 7\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}})\\ &= 1\,\hat{\mathbf{i}} - 10\,\hat{\mathbf{j}} + 8\,\hat{\mathbf{k}}\\ \boldsymbol{A}\cdot(\boldsymbol{B}+\boldsymbol{C}) &= (3)(1) + (6)(-10) + (-2)(8)\\ &= -73\\ \boldsymbol{A}\cdot(\boldsymbol{B}+\boldsymbol{C})(-\boldsymbol{A}) &= -73(-3\,\hat{\mathbf{i}} - 6\,\hat{\mathbf{j}} + 2\,\hat{\mathbf{k}})\\ &= 219\,\hat{\mathbf{i}} + 438\,\hat{\mathbf{j}} - 146\,\hat{\mathbf{k}}\\ (3\boldsymbol{B}-5\boldsymbol{C}) &= 3(-3\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}}) - 5(1\,\hat{\mathbf{i}} - 7\,\hat{\mathbf{j}} + 4\,\hat{\mathbf{k}})\\ &= -5\,\hat{\mathbf{i}} + 26\,\hat{\mathbf{j}} - 8\,\hat{\mathbf{k}}\end{aligned}$$

$$\boldsymbol{A}\cdot(\boldsymbol{B}+\boldsymbol{C})(-\boldsymbol{A})\cdot(3\boldsymbol{B}-5\boldsymbol{C})$$

$$= (219)(-5) + (438)(26) + (-146)(-8) = 11{,}461$$

RESULTS (b):

$$\boxed{\boldsymbol{A}\cdot(\boldsymbol{B}+\boldsymbol{C})(-\boldsymbol{A})\cdot(3\boldsymbol{B}-5\boldsymbol{C}) = 11{,}461}$$

CHECK : Double-check calculations, or use the distributive property to re-arrange the equations and solve again.

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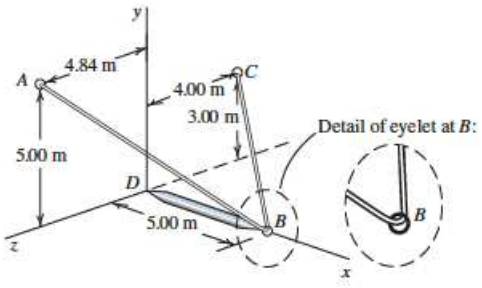
PROBLEM 2.7.6

Boom *BD* is held up by a continuous cable that runs from *A* through an eyelet at *B* to *C*. The cable is attached to the wall via hooks at *A* and *C*. Denote as $\boldsymbol{T_{BC}}$ the force applied by cable *BC* on member *BD*. Determine the magnitude of the projection of $\boldsymbol{T_{BC}}$ along line *AB*. The tension in the cable is 5 kN.

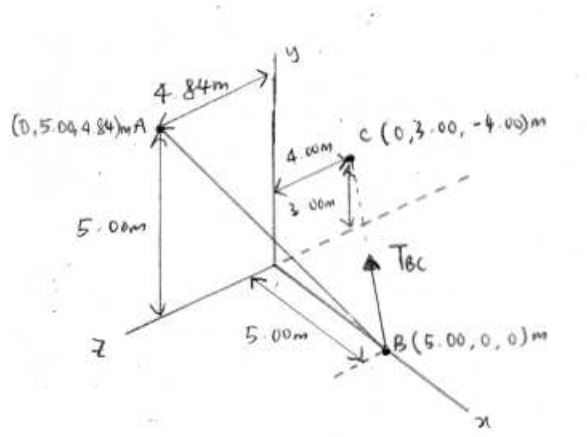


GOAL : Determine the magnitude of the projection of $\boldsymbol{T_{BC}}$ along line *AB*.

GIVEN : The orientation of the tension force and the magnitude of the tension force (5 kN).

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

First, calculate the unit vector along *BC* and *AB*.
Along *BC*

$$||\boldsymbol{u}_{BC}|| = \sqrt{(0-5.00)\,\text{m}^2 + (3.00-0)\,\text{m}^2 + (-4.00-0)\,\text{m}^2}$$
$$= 7.07\,\text{m}$$
$$\boldsymbol{u}_{BC} = -0.7071\,\hat{\mathbf{i}} + 0.4243\,\hat{\mathbf{j}} - 0.5657\,\hat{\mathbf{k}}$$
$$\boldsymbol{T}_{BC} = -3.54\,\text{kN}\,\hat{\mathbf{i}} + 2.12\,\text{kN}\,\hat{\mathbf{j}} - 2.83\,\text{kN}\,\hat{\mathbf{k}}$$

Along *AB*

$$||\boldsymbol{u}_{AB}|| = \sqrt{(0-5.00)m^2 + (5.00-0)m^2 + (-4.84-0)m^2}$$
$$= 8.57\,\text{m}$$
$$\boldsymbol{u}_{AB} = -0.5835\,\hat{\mathbf{i}} + 0.5835\,\hat{\mathbf{j}} + 0.5648\,\hat{\mathbf{k}}$$

To get the projection, we dot both $\boldsymbol{T_{BC}}$ and $\boldsymbol{u}_{AB}$.

$$\boldsymbol{T_{BC}} \cdot \boldsymbol{u}_{AB} = (-0.5835)(-3.54\,\text{kN}) + (0.5835)(2.12\,\text{kN})$$
$$+ (0.5648)(-2.83\,\text{kN})$$
$$= 1.703\,\text{kN}$$

RESULTS :

$$\boxed{\boldsymbol{T_{BC}} \cdot \boldsymbol{u}_{AB} = 1.703\,\text{kN}}$$

CHECK : Double-check calculations, or use the distributive property to re-arrange the equations and solve again.

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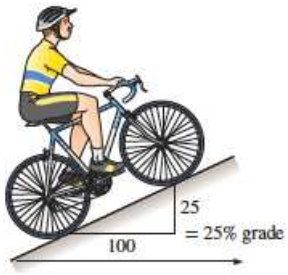
PROBLEM 2.7.7

The bicycle and cyclist moving up the incline have a combined weight of 190 lb. Use the dot product to determine the magnitude of the component of the 180-lb gravity force directed down the incline. "Percent grade" defines the rise (upward movement) relative to the run (horizontal movement). For example, a 25% grade means that for every 100 ft of horizontal movement (run) there is 25 ft of upward movement (rise).

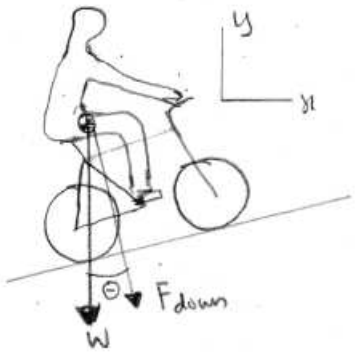


GOAL : Determine the magnitude of the component of the gravity force directed down the incline using the dot product.

GIVEN : The combined weight of the bicycle and the cyclist and the percent grade.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

From the percent grade, we know that

$$\theta = \tan^{-1}\left(\frac{25}{100}\right) = 14.04^\circ$$

We also know that

$$\boldsymbol{W} = -180\,\text{lb}\,\hat{\mathbf{j}}$$

We then write the unit vector of the line of action of the force directed down the incline, $\boldsymbol{u}_{\text{down}}$.

$$\boldsymbol{u}_{\text{down}} = \sin\theta\,\hat{\mathbf{i}} - \cos\theta\,\hat{\mathbf{j}}$$

We then dot both of these to obtain

$$\begin{aligned} |||vvF_{\text{down}}|| &= \boldsymbol{u}_{\text{down}} \cdot \boldsymbol{W} \\ &= 180\,\text{lb}\cos\theta \\ &= 174.6\,\text{lb} \end{aligned}$$

RESULTS :

$$\boxed{||vvF_{\text{down}}|| = \boldsymbol{u}_{\text{down}} \cdot \boldsymbol{W} = 174.6\,\text{lb}}$$

CHECK : Double-check calculations, or use the distributive property to re-arrange the equations and solve again.

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PROBLEM 2.7.08

Use the properties of the dot product to prove the identity

$$(\boldsymbol{A}+\boldsymbol{B})\cdot(\boldsymbol{A}-\boldsymbol{B}) = ||\boldsymbol{A}||^2 - ||\boldsymbol{B}||^2$$

GOAL : To prove the given identity.

