ENGINEERING MECHANICS STATICS

Dr. S V Venkatesh
Civil Engineering
Department of S & H

Engineering Mechanics

Statics

Eighth edition
SI Version

J. L. Meriam and L. G. Kraige

Chapter 1

Introduction to Statics

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Civil Engineering

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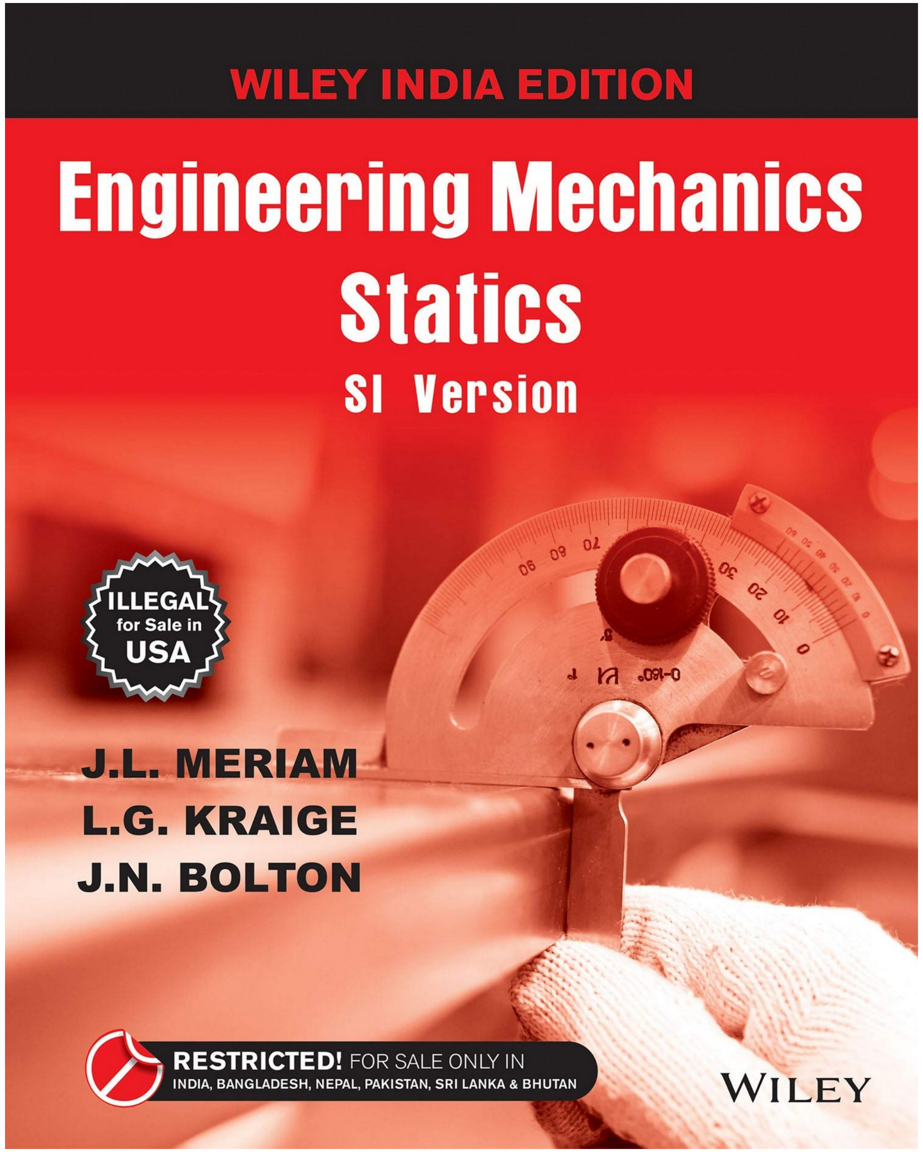
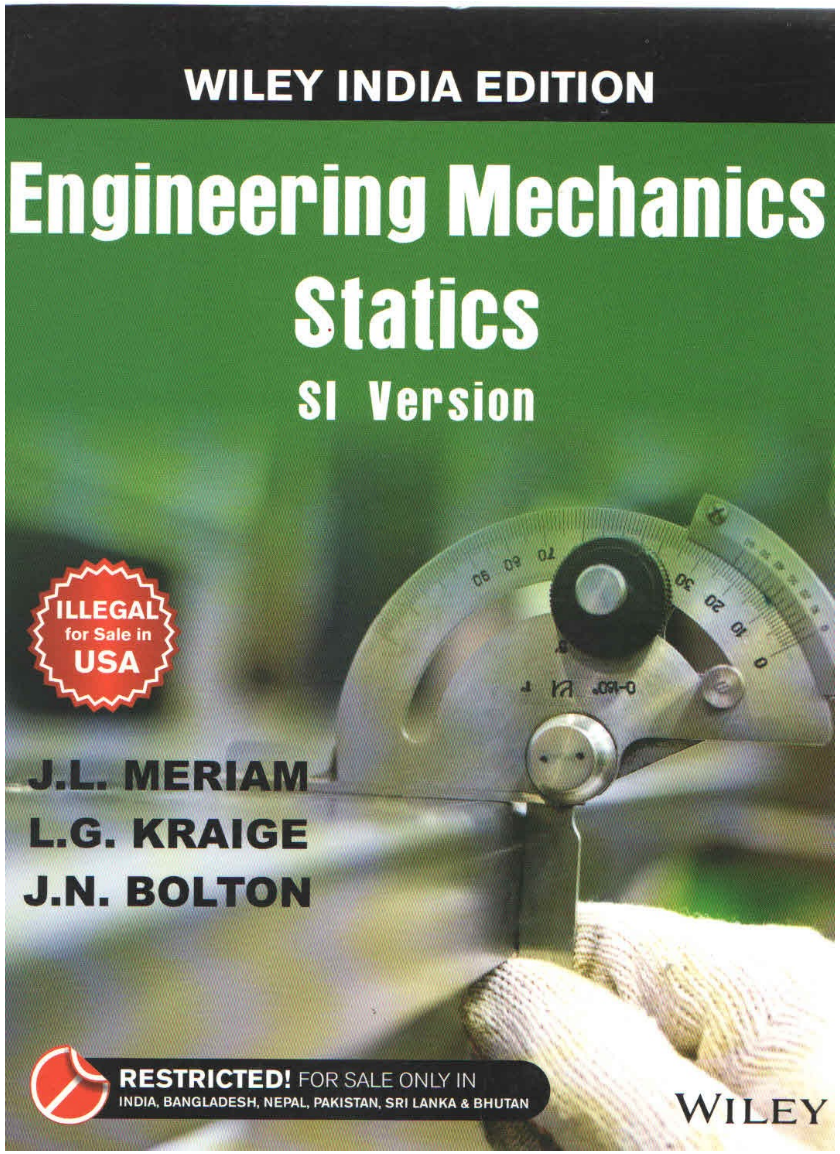
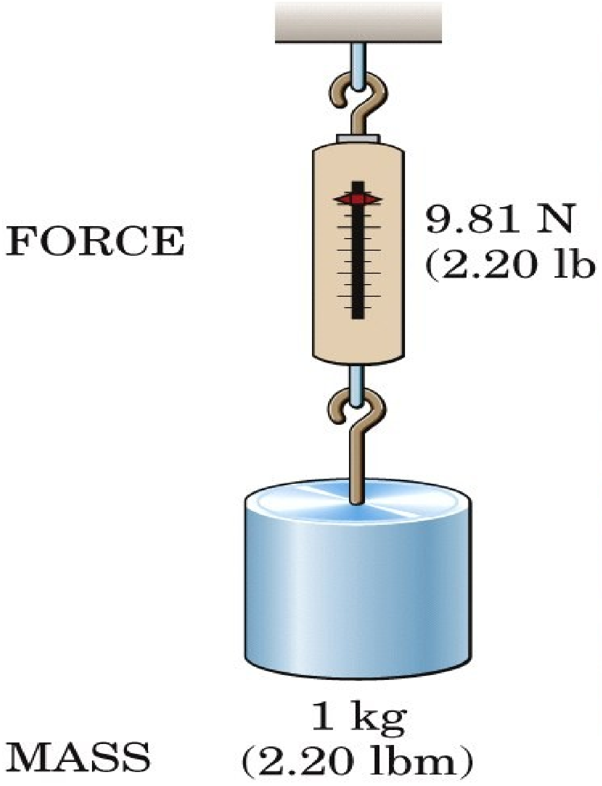
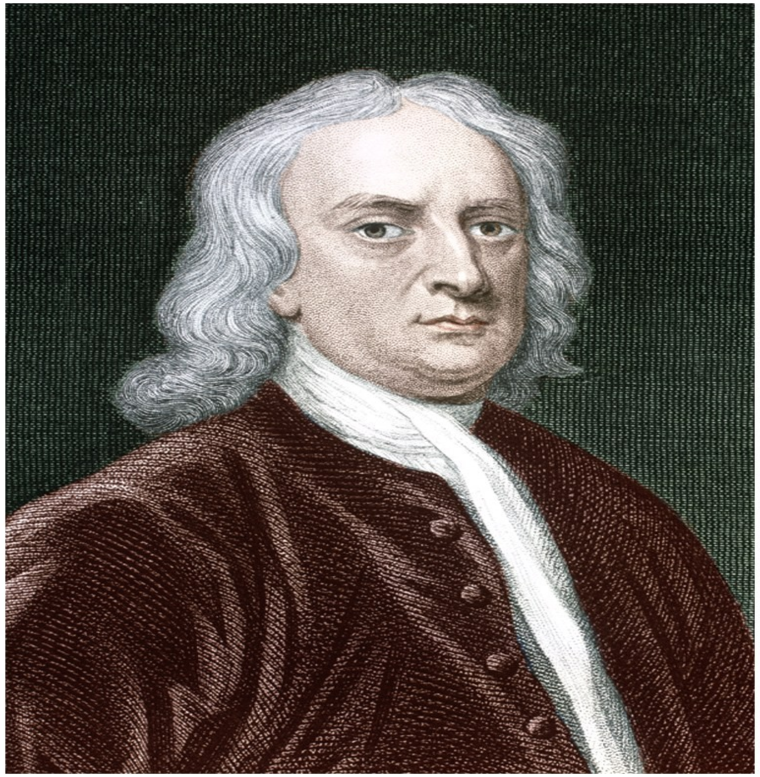




Mechanics – Statics and dynamics

Space
Mass
Time
Particle
Rigid body
Elastic body
Plastic body
Force
Types of force
Units of force
Newton's laws
Characteristics of force





Sir Isaac Newton

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Mechanics – Statics and dynamics

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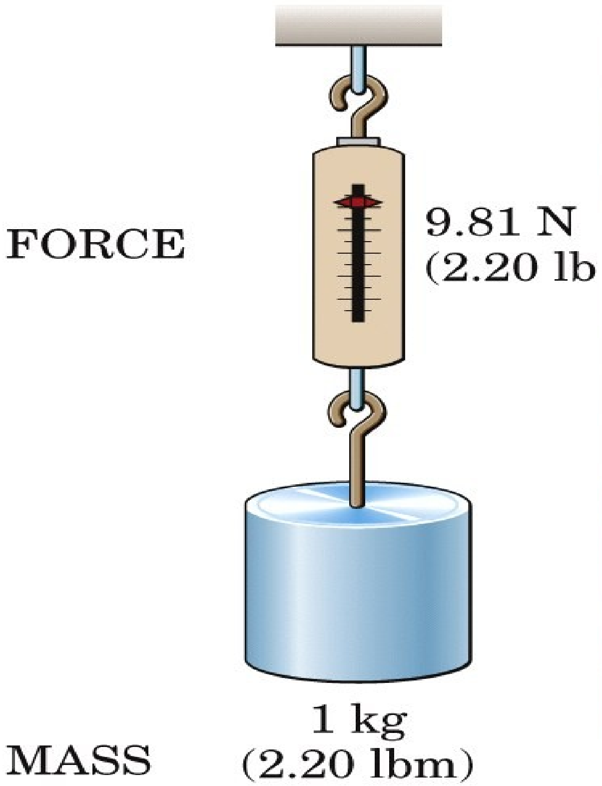

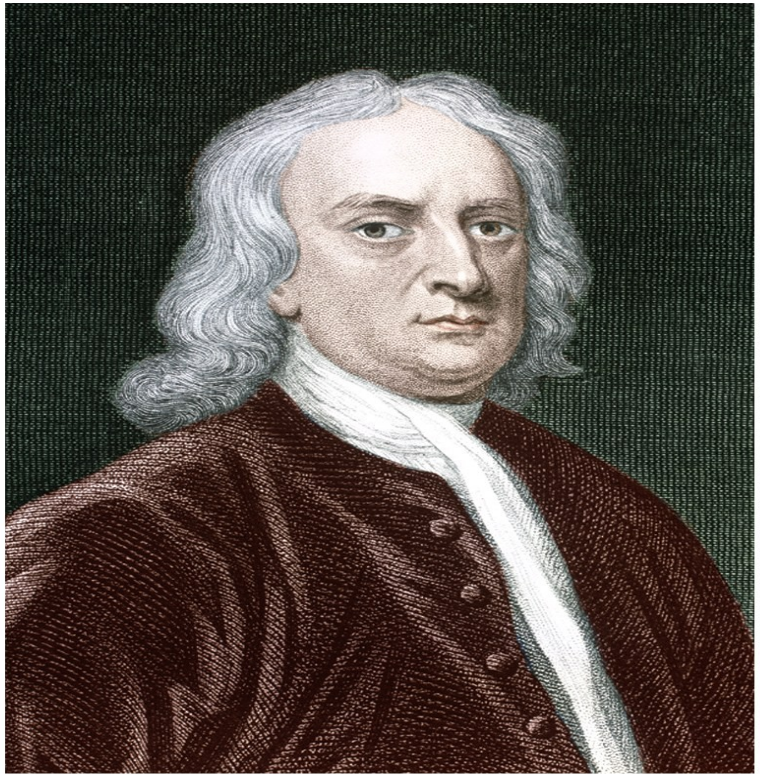

Unnumbered 1 p3
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Sir Isaac Newton

Mathematics

Similar triangles
Law of Sines
Law of Cosines
Trigonometry
Integration

Deformation
Displacement
Deflection

Translatory motion
Rotatory Motion

Resultant
Coordinate system

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Mathematics

Similar triangles
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Law of triangle of forces,
Law of parallelogram of forces