GIVEN : The identity to prove:

$$(\boldsymbol{A}+\boldsymbol{B})\cdot(\boldsymbol{A}-\boldsymbol{B}) = ||\boldsymbol{A}||^2 - ||\boldsymbol{B}||^2$$

ASSUME : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

$$\begin{aligned}(\boldsymbol{A}+\boldsymbol{B})\cdot(\boldsymbol{A}-\boldsymbol{B}) &= (\boldsymbol{A})\cdot(\boldsymbol{A}-\boldsymbol{B})+(\boldsymbol{B})\cdot(\boldsymbol{A}-\boldsymbol{B}) \\ &= \boldsymbol{A}\cdot\boldsymbol{A}-\boldsymbol{A}\cdot\boldsymbol{B}+\boldsymbol{B}\cdot\boldsymbol{A}-\boldsymbol{B}\cdot\boldsymbol{B}\end{aligned}$$

Because $\boldsymbol{A}\cdot\boldsymbol{B} = \boldsymbol{B}\cdot\boldsymbol{A}$ these terms cancel with each other.

$$\begin{aligned}(\boldsymbol{A}+\boldsymbol{B})\cdot(\boldsymbol{A}-\boldsymbol{B}) &= \boldsymbol{A}\cdot\boldsymbol{A}-\boldsymbol{B}\cdot\boldsymbol{A}+\boldsymbol{B}\cdot\boldsymbol{A}-\boldsymbol{B}\cdot\boldsymbol{B} \\ &= ||\boldsymbol{A}||\,||\boldsymbol{A}||\cos\theta_{AA} - ||\boldsymbol{B}||\,||\boldsymbol{B}||\cos\theta_{BB} \\ &= ||\boldsymbol{A}||^2\cos 0^\circ - ||\boldsymbol{B}||^2\cos 0^\circ \\ &= ||\boldsymbol{A}||^2 - ||\boldsymbol{B}||^2\end{aligned}$$

$\theta_{AA} = \theta_{BB} = 0^\circ$ (since angle between vector & itself)

$$\cos 0^\circ = 1$$

RESULTS :

$$\boxed{(\boldsymbol{A}+\boldsymbol{B})\cdot(\boldsymbol{A}-\boldsymbol{B}) = ||\boldsymbol{A}||^2 - ||\boldsymbol{B}||^2}$$

CHECK : Review steps to ensure accuracy.

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PROBLEM 2.7.9

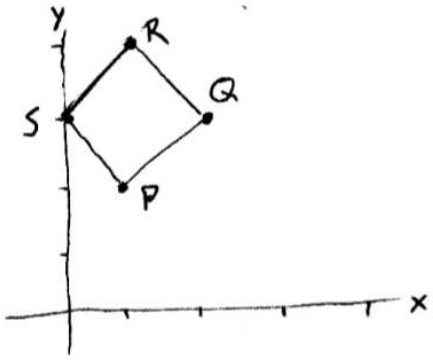
Use the dot product to show that the four points $P = (1,2)$, $Q = (2,3)$, $R = (1,4)$, and S = (0, 3), are the vertices of a square.

GOAL : Prove that the four given points are the vertices of a square using the dot product.

GIVEN : Coordinates of the four points: $P = (1,2)$, $Q = (2,3)$, $R = (1,4)$, and S = (0,3) , which all lie in the same plane.

ASSUME : None needed.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

First, check the lengths of each side:

$$\boldsymbol{V}_1 = \overrightarrow{PQ} = (1\,\hat{\mathbf{i}} + 1\,\hat{\mathbf{j}}) \qquad ||\boldsymbol{V}_1|| = \sqrt{2}$$
$$\boldsymbol{V}_2 = \overrightarrow{QR} = (-1\,\hat{\mathbf{i}} + 1\,\hat{\mathbf{j}}) \qquad ||\boldsymbol{V}_2|| = \sqrt{2}$$
$$\boldsymbol{V}_3 = \overrightarrow{RS} = (-1\,\hat{\mathbf{i}} - 1\,\hat{\mathbf{j}}) \qquad ||\boldsymbol{V}_3|| = \sqrt{2}$$
$$\boldsymbol{V}_4 = \overrightarrow{SP} = (1\,\hat{\mathbf{i}} - 1\,\hat{\mathbf{j}}) \qquad ||\boldsymbol{V}_4|| = \sqrt{2}$$

Then, check the angles:

$$\theta_{\angle PQR} = \cos^{-1}\left(\frac{\boldsymbol{V}_1 \cdot \boldsymbol{V}_2}{||\boldsymbol{V}_1||\,||\boldsymbol{V}_2||}\right) = \cos^{-1}\left(\frac{-1+1}{2}\right) = 90^\circ$$

$$\theta_{\angle QRS} = \cos^{-1}\left(\frac{\boldsymbol{V}_2 \cdot \boldsymbol{V}_3}{||\boldsymbol{V}_2||\,||\boldsymbol{V}_3||}\right) = \cos^{-1}\left(\frac{1-1}{2}\right) = 90^\circ$$

$$\theta_{\angle SRP} = \cos^{-1}\left(\frac{\boldsymbol{V}_3 \cdot \boldsymbol{V}_4}{||\boldsymbol{V}_3||\,||\boldsymbol{V}_4||}\right) = \cos^{-1}\left(\frac{-1+1}{2}\right) = 90^\circ$$

$$\theta_{\angle SPQ} = \cos^{-1}\left(\frac{\boldsymbol{V}_4 \cdot \boldsymbol{V}_1}{||\boldsymbol{V}_4||\,||\boldsymbol{V}_1||}\right) = \cos^{-1}\left(\frac{1-1}{2}\right) = 90^\circ$$

RESULTS :

All lengths are $\sqrt{2}$ and all angles are 90°.

Thus, it is a square.

CHECK : Plotting the points shows that the points are indeed in a square.

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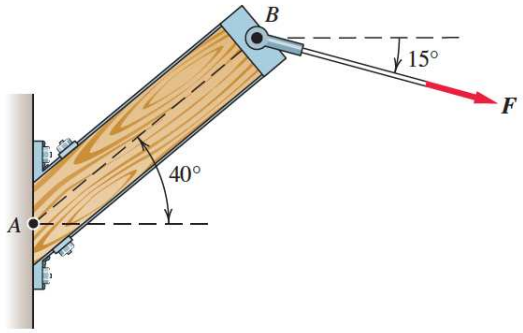
PROBLEM 2.7.10

A force $\boldsymbol{F}$ acts on the end of the box beam in the direction shown below.

a. Find the component of $\boldsymbol{F}$ in the direction AB. Call this value F_{AB}.

b. Find the component of $\boldsymbol{F}$ in the direction perpendicular to AB. Call this value F_{perp}.

c. For the beam design to be acceptable, neither F_{AB} nor F_{perp} should exceed 2.0 kN. What is the largest acceptable magnitude of $\boldsymbol{F}$?

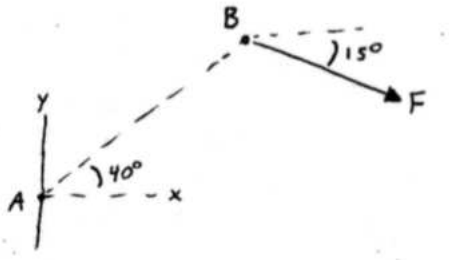


GOAL : Determine (a) the projection of $\boldsymbol{F}$ in the direction AB, (b) the projection of $\boldsymbol{F}$ in the direction perpendicular to AB, and (c) calculate $||\boldsymbol{F}||$ for the design to be acceptable.

GIVEN : Orientation of box beam and applied force. For an acceptable design, neither F_{AB} nor F_{perp} should exceed 2.0 kN.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$F_{AB} = ||\boldsymbol{F}||\cos(15^\circ + 40^\circ) = ||\boldsymbol{F}||\cos 55^\circ$$
$$= 0.574\,||\boldsymbol{F}||$$

RESULTS (a): The projection onto AB:

$$\boxed{F_{AB} = 0.574\,||\boldsymbol{F}||}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$F_{\perp} = ||\boldsymbol{F}||\cos(15^\circ + 40^\circ - 90^\circ) = ||\boldsymbol{F}||\cos(-35^\circ)$$
$$= 0.819\,||\boldsymbol{F}||$$

RESULTS (b): The projection onto the perpendicular to AB:

$$\boxed{F_{\perp} = 0.819\,||\boldsymbol{F}||}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$F_{AB} = 0.574\,||\boldsymbol{F}|| < 2.0\,\text{kN} \qquad \Rightarrow ||\boldsymbol{F}|| < 3.48\,\text{kN}$$

$$F_{\perp} = 0.819\,||\boldsymbol{F}|| < 2.0\,\text{kN} \qquad \Rightarrow ||\boldsymbol{F}|| < 2.44\,\text{kN}$$

RESULTS (c): The perpendicular component governs the solution. The maximum $||\boldsymbol{F}||$ is:

$$\boxed{||\boldsymbol{F}_{\max}|| = 2.44\,\text{kN}}$$

CHECK : Verify the angles used and check calculations. Since the two projections were perpendicular, the sum of their squares should equal one:

$$\sqrt{(0.574\,\text{kN})^2 + (0.819\,\text{kN})^2} = 1.000$$

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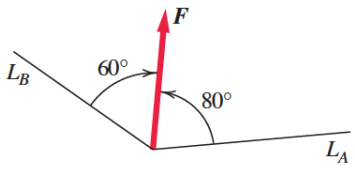
PROBLEM 2.7.11

A force $\boldsymbol{F}$ lies in the plane defined by the lines L_A and L_B, as shown below. Its magnitude is 400 N. Resolve $\boldsymbol{F}$ into projections parallel to L_A and L_B.



GOAL : To resolve a $\boldsymbol{F}$ into its components parallel to L_A and L_B.

GIVEN : $||\boldsymbol{F}|| = 400\,\text{N}$ and orientation of $\boldsymbol{F}$ relative to L_A and L_B.

ASSUME : Planar.

DRAW : No additional drawing needed.

FORMULATE EQUATIONS and **SOLVE** : Create a coordinate system with the x axis parallel to the L_A axis.

$$\begin{aligned} F_{LA} &= \boldsymbol{F}\cdot\boldsymbol{u}_{LA} = (||\boldsymbol{F}||\cos 80^\circ\,\hat{\mathbf{i}} + ||\boldsymbol{F}||\sin 80^\circ\,\hat{\mathbf{j}})\cdot\hat{\mathbf{i}} \\ &= ||\boldsymbol{F}||\cos 80^\circ = (400\,\text{lb})\cos 80^\circ = 69.5\,\text{N} \end{aligned}$$

$$\begin{aligned} F_{LB} &= \boldsymbol{F}\cdot\boldsymbol{u}_{LA} = (||\boldsymbol{F}||\cos 80^\circ\,\hat{\mathbf{i}} + ||\boldsymbol{F}||\sin 80^\circ\,\hat{\mathbf{j}})\cdot(\cos 140^\circ\,\hat{\mathbf{i}} + \sin 140^\circ\,\hat{\mathbf{j}}) \\ &= ||\boldsymbol{F}||(\cos 80^\circ\cos 140^\circ + \sin 80^\circ\sin 140^\circ) \\ &= (400\,\text{lb})(0.500) = 200\,\text{N} \end{aligned}$$

RESULTS :

$$\boxed{\begin{aligned} F_{LA} &= 69.5\,\text{N} \\ F_{LB} &= 200\,\text{N} \end{aligned}}$$

CHECK :

$$F_{LA} = ||\boldsymbol{F}||\cos 80^\circ = (400\,\text{lb})\cos 80^\circ = 69.5\,\text{N}$$

$$F_{LB} = ||\boldsymbol{F}||\cos 60^\circ = (400\,\text{lb})\cos 60^\circ = 200\,\text{N}$$

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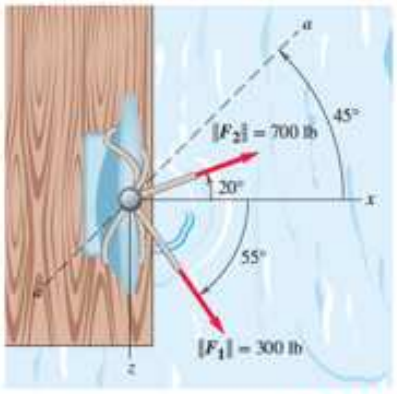
PROBLEM 2.7.12

Two boats are attached to a cleat on a dock by their bow lines as shown.



EX 2.7.12

a. Determine the magnitude of the projection of $\boldsymbol{F}_1$ along *a*-*a*.

b. Determine the magnitude of the projection of $\boldsymbol{F}_2$ along *a*-*a*.

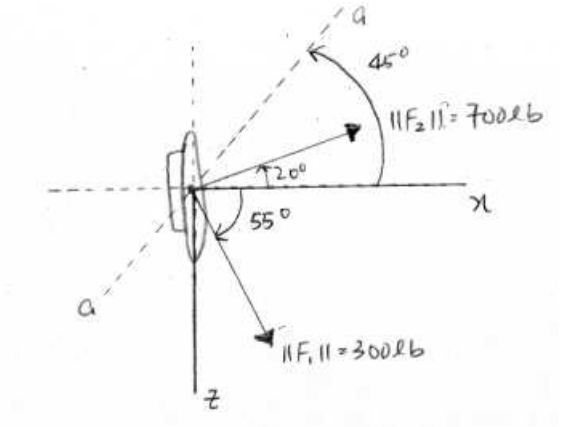
c. Use the results from **a.** and **b.** to find the total force at *O* in the *a*-*a* direction due to $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$.

GOAL : To determine (a) the magnitude of the projection of $\boldsymbol{F}_1$ along *a*-*a*, (b) the magnitude of the projection of $\boldsymbol{F}_2$ along *a*-*a*, and (c) the total force at *O*.

GIVEN : Magnitude and orientation of $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$, the orientation of *a*-*a*.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

Obtaining the unit vectors and force vectors

$$\begin{aligned}
\boldsymbol{u}_{a\text{-}a} &= \cos 45^\circ\,\hat{\mathbf{i}} - \sin 45^\circ\,\hat{\mathbf{k}} \\
\boldsymbol{u}_{F_1} &= \cos 55^\circ\,\hat{\mathbf{i}} + \sin 55^\circ\,\hat{\mathbf{k}} \\
\boldsymbol{F}_1 &= 300\,\text{lb}\cos 55^\circ\,\hat{\mathbf{i}} + 300\,\text{lb}\sin 55^\circ\,\hat{\mathbf{k}} \\
\boldsymbol{u}_{F_2} &= \cos 20^\circ\,\hat{\mathbf{i}} - \sin 20^\circ\,\hat{\mathbf{k}} \\
\boldsymbol{F}_2 &= 700\,\text{lb}\cos 20^\circ\,\hat{\mathbf{i}} - 700\,\text{lb}\sin 20^\circ\,\hat{\mathbf{k}}
\end{aligned}$$

With the formulation, for (a),

$$\begin{aligned}
\boldsymbol{F}_{\text{P1}} &= \boldsymbol{u}_{a\text{-}a} \cdot \boldsymbol{F}_1 \\
&= (\cos 45^\circ\,\hat{\mathbf{i}} - \sin 45^\circ\,\hat{\mathbf{k}}) \cdot 300\,\text{lb}(\cos 55^\circ\,\hat{\mathbf{i}} + \sin 55^\circ\,\hat{\mathbf{k}}) \\
&= -52.1\,\text{lb}
\end{aligned}$$

For (b),

$$\begin{aligned}
\boldsymbol{F}_{\text{P2}} &= \boldsymbol{u}_{a\text{-}a} \cdot \boldsymbol{F}_2 \\
&= (\cos 45^\circ\,\hat{\mathbf{i}} - \sin 45^\circ\,\hat{\mathbf{k}}) \cdot 700\,\text{lb}(\cos 20^\circ\,\hat{\mathbf{i}} - \sin 20^\circ\,\hat{\mathbf{k}}) \\
&= 634.4\,\text{lb}
\end{aligned}$$

For (c),

$$\begin{aligned}
\boldsymbol{F}_{\text{P}a\text{-}a} &= \boldsymbol{F}_{\text{P1}} + \boldsymbol{F}_{\text{P2}} \\
&= 582.3\,\text{lb}
\end{aligned}$$

RESULTS

$$\boxed{\begin{aligned}
\boldsymbol{F}_{\text{P1}} &= -52.1\,\text{lb} \\
\boldsymbol{F}_{\text{P2}} &= 634\,\text{lb} \\
\boldsymbol{F}_{\text{P}a\text{-}a} &= 582\,\text{lb}
\end{aligned}}$$

CHECK : Check the calculations of the dot product and also the unit vectors formulation.