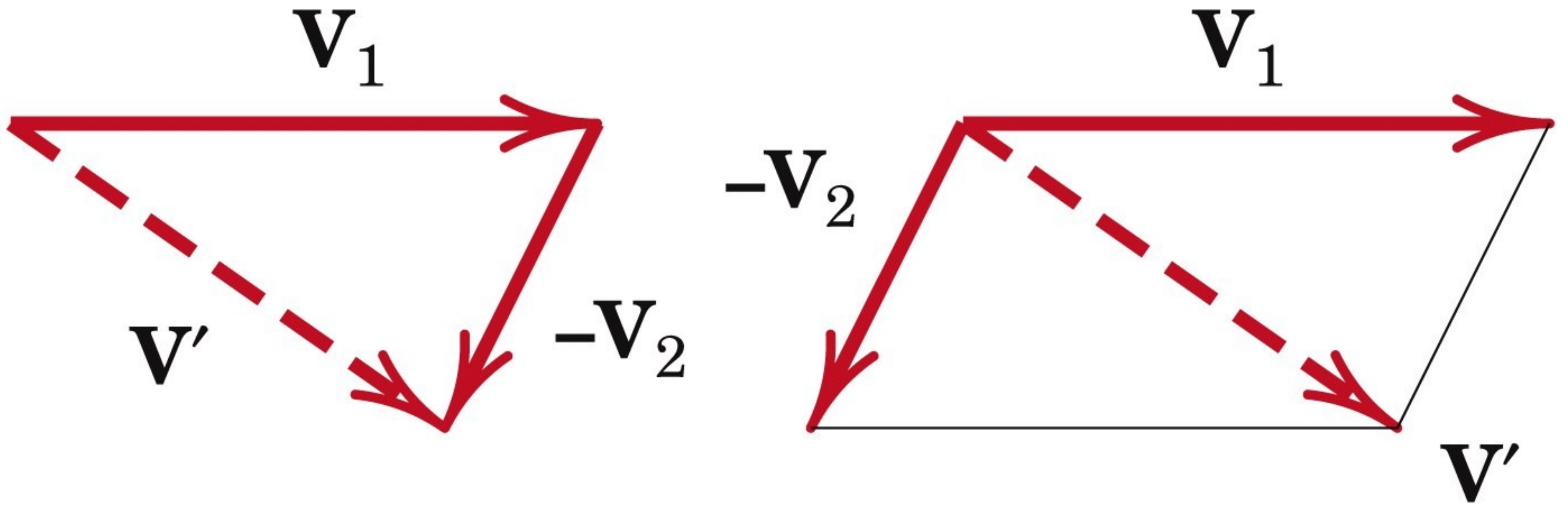

Figure 1-3

Cross Product

Scalars and Vectors

- Vector
- Free vector
- Sliding vector
- Fixed or bound
- Sign convention

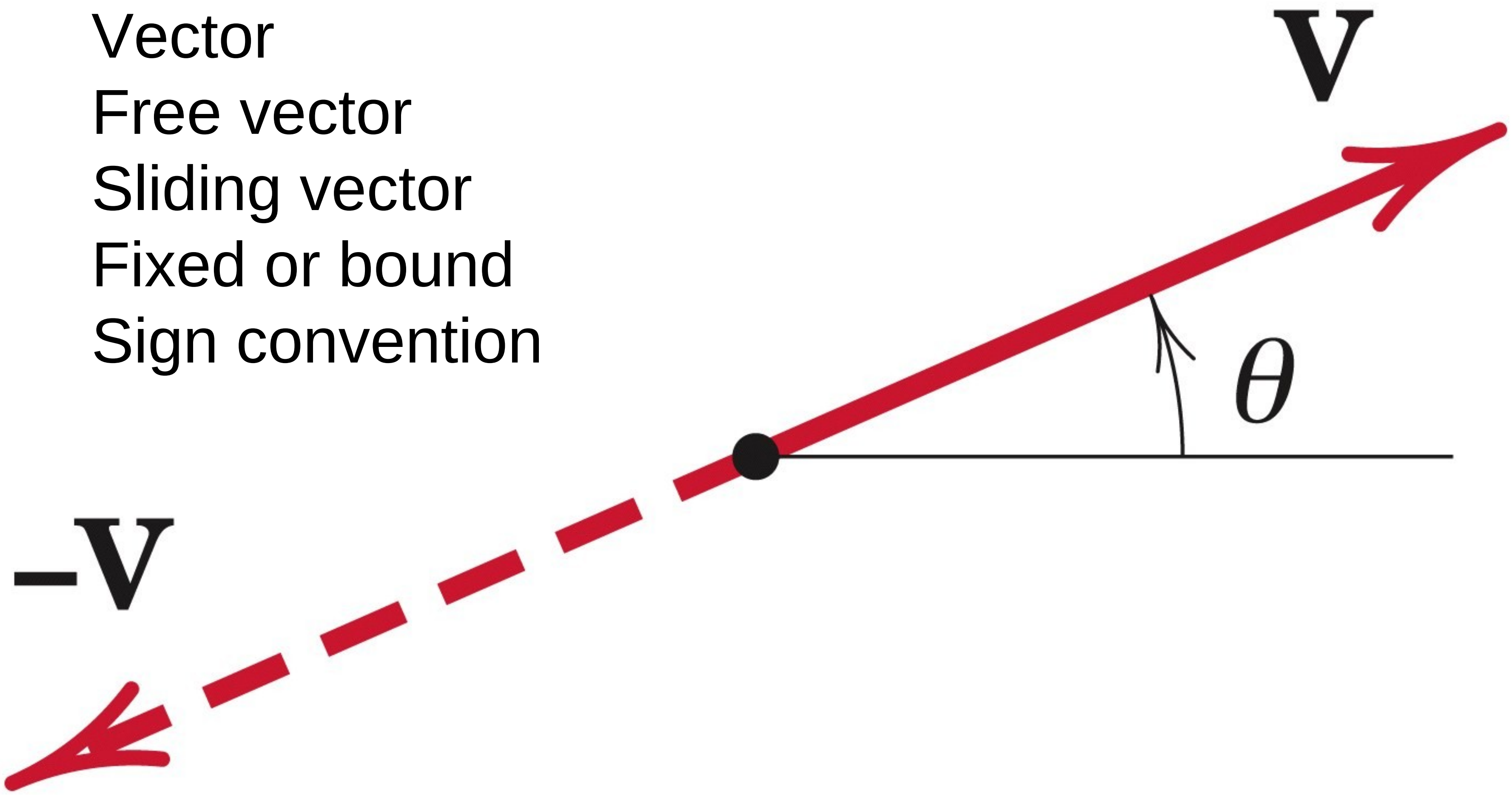

Figure 1-1

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Law of triangle of forces,
Law of parallelogram of forces