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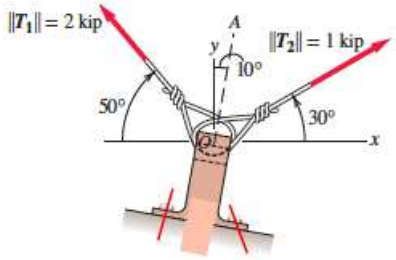
PROBLEM 2.7.13

Two support cables are tethered to a support at O. The support is embedded in concrete as shown.

a. Determine the magnitude of the projection of $\boldsymbol{T_1}$ along O-A.

b. Determine the magnitude of the projection of $\boldsymbol{T_2}$ along O-A.

c. Engineers are concerned that the support will pull out of the concrete if the force pulling along the axis of the support is greater that 2500 lb. Use the results from a and b to analyze the situation and determine if failure will occur.

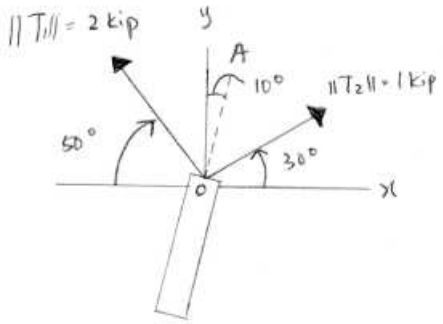


GOAL : To determine (a) the magnitude of the projection of $\boldsymbol{T}_1$ along OA, (b) the magnitude of the projection of $\boldsymbol{T}_2$ along OA, and (c) to determine whether failure would occur from $\boldsymbol{T}_1$ and $\boldsymbol{T}_2$.

GIVEN : Set of axes, and magnitude and direction of forces applied to point O.

ASSUME : Planar.

DRAW :



FORMULATE EQUATIONS and **SOLVE** (a):

$$\begin{aligned}||\boldsymbol{T}_{1_{OA}}|| &= ||\boldsymbol{T}_1||\cos(290^\circ - 50^\circ + 10^\circ) \\ &= (2000\,\text{lb})\cos 50^\circ = 1285.0\,\text{lb}\end{aligned}$$

RESULTS (a): The projection of $\boldsymbol{T}_1$ onto OA:

$$\boxed{||\boldsymbol{T}_{1_{OA}}|| = 1285\,\text{lb}}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}||\boldsymbol{T}_{2_{OA}}|| &= ||\boldsymbol{T}_2||\cos(90^\circ - 30^\circ - 10^\circ) \\ &= (1000\,\text{lb})\cos 50^\circ = 643.0\,\text{lb}\end{aligned}$$

RESULTS (b): The projection of $\boldsymbol{T}_2$ onto OA:

$$\boxed{||\boldsymbol{T}_{2_{OA}}|| = 643\,\text{lb}}$$

FORMULATE EQUATIONS and **SOLVE** (c):

$$||\boldsymbol{T}_{R_{OA}}|| = ||\boldsymbol{T}_{1_{OA}}|| + ||\boldsymbol{T}_{2_{OA}}|| = 1928.0\,\text{lb}$$

RESULTS (c): The net force along OA:

$$\boxed{||\boldsymbol{T}_{R_{OA}}|| = 1928.0\,\text{lb}}$$

Since $\boldsymbol{T}_{R_{OA}} < 2500\,\text{lb}$, failure will not occur.

CHECK : Verify the angles and check the calculations.

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PROBLEM 2.7.14

Let $\boldsymbol{A} = \boldsymbol{i} + 5\boldsymbol{j} - 3\boldsymbol{k}$ and $\boldsymbol{B} = 4\boldsymbol{i} - \boldsymbol{j} + 7\boldsymbol{k}$. Determine the scalar component of $\boldsymbol{A}$ in the direction of $\boldsymbol{B}$.

GOAL : Determine the scalar component of $\boldsymbol{A}$ in the direction of $\boldsymbol{B}$.

GIVEN : Two different forces in vector notation:

$$\boldsymbol{A} = \hat{\mathbf{i}} + 5\,\hat{\mathbf{j}} - 3\,\hat{\mathbf{k}}$$

$$\boldsymbol{B} = 4\,\hat{\mathbf{i}} - \hat{\mathbf{j}} + 7\,\hat{\mathbf{k}}$$

ASSUME : None necessary.

DRAW : None necessary.

FORMULATE EQUATIONS and **SOLVE** :

Find the unit vector along $\boldsymbol{B}$:

$$\hat{\boldsymbol{u}}_B = \frac{\boldsymbol{B}}{\|\boldsymbol{B}\|} = \frac{4\,\hat{\mathbf{i}} - \hat{\mathbf{j}} + 7\,\hat{\mathbf{k}}}{\sqrt{(4)^2 + (-1)^2 + (7)^2}}$$
$$= 0.492\,\hat{\mathbf{i}} - 0.123\,\hat{\mathbf{j}} + 0.862\,\hat{\mathbf{k}}$$

Project $\boldsymbol{A}$ onto the unit vector along $\boldsymbol{B}$:

$$\boldsymbol{A} \cdot \hat{\boldsymbol{u}}_B = (1)(0.492) + (5)(-0.123) + (-3)(0.862)$$
$$= -2.709$$

RESULTS : The scalar component of $\boldsymbol{A}$ in the direction of $\boldsymbol{B}$ is:

$$\boxed{\boldsymbol{A} \cdot \hat{\boldsymbol{u}}_B = -2.71}$$

CHECK : Find the angle between $\boldsymbol{A}$ and $\boldsymbol{B}$ using (4.25) then find the projection onto $\boldsymbol{B}$:

$$\theta = \cos^{-1}\left(\frac{(1)(4) + (5)(-1) + (-3)(7)}{(5.916)(8.124)}\right) = 117.2^\circ$$

$$||\boldsymbol{A}||\cos\theta = (5.916)\cos 117.2^\circ = -2.71$$

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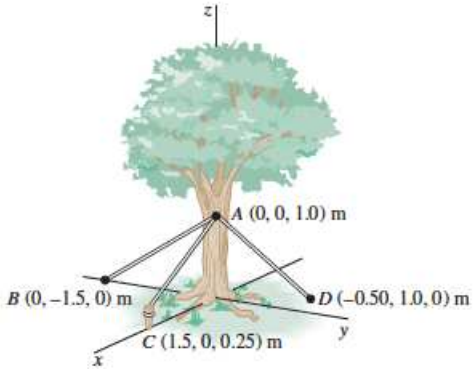
PROBLEM 2.7.15

Three cables are attached to a tree as shown. Determine the angles between

a. cables *AB* and *AC*

b. cables *AB* and *AD*

c. cables *AC* and *AD*

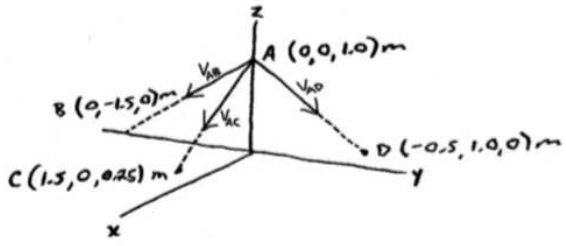


GOAL : To use (4.25) to determine the angles between cables: (a) *AB* and *AC*, (b) *AB* and *AD*, (c) *AC* and *AD*.