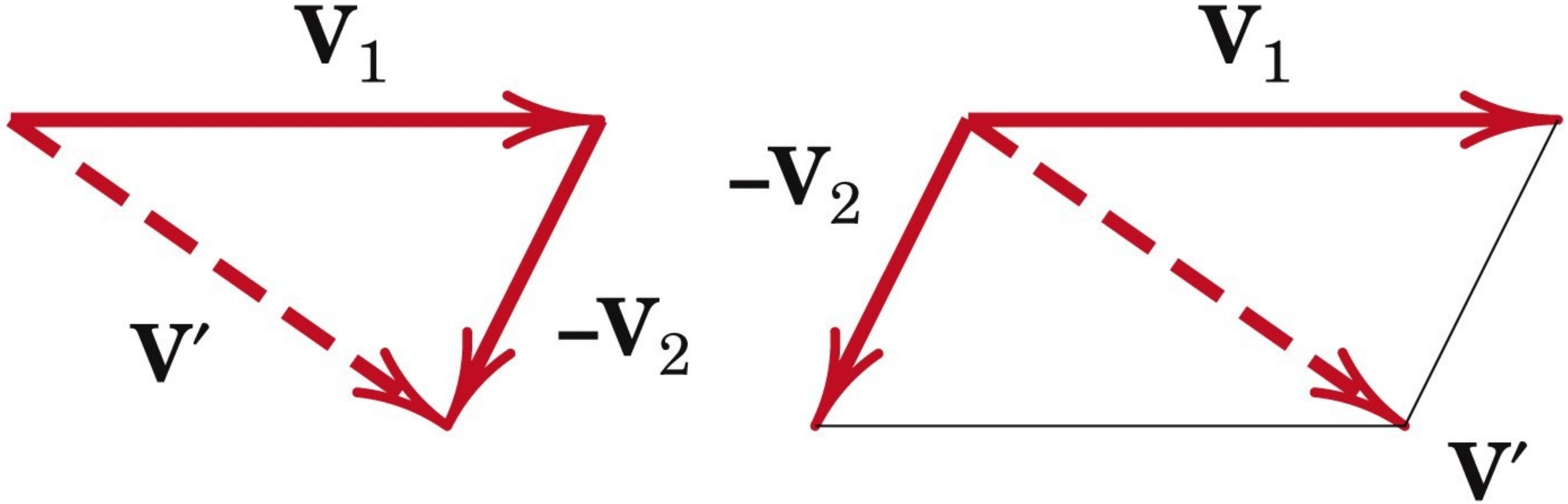

Figure 1-3

Cross Product

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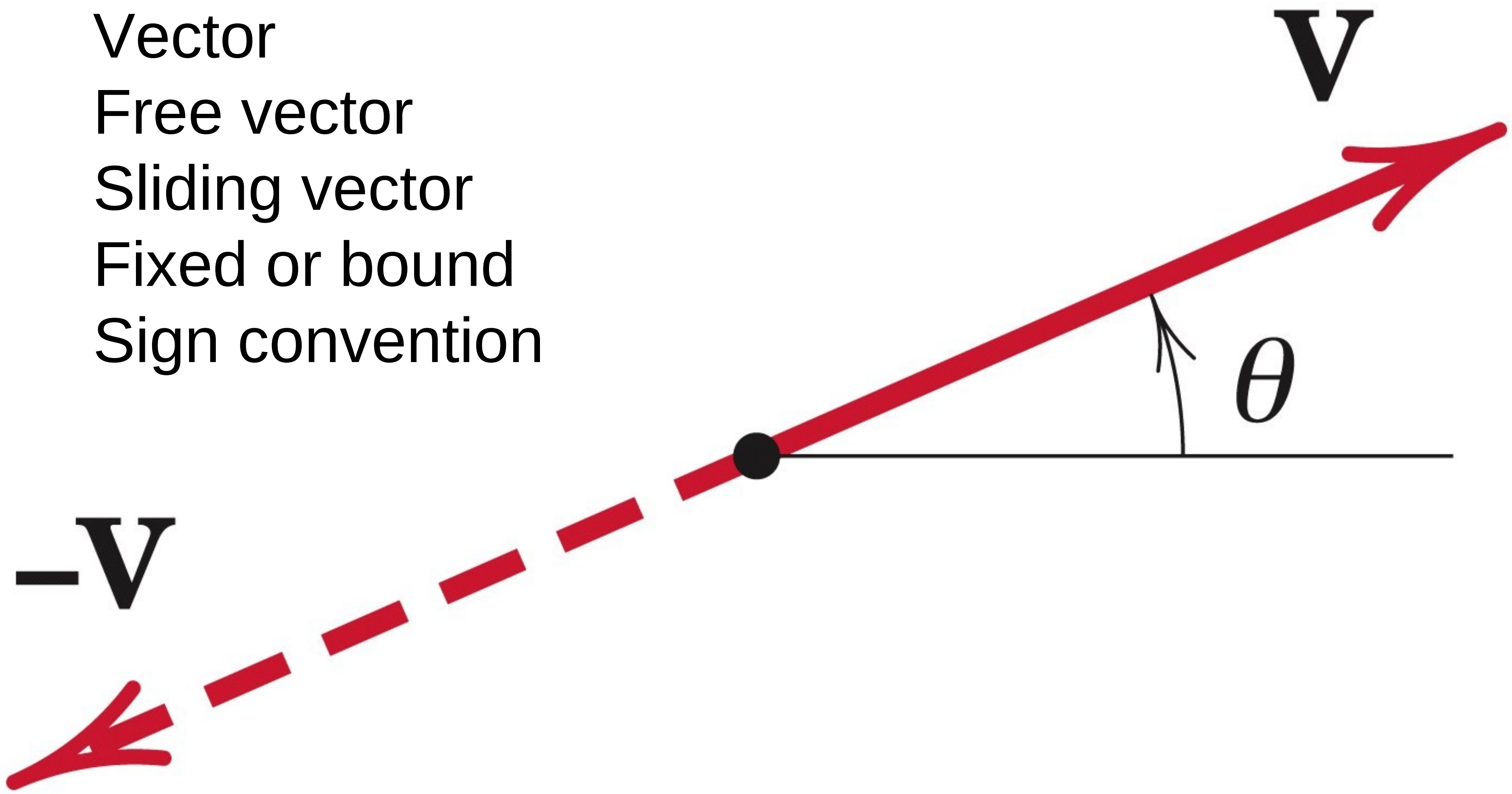


Figure 1-1

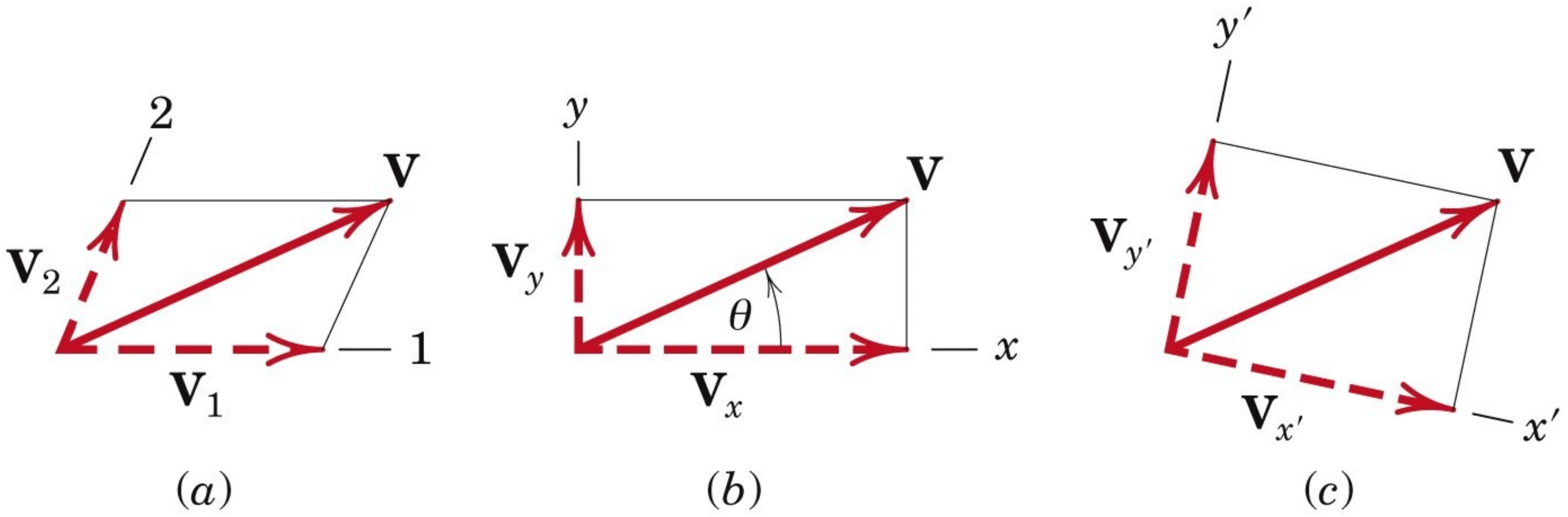


Figure 1-4

$$V = V_x i + V_y j$$
$$V = V\cos\theta i + V\sin\theta j$$

Vector addition

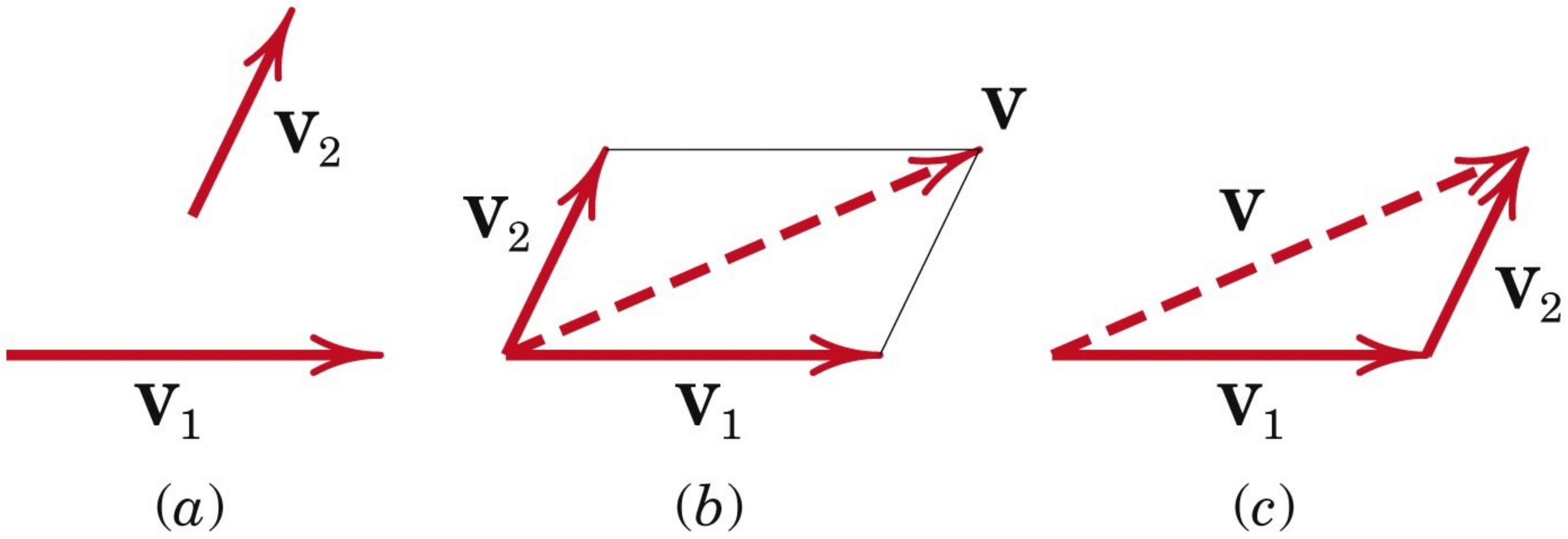
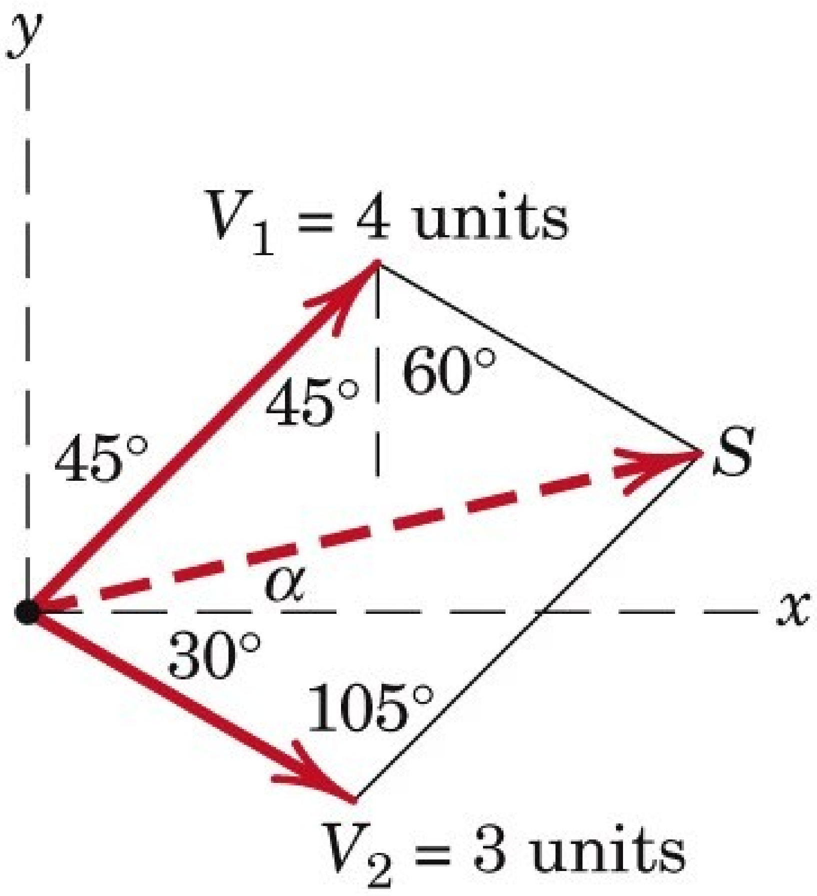
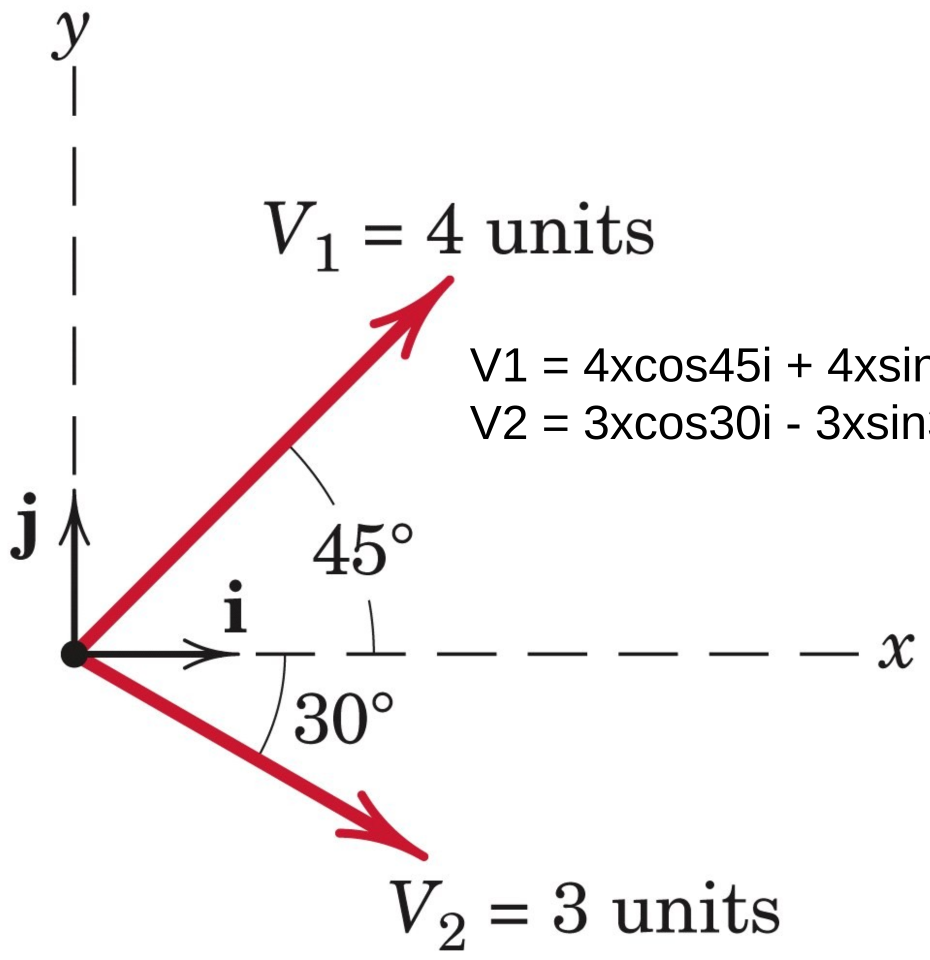