GIVEN : Sketch of the tree and coordinates of supporting cables.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

First, express each cable as a vector and calculate it's magnitude:

$$\boldsymbol{V}_{AB} = (0\,\hat{\mathbf{i}} - 1.5\,\hat{\mathbf{j}} - 1.0\,\hat{\mathbf{k}})\ \text{m}$$
$$\boldsymbol{V}_{AC} = (1.5\,\hat{\mathbf{i}} + 0\,\hat{\mathbf{j}} - 0.75\,\hat{\mathbf{k}})\ \text{m}$$
$$\boldsymbol{V}_{AD} = (-0.5\,\hat{\mathbf{i}} + 1.0\,\hat{\mathbf{j}} - 1.0\,\hat{\mathbf{k}})\ \text{m}$$

$$||\boldsymbol{V}_{AB}|| = \sqrt{(0\,\text{m})^2 + (-1.5\,\text{m})^2 + (-1.0\,\text{m})^2} = 1.803\,\text{m}$$
$$||\boldsymbol{V}_{AC}|| = \sqrt{(1.5\,\text{m})^2 + (0\,\text{m})^2 + (-0.75\,\text{m})^2} = 1.677\,\text{m}$$
$$||\boldsymbol{V}_{AD}|| = \sqrt{(-0.5\,\text{m})^2 + (1.0\,\text{m})^2 + (-1.0\,\text{m})^2} = 1.500\,\text{m}$$

$$\theta = \cos^{-1}\left(\frac{V_{1_x}V_{2_x} + V_{1_y}V_{2_y} + V_{1_z}V_{2_z}}{||\boldsymbol{V}_1||\,||\boldsymbol{V}_2||}\right) \qquad (4.25)$$

For (a), *AB* and *AC*:

$$\theta = \cos^{-1}\left(\frac{(0)(1.5) + (-1.5)(0) + (-1.0)(-0.75)}{(1.803)(1.677)}\right) = 75.6^\circ$$

For (b), *AB* and *AD*:

$$\theta = \cos^{-1}\left(\frac{(0)(-0.5) + (-1.5)(1.0) + (-1.0)(-1.0)}{(1.803)(1.500)}\right) = 100.7^\circ$$

For (c), *AC* and *AD*:

$$\theta = \cos^{-1}\left(\frac{(1.5)(-0.5) + (0)(1.0) + (-0.75)(-1.0)}{(1.677)(1.500)}\right) = 90^\circ$$

RESULTS :

Angle between
(a) *AB* and *AC*: 75.6°
(b) *AB* and *AD*: 100.7°
(c) *AC* and *AD*: 90.0°

CHECK : First, check your intuition using the figure to make sure the angles seem reasonable. Also check calculations carefully, or substitute the answers into equation (4.24) and ensure equality.

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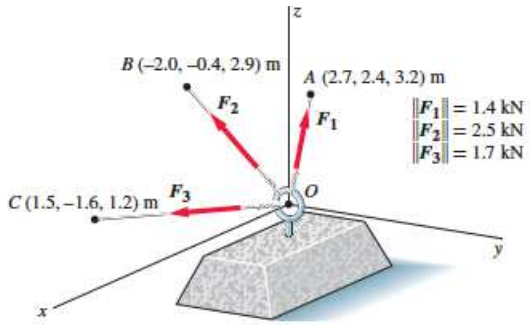
PROBLEM 2.7.16

Three cables are attached to a block as shown below. Use (4.25) to determine the angles between

a. cables *OA* and *OB*

b. cables *OA* and *OC*

c. cables *OB* and *OC*

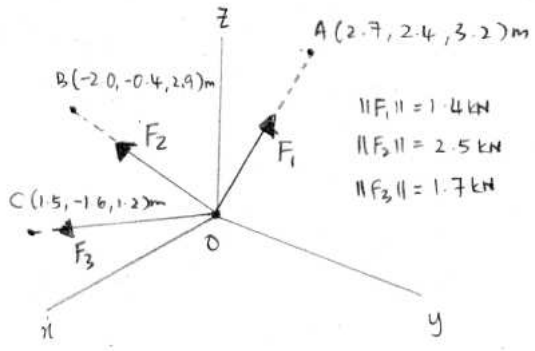


GOAL : To determine the angles between cables: (a) *OA* and *OB*, (b) *OA* and *OC*, (c) *OB* and *OC*.

GIVEN : Magnitude and line of action of forces acting on a block.

ASSUME : None necessary.

DRAW :



FORMULATE EQUATIONS and **SOLVE** :

First, express each cable as a vector and calculate it's magnitude:

$$\boldsymbol{V}_{OA} = (2.7\,\hat{\mathbf{i}} + 2.4\,\hat{\mathbf{j}} + 3.2\,\hat{\mathbf{k}})\ \text{m}$$
$$\boldsymbol{V}_{OB} = (-2.0\,\hat{\mathbf{i}} - 0.4\,\hat{\mathbf{j}} + 2.9\,\hat{\mathbf{k}})\ \text{m}$$
$$\boldsymbol{V}_{OC} = (1.5\,\hat{\mathbf{i}} - 1.6\,\hat{\mathbf{j}} + 1.2\,\hat{\mathbf{k}})\ \text{m}$$

$$||\boldsymbol{V}_{OA}|| = \sqrt{(2.7\,\text{m})^2 + (2.4\,\text{m})^2 + (3.2\,\text{m})^2} = 4.8\,\text{m}$$
$$||\boldsymbol{V}_{OB}|| = \sqrt{(-2.0\,\text{m})^2 + (-0.4\,\text{m})^2 + (2.9\,\text{m})^2} = 3.5\,\text{m}$$
$$||\boldsymbol{V}_{OC}|| = \sqrt{(1.5\,\text{m})^2 + (-1.6\,\text{m})^2 + (1.2\,\text{m})^2} = 2.5\,\text{m}$$

$$\theta = \cos^{-1}\left(\frac{V_{1_x}V_{2_x} + V_{1_y}V_{2_y} + V_{1_z}V_{2_z}}{||\boldsymbol{V}_1||\,||\boldsymbol{V}_2||}\right)$$

For (a) *OA* and *OB*:

$$\theta = \cos^{-1}\left(\frac{(2.7)(-2.0) + (2.4)(-0.4) + (3.2)(2.9)}{(4.8)(3.5)}\right) = 80.2^\circ$$

For (b) *OA* and *OC*:

$$\theta = \cos^{-1}\left(\frac{(2.7)(1.5) + (2.4)(-1.6) + (3.2)(1.2)}{(4.8)(2.5)}\right) = 70.4^\circ$$

For (c) *OB* and *OC*:

$$\theta = \cos^{-1}\left(\frac{(-2.0)(1.5) + (-0.4)(-1.6) + (2.9)(1.2)}{(3.5)(2.5)}\right) = 82.7^\circ$$

RESULTS :

Angle between
(a) *OA* and *OB*: 80.2°
(b) *OA* and *OC*: 70.4°
(c) *OB* and *OC*: 82.7°

CHECK : First, check your intuition using the figure to make sure the angles seem reasonable. Also check calculations carefully.

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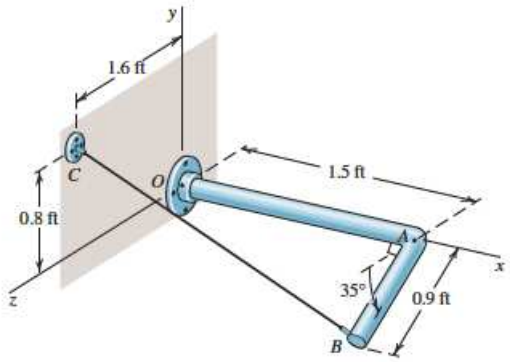
PROBLEM 2.7.17

A cable is attached at B to support the frame OAB. The tension in the cable is 500 lb.

a. Determine the angle between the cable and member BA.

b. Determine the components of $\boldsymbol{F}_{\mathbf{BC}}$ (the cable force acting at B) parallel and perpendicular to member BA.

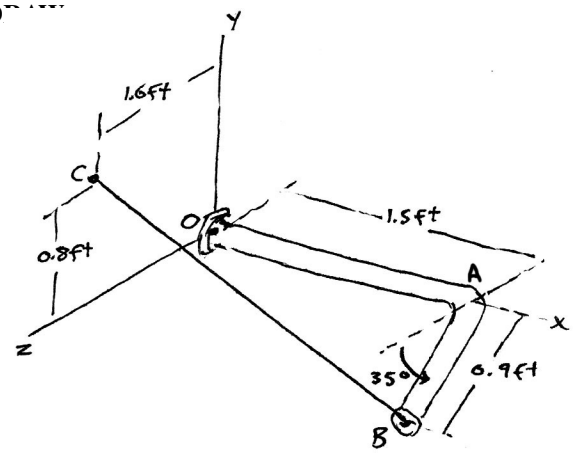


GOAL : To (a) determine the angle between the cable and member BA, and (b) determine the components of $\boldsymbol{F}_{BC}$ parallel and perpendicular to member BA.

GIVEN : System geometry, a coordinate system, $||\boldsymbol{T}_{BC}|| = 500$ lb.

ASSUME : None necessary.