Figure 1-2

V = V1 + V2

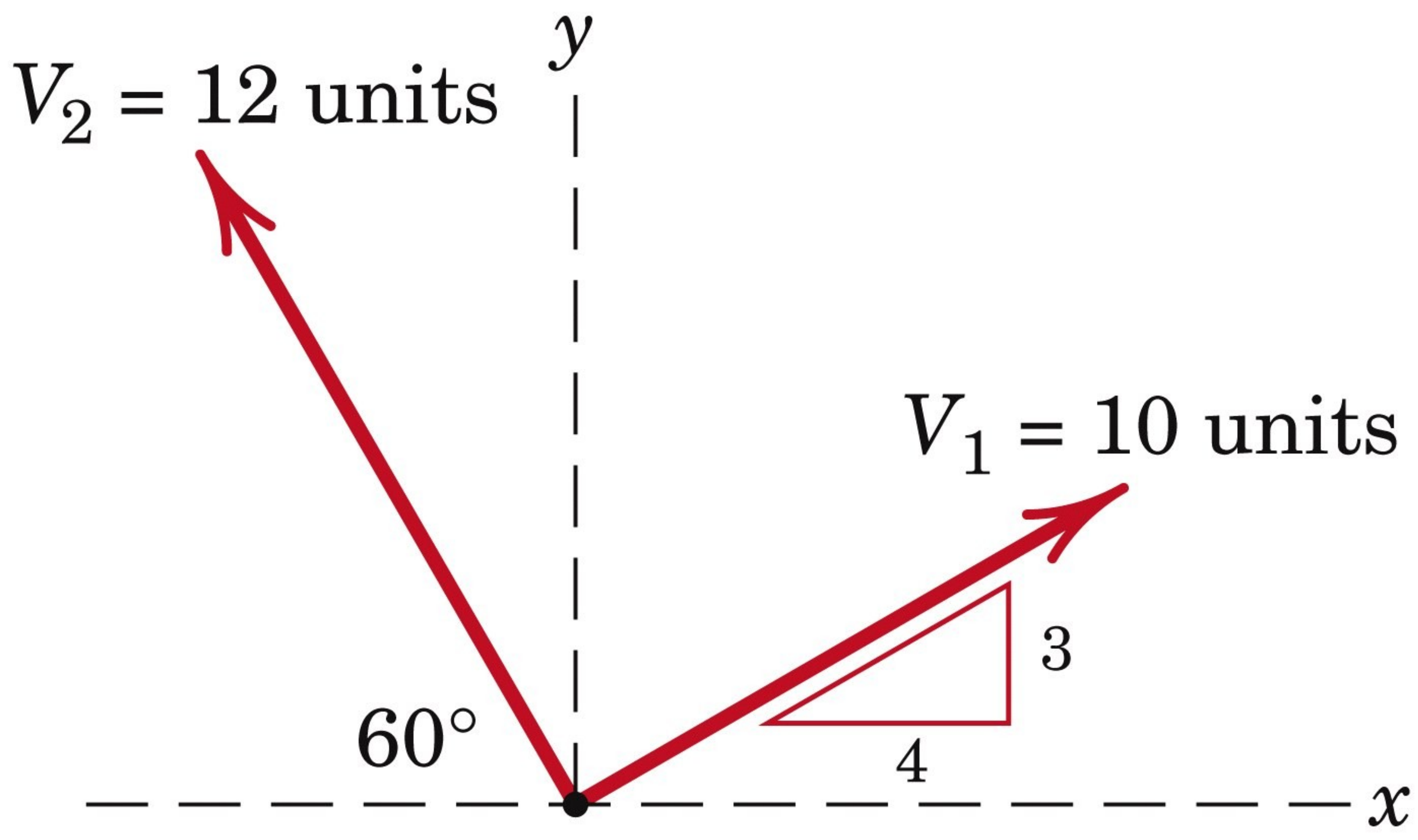
Dot product





V1 = 4xcos45i + 4xsin45j
V2 = 3xcos30i - 3xsin30j

Sample Problem 1-3a



Problem 1-2

FORMULATING PROBLEMS AND OBTAINING SOLUTIONS

In statics, as in all engineering problems, we need to use a precise and logical method for formulating problems and obtaining their solutions . We formulate each problem and develop its solution through the following sequence of steps .

1.Formulate the problem:

(a)State the given data.
(b) State the desired result.
(c) State your assumptions and approximations.

FORMULATING (conti…..)

2. Develop the solution:

(a)Draw any diagrams you need to understand the relationships

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(d)Ensure that your calculations are consistent with the accuracy justified by the data .

(e)Be sure that you have used consistent units throughout your calculations.

(f)Ensure that your answers are reasonable in terms of magnitudes, directions, common sense, etc .

(g)Draw conclusions.

FORMULATING (conti…..)

Keeping your work neat and orderly will help your thought process and enable others to understand your work .

The discipline of doing orderly work will help you develop skill in formulation and analysis .

Problems which seem complicated at first often become clear when you approach them with logic and discipline

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Resolution

Moment

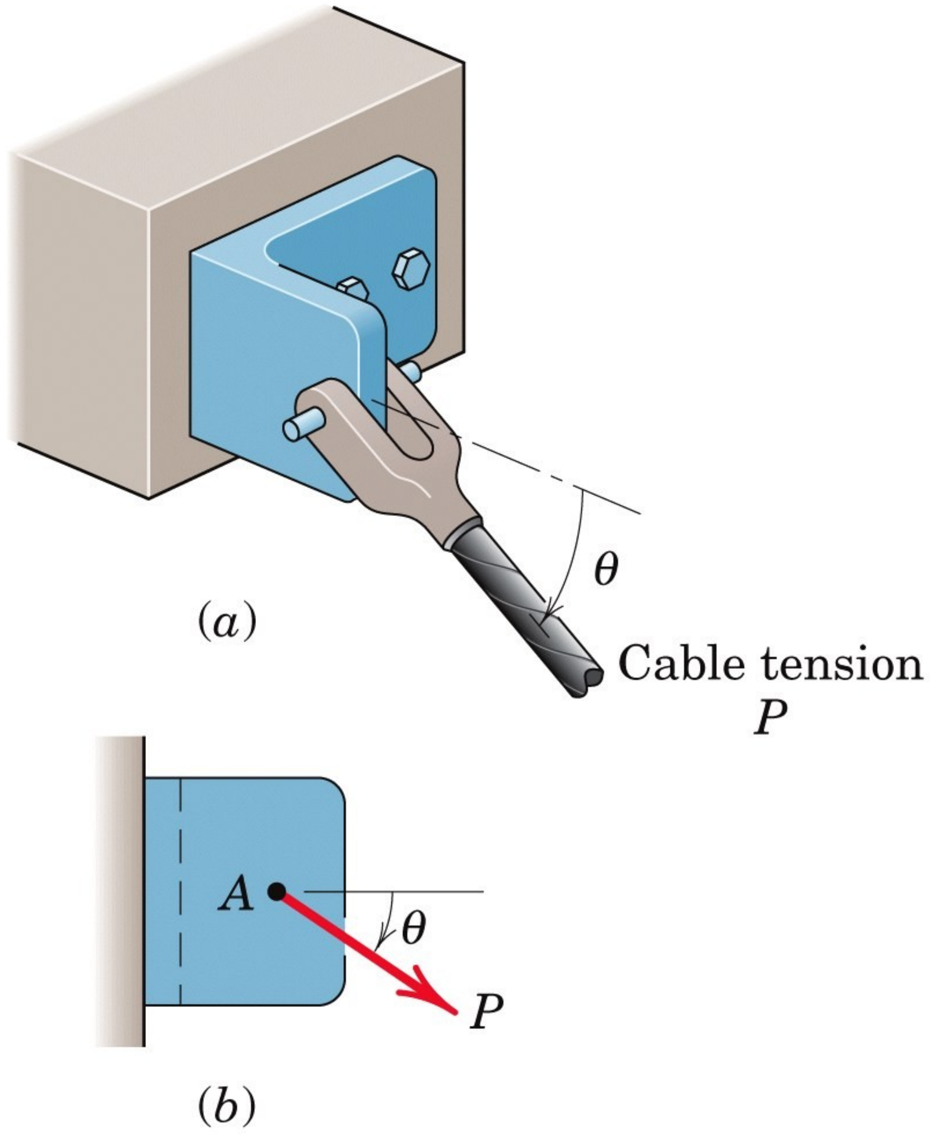
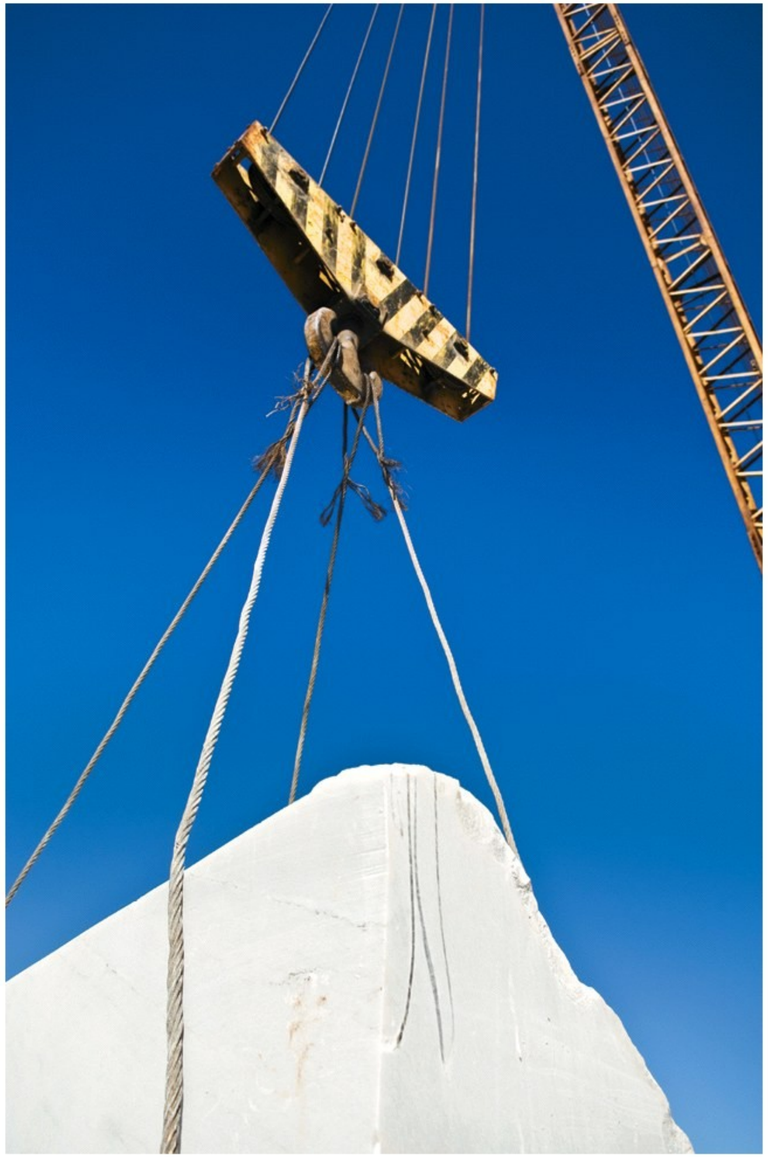


Figure 2-1

Tension in cable



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Principle of transmissibility of forces