DRAW



FORMULATE EQUATIONS and **SOLVE** (a):

Find the unit vector pointing from B to A:

$$\begin{aligned}\boldsymbol{u}_{BA} &= (0\,\hat{\mathbf{i}} + \sin 35^\circ\,\hat{\mathbf{j}} - \cos 35^\circ\,\hat{\mathbf{k}}) \\ &= 0.574\,\hat{\mathbf{j}} - 0.819\,\hat{\mathbf{k}}\end{aligned}$$

Find the unit vector pointing from B to C:

$$\begin{aligned}\boldsymbol{p}_{BC} &= [-1.5\,\hat{\mathbf{i}} + (0.8 + 0.9\sin 35^\circ)\,\hat{\mathbf{j}} \\ &\quad + (1.6 - 0.9\cos 35^\circ)\,\hat{\mathbf{k}}]\ \text{m}\end{aligned}$$

$$\begin{aligned}||\boldsymbol{p}_{BC}|| &= \sqrt{(-1.5)^2 + (0.8 + 0.9\sin 35^\circ)^2 + (1.6 - 0.9\cos 35^\circ)^2} \\ &= 2.174\ \text{m}\end{aligned}$$

$$\begin{aligned}\hat{\boldsymbol{u}}_{BC} &= \frac{1}{||\boldsymbol{p}_{BC}||}\boldsymbol{p}_{BC} \\ &= \frac{[-1.5\,\hat{\mathbf{i}} + (0.8 + 0.9\sin 35^\circ)\,\hat{\mathbf{j}} + (1.6 - 0.9\cos 35^\circ)\,\hat{\mathbf{k}}]\ \text{m}}{2.174\ \text{m}} \\ &= -0.690\,\hat{\mathbf{i}} + 0.605\,\hat{\mathbf{j}} + 0.397\,\hat{\mathbf{k}}\end{aligned}$$

Find angle between the two unit vectors:

$$\begin{aligned}\theta &= \cos^{-1}\left(\frac{V_{1_x}V_{2_x} + V_{1_y}V_{2_y} + V_{1_z}V_{2_z}}{||\boldsymbol{V}_1||\,||\boldsymbol{V}_2||}\right) \\ &= \cos^{-1}[(-0.690)(0) + (0.605)(0.574) + (0.397)(-0.819)] \\ &= 88.73^\circ\end{aligned}$$

RESULTS (a): The angle between the cable and member BA is:

$$\boxed{\theta = 88.7^\circ}$$

FORMULATE EQUATIONS and **SOLVE** (b):

$$\begin{aligned}F_{\parallel,BA} &= ||\boldsymbol{F}_{BC}||\cos\theta = (500\ \text{lb})\cos 88.73^\circ \\ &= 11.08\ \text{lb} \\ F_{\perp,BA} &= ||\boldsymbol{F}_{BC}||\cos(90^\circ - \theta) = (500\ \text{lb})\cos 1.27^\circ \\ &= 499.9\ \text{lb}\end{aligned}$$

RESULTS (b): The projections parallel and perpendicular to member BA are:

$$\boxed{\begin{aligned}F_{\parallel,BA} &= 11.08\ \text{lb} \\ F_{\perp,BA} &= 500\ \text{lb}\end{aligned}}$$

CHECK : To check part (a), an examination of the figure shows that the angle should be close to 90°, but be slightly smaller because member BA is pointing slightly downward. To check part (b), find the resultant and ensure the magnitude is the same as $||\boldsymbol{F}_{BC}||$:

$$\sqrt{(11.08\ \text{lb})^2 + (499.9\ \text{lb})^2} = 500\ \text{lb}$$

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2.2.1

$g_v = 27.8 \text{ ft/s}^2$

$g_v / g_e = 86.3\%$

2.2.3

$||F_g|| = 3.55 \times 10^{22} \text{ N}$

2.2.5

$d = 340 \times 10^3 \text{ km}$

2.3.1

Part of the System	**Type of Force**
Cable *AB*-eyelet interface at *B*	Normal Contact Force
	Friction Force
Within cable *BD*	Tension Force
Weight of Object	Gravity Force
None	Compression Force

2.3.3

Type of Force	**Part of System**
Normal Contact Force	Hand-door knob interface
Tension Force	Within woman's arm muscle
Gravity Force	Door Weight
Friction Force	Hand-Door knob interface
Compression Force	Within woman's leg bone

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2.4.1

Case 1: The pair of vice-grips and the nut are defined as the system.
Case 2: The pair of vice-grips are defined as the system.
Case 3: The nut is defined as the system.

Forces	Case 1	Case 2	Case 3
Tension in spring	I	I	—
Normal contact force between pin A and member B	I	I	—
Normal contact force between nut and member B	I	E	E
Normal contact force between nut and member C	I	E	E
Normal contact force and friction forces between thumb and vice grips at D	E	E	—
Normal and friction forces between fingers and vice grips at E	E	E	—
Weight of vice grips	E	E	—
Weight of the nut	E	—	E
Weight of bolt	—	—	—
Normal contact force and friction forces between nut and bolt	E	—	E

2.5.1

$$\mathbf{u} = 0.894\,\hat{\mathbf{i}} + 0.447\,\hat{\mathbf{j}}$$

2.5.3

$\theta_x = 29.7°$

$\theta_y = 60.3°$

$\theta_z = 90°$

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2.5.5

$$\hat{u} = -0.866\,\hat{\mathbf{i}} - 0.500\,\hat{\mathbf{j}}$$

2.5.7

$$\theta_x = 150^\circ$$
$$\theta_y = 120^\circ$$

2.5.9

$$u = -\frac{3}{\sqrt{58}}\,\hat{\mathbf{i}} - \frac{4}{\sqrt{58}}\,\hat{\mathbf{j}} = -0.393\,\hat{\mathbf{i}} - 0.919\,\hat{\mathbf{j}}$$

2.5.11

$$\theta_x = 113.2^\circ$$

$$\theta_y = 156.8^\circ$$

2.5.13

$$\hat{u} = -0.766\,\hat{\mathbf{i}} + 0.643\,\hat{\mathbf{j}}$$

2.5.15

$$\theta_x = 140^\circ$$

$$\theta_y = 50^\circ$$

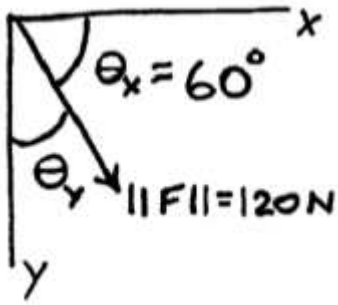
$$\theta_z = 90^\circ$$

2.5.17

$$F_x = 60\,\text{N}$$

$$F_y = 104\,\text{N}$$

$$F_z = 0\,\text{N}$$



2.5.19

$\theta_x = 60°$

$\theta_y = 30°$

$\theta_z = 90°$

2.5.21

$F_x = 6.0\,\text{lb}$

$F_y = 8.0\,\text{lb}$

$F_z = 0.0\,\text{lb}$

2.5.23

$\hat{u} = 0.294\,\hat{\mathbf{i}} - 0.956\,\hat{\mathbf{j}}$

2.5.25

$\theta_x = 72.9°$

$\theta_y = 162.9°$

$\theta_z = 90°$

2.5.27

$||F|| = 38.0 kips$

2.5.29

We know that we can we can write the force vector in Cartesian by multiplying the force magnitude with the unit vector, $F = ||F||u$. With that, we can write,

$$F = ||F||0.5\,\hat{\mathbf{i}} + 0.8658\,\hat{\mathbf{j}}$$

We are told that the horizontal force exerted by the shoring is 2250 lb. This means

$$||F||0.5 = 2250\,\text{lb}$$

and we get

$$\boxed{||F|| = 4500\,\text{lb}}$$

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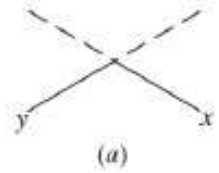
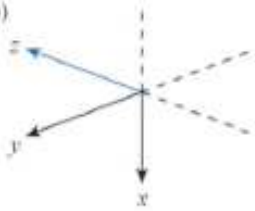
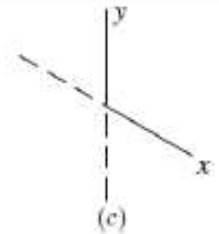
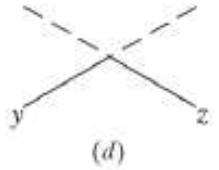
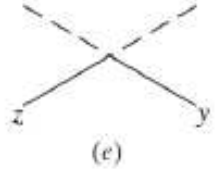
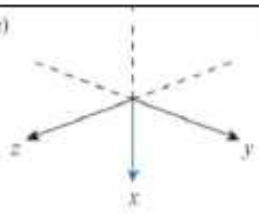
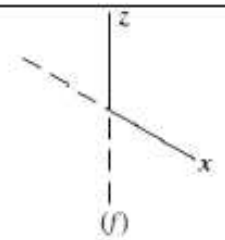
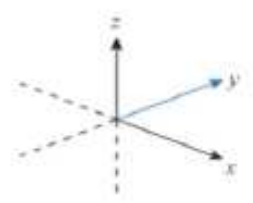
2.5.31

Partial Coordinate System	Answer
 (a)	(a)
(b)	(b) 
 (c)	(c)
 (d)	(d)
 (e)	(e) 
 (f)	(f) 

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2.5.33

(a): $\boldsymbol{u}_{AB} = 0.1163\,\hat{\mathbf{i}} + 0.3488\,\hat{\mathbf{j}} - 0.9302\,\hat{\mathbf{k}}$

(b): $\boldsymbol{F} = 17.45\,\text{N}\,\hat{\mathbf{i}} + 52.3\,\text{N}\,\hat{\mathbf{j}} - 139.5\,\text{N}\,\hat{\mathbf{k}}$

(c): $\boldsymbol{F}_{onMan} = -17.45\,\text{N}\,\hat{\mathbf{i}} - 52.3\,\text{N}\,\hat{\mathbf{j}} + 139.5\,\text{N}\,\hat{\mathbf{k}}$

2.5.35

$\boldsymbol{F}_1 = (-200\,\hat{\mathbf{i}} + 200\,\hat{\mathbf{j}} + 282.8\,\hat{\mathbf{k}})\,\text{N}$

2.5.37

(a): $\hat{\boldsymbol{u}} = 0.894\,\hat{\mathbf{i}} + 0.447\,\hat{\mathbf{j}}$

$\hat{\boldsymbol{u}} = -0.894\,\hat{\mathbf{i}} - 0.447\,\hat{\mathbf{j}}$

$\boldsymbol{F} = 107.3\,\hat{\mathbf{i}} + 53.7\,\hat{\mathbf{j}}\,\text{lb}$

or

(b): $\boldsymbol{F} = -107.3\,\hat{\mathbf{i}} - 53.7\,\hat{\mathbf{j}}\,\text{lb}$

The space angles are

$$\boxed{\begin{aligned}\theta_x &= 26.6^\circ\\ \theta_y &= 63.4^\circ\\ \theta_z &= 90^\circ\end{aligned}}$$

(c):

For $\boldsymbol{F} = -107.3\,\hat{\mathbf{i}} - 53.7\,\hat{\mathbf{j}}\,\text{lb}$ use

$$\boxed{\begin{aligned}\theta_x &= 153.4^\circ\\ \theta_y &= 116.6^\circ\\ \theta_z &= 90^\circ\end{aligned}}$$

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The magnitude and angles are

$$\boxed{\begin{aligned} ||\boldsymbol{F}|| &= 120\,\text{lb} \\ \theta &= 26.6^\circ \\ \phi &= 90^\circ \end{aligned}}$$

(d):

For $\boldsymbol{F} = -107.3\,\hat{\mathbf{i}} - 53.7\,\hat{\mathbf{j}}$ lb use

$$\boxed{\begin{aligned} ||\boldsymbol{F}|| &= 120\,\text{lb} \\ \theta &= 206.6^\circ \\ \phi &= 90^\circ \end{aligned}}$$

2.5.39

$\theta_{x1} = 78.7^\circ$	$\theta_{y1} = 11.3^\circ$
$\theta_{x2} = 78.7^\circ$	$\theta_{y2} = 168.7^\circ$
$\theta_{x3} = 101.3^\circ$	$\theta_{y3} = 168.7^\circ$
$\theta_{x4} = 101.3^\circ$	$\theta_{y4} = 11.3^\circ$

2.5.41

$\boldsymbol{F}_{A,C_1} = (383\,\hat{\mathbf{i}} - 321\,\hat{\mathbf{j}})$ lb

2.5.43

(NOTE: The tension acting on B is the negative of T_{AB}).

$\boldsymbol{T}_{AB} = (-10.0\,\hat{\mathbf{i}} + 17.3\,\hat{\mathbf{j}})$ kip

2.5.45

With equation (1), we can solve for T . Then, we can solve for the vertical component to write T in the Cartesian vector notation. This gives

$\boldsymbol{T} = 55$ lb

$\boldsymbol{T} = -22\,\text{lb}\,\hat{\mathbf{i}} + 50.4\,\text{lb}\,\hat{\mathbf{j}}$

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2.5.47

$$\boldsymbol{F}_A = \boldsymbol{F}_{Ax} + \boldsymbol{F}_{Ay}$$

$$\boldsymbol{F}_A = 13.87\,\text{kN}\,\hat{\mathbf{i}} + 10.38\,\text{kN}\,\hat{\mathbf{j}}$$

$$\boldsymbol{F}_B = \boldsymbol{F}_{Bx} + \boldsymbol{F}_{By}$$

$$\boldsymbol{F}_B = -13.87\,\text{kN}\,\hat{\mathbf{i}} + 8.01\,\text{kN}\,\hat{\mathbf{j}}$$

2.5.49

$$\boldsymbol{T}_1 = \boldsymbol{T}_{1x} + \boldsymbol{T}_{1y}$$

$$\boldsymbol{T}_1 = 25.9\,\text{kip}\,\hat{\mathbf{i}} + 96.6\,\text{kip}\,\hat{\mathbf{j}}$$

$$\boldsymbol{T}_2 = \boldsymbol{T}_{2x} + \boldsymbol{T}_{2y}$$

$$\boldsymbol{T}_2 = -90.6\,\text{kip}\,\hat{\mathbf{i}} + 42.3\,\text{kip}\,\hat{\mathbf{j}}$$

$$\boldsymbol{T}_3 = \boldsymbol{T}_{3x} + \boldsymbol{T}_{3y}$$

$$\boldsymbol{T}_3 = 64.7\,\text{kip}\,\hat{\mathbf{i}} - 138.7\,\text{kip}\,\hat{\mathbf{j}}$$

2.5.51

$W_{\parallel} = 48.5\,\text{lb}$ (down the incline)

$W_{\perp} = 194.0\,\text{lb}$ (perpendicular to the incline)

2.5.53

$W_{\parallel} = 59.3\,\text{N}$

$W_{\perp} = 396\,\text{N}$

2.5.55

(a): 1, 2, 3, 4, 5, 6
1, 3, and 5 are the same

(b): 2, 4, and 6 are the same

2.5.57

$$\boldsymbol{F} = 28.0\,\text{lb}\,\hat{\mathbf{i}} - 168.2\,\text{lb}\,\hat{\mathbf{j}} - 84.1\,\text{lb}\,\hat{\mathbf{k}}$$

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2.5.59

$F_x = 60.0\,\text{lb} \quad \theta_x = 64.6°$

$F_y = -40.0\,\text{lb} \quad \theta_y = 106.6°$

$F_z = 120.0\,\text{lb} \quad \theta_z = 31.0°$

2.5.61

(a): $\boldsymbol{F}_1 = (-11.9\,\hat{\mathbf{i}} + 16.3\,\hat{\mathbf{j}} + 22.2\,\hat{\mathbf{k}})\,\text{N}$

(b): $\boldsymbol{F}_2 = (11.9\,\hat{\mathbf{i}} - 16.3\,\hat{\mathbf{j}} - 22.2\,\hat{\mathbf{k}})\,\text{N}$

(c): $\boldsymbol{F}_1 = -\boldsymbol{F}_2$ by comparing results from (a) and (b)

2.5.63

$\theta = 72.8°$

2.5.65

$\boldsymbol{T}_{BA} = (4.06\,\hat{\mathbf{i}} - 7.61\,\hat{\mathbf{j}} + 5.07\,\hat{\mathbf{k}})\,\text{kN}$

$\boldsymbol{T}_{BC} = (-4.06\,\hat{\mathbf{i}} - 7.61\,\hat{\mathbf{j}} + 5.07\,\hat{\mathbf{k}})\,\text{kN}$

$\boldsymbol{F}_E = -5.0\,\text{kN}\,\hat{\mathbf{k}}$

$\boldsymbol{F}_D = (15.2\,\hat{\mathbf{j}} - 5.14\,\hat{\mathbf{k}})\,\text{kN}$

2.6.1

$\boldsymbol{F}_R = (6.95\,\hat{\mathbf{i}} + 1.98\,\hat{\mathbf{j}})\,\text{kN}$

$\theta_x = 16°$

2.6.3

$\boldsymbol{F}_R = (6.92\,\hat{\mathbf{i}} + 2.03\,\hat{\mathbf{j}})\,\text{kN}$

2.6.5

$||\boldsymbol{F}|| = 56.9\,\text{kip}$

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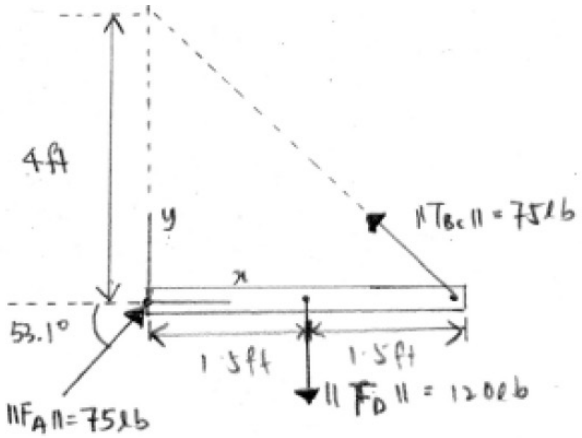
2.6.7



2.6.9

$\boldsymbol{F}_R = (14\,\hat{\mathbf{i}} - 2\,\hat{\mathbf{j}})$ lb

2.6.11

$\boldsymbol{F}_R = (2.5\,\hat{\mathbf{i}} + 1.54\,\hat{\mathbf{j}} + 2.5\,\hat{\mathbf{k}})$ kN

2.6.13

$\hat{\boldsymbol{u}}_R = 0.649\,\hat{\mathbf{i}} + 0.398\,\hat{\mathbf{j}} + 0.649\,\hat{\mathbf{k}}$

2.6.15

α will get smaller.

2.6.17

$R_x = -0.20$ kip

(a): $R_y = -3.29$ kip

$||\boldsymbol{R}|| = 3.30$ kip

$\theta_x = 93.5°$

$\theta_y = 176.5°$

(b): $\theta_z = 90°$

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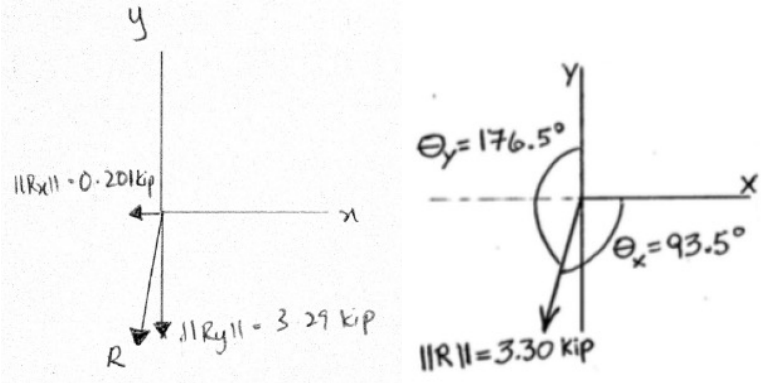


2.6.19

$$\boldsymbol{R} = ||\boldsymbol{T}||(-0.647\,\hat{\mathbf{i}} + 1.389\,\hat{\mathbf{j}})$$

$\theta_x = 115.0°$, which bisects the angles of $\boldsymbol{T}_1$ and $\boldsymbol{T}_2$

2.6.21

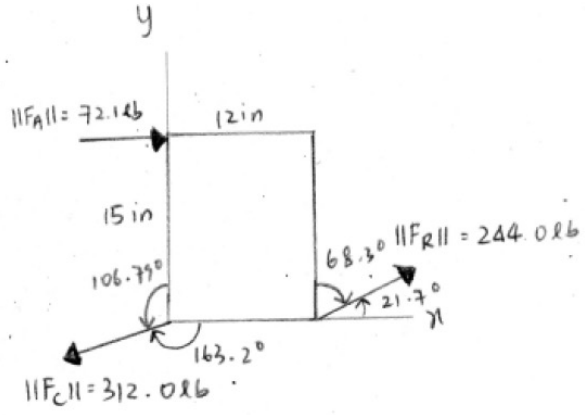
(a): $||\boldsymbol{F}_B|| = 245\,\text{lb}$

(b): $\boldsymbol{F}_R = (-89.3\,\hat{\mathbf{j}})\,\text{lb}$

2.6.23

$F_N = 8.66\,\text{lb}, \quad F_{push} = 5\,\text{lb}$

2.6.25



2.6.27

$||\boldsymbol{F}_u|| = 2000\,\text{lb}$

$||\boldsymbol{F}_v|| = -2000\,\text{lb}$

2.6.29

$$\boldsymbol{F}_R = (143.9\,\hat{\mathbf{i}} + 460.\,\hat{\mathbf{j}} + 9.81\,\hat{\mathbf{k}})\ \text{lb}$$

2.6.31

$$\boldsymbol{R} = -14.98\ \text{lb}\,\hat{\mathbf{i}} + 7.82\ \text{lb}\,\hat{\mathbf{k}}$$

2.6.33

$$\boldsymbol{T}_R = (140.7\,\hat{\mathbf{i}} - 41.3\,\hat{\mathbf{j}} - 417\,\hat{\mathbf{k}})\ \text{N}$$

2.6.35

$$\theta_x = 32.8°$$

$$\theta_y = 97.9°$$

$$\theta_z = 58.4°$$

2.6.37

$$\text{Minimum } ||\boldsymbol{T}|| \approx 10.16\ \text{lb}$$

2.6.39

$$\boldsymbol{F}_u = 440\ \text{N}$$

$$\boldsymbol{F}_v = 54.2\ \text{N}$$

2.6.41

$$\boldsymbol{F}_{\text{cable}} =$$

$$(50\ \text{N}/\cos\theta) \text{ for } \theta < 63.4°$$

$$(10\ \text{N}/\sin\theta) \text{ for } \theta > 63.4°$$

2.6.43

$$||\boldsymbol{T}|| = 77.6\ \text{lb}$$

$$||\boldsymbol{P}|| = 290\ \text{lb}$$

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2.6.45

$\theta_x = 77.2°$

$\theta_y = 104.0°$

$\theta_z = 19.2°$

2.7.1

(a): $\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = -41582\,\text{lb}^2$

(b): $\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = -41582\,\text{lb}^2$

2.7.3

$\boldsymbol{F}_{OA} = ||\boldsymbol{F}|| \cos 30°$

(a): $\boldsymbol{F}_{OA} = 693\,\text{lb}$

$\boldsymbol{F}_{OB} = ||\boldsymbol{F}|| \cos 45°$

(b): $\boldsymbol{F}_{OB} = 566\,\text{lb}$

2.7.5

(a): $(\boldsymbol{A} \cdot \boldsymbol{B})\,\boldsymbol{C} = -26\,\hat{\mathbf{i}} + 182\,\hat{\mathbf{j}} - 104\,\hat{\mathbf{k}}$

(b): $\boldsymbol{A} \cdot (\boldsymbol{B} + \boldsymbol{C})(-\boldsymbol{A}) \cdot (3\boldsymbol{B} - 5\boldsymbol{C}) = 11{,}461$

2.7.7

$||\boldsymbol{F}_{\text{parallel}}|| = \boldsymbol{u}_{\text{parallel}} \cdot \boldsymbol{W} = 43.7\,\text{lb}$

2.7.9

All lengths are $\sqrt{2}$ and all angles are 90°.

Thus, it is a square.

2.7.11

$F_{LA} = 69.5\,\text{N}$

$F_{LB} = 200\,\text{N}$

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2.7.13

(a): $||\boldsymbol{T}_{1_{OA}}|| = 1285\,\text{lb}$

(b): $||\boldsymbol{T}_{2_{OA}}|| = 643\,\text{lb}$

(c): $||\boldsymbol{T}_{R_{OA}}|| = 1928.0\,\text{lb}$

2.7.15

Angle between

(a) AB and AC: $75.6°$

(b) AB and AD: $100.7°$

(c) AC and AD: $90.0°$

2.7.17

(a): $\theta = 88.7°$

$F_{\parallel,BA} = 11.08\,\text{lb}$

(b): $F_{\perp,BA} = 500\,\text{lb}$

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