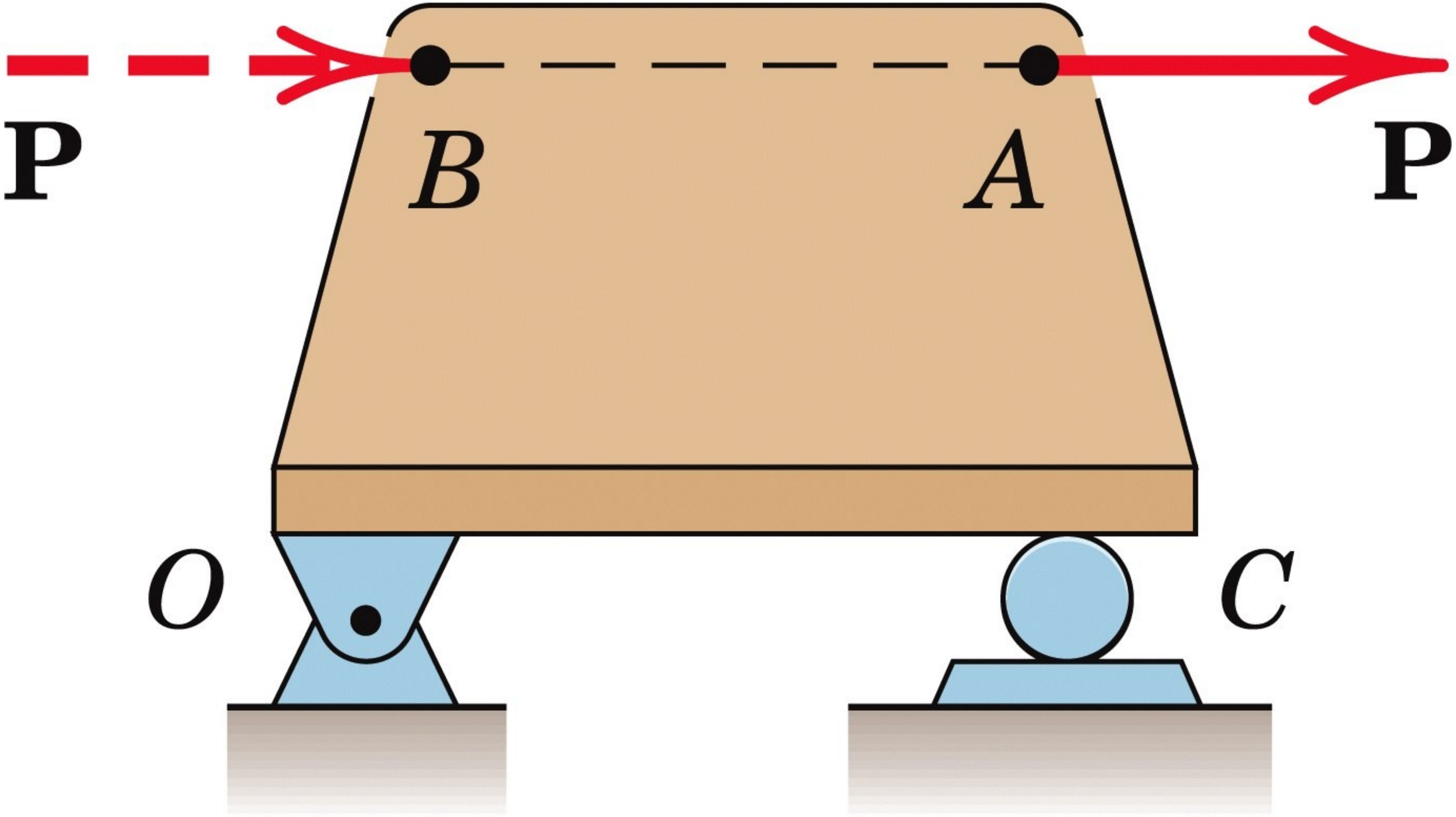


Figure 2-2

Projection and components of a force

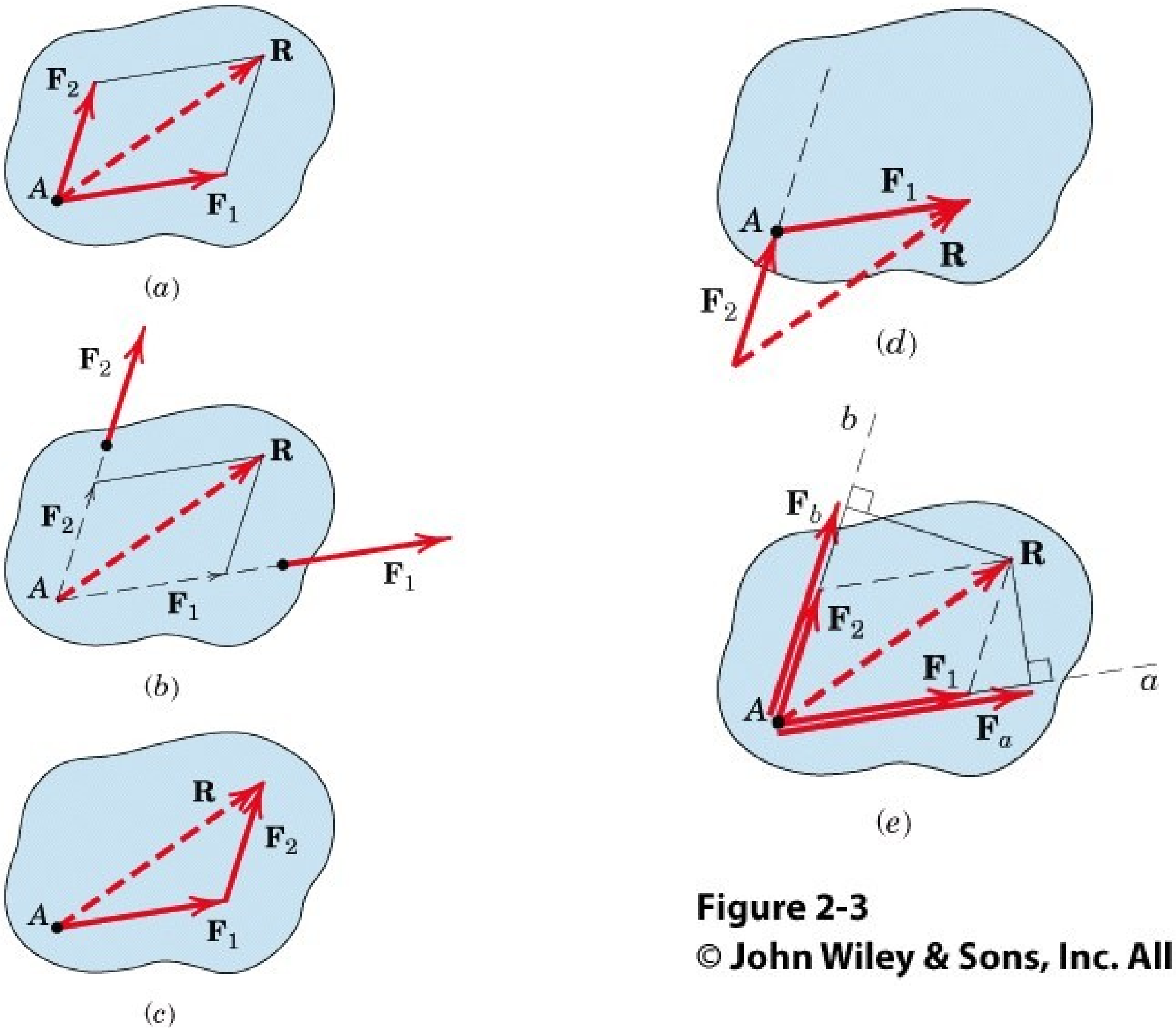


Figure 2-3

Resultant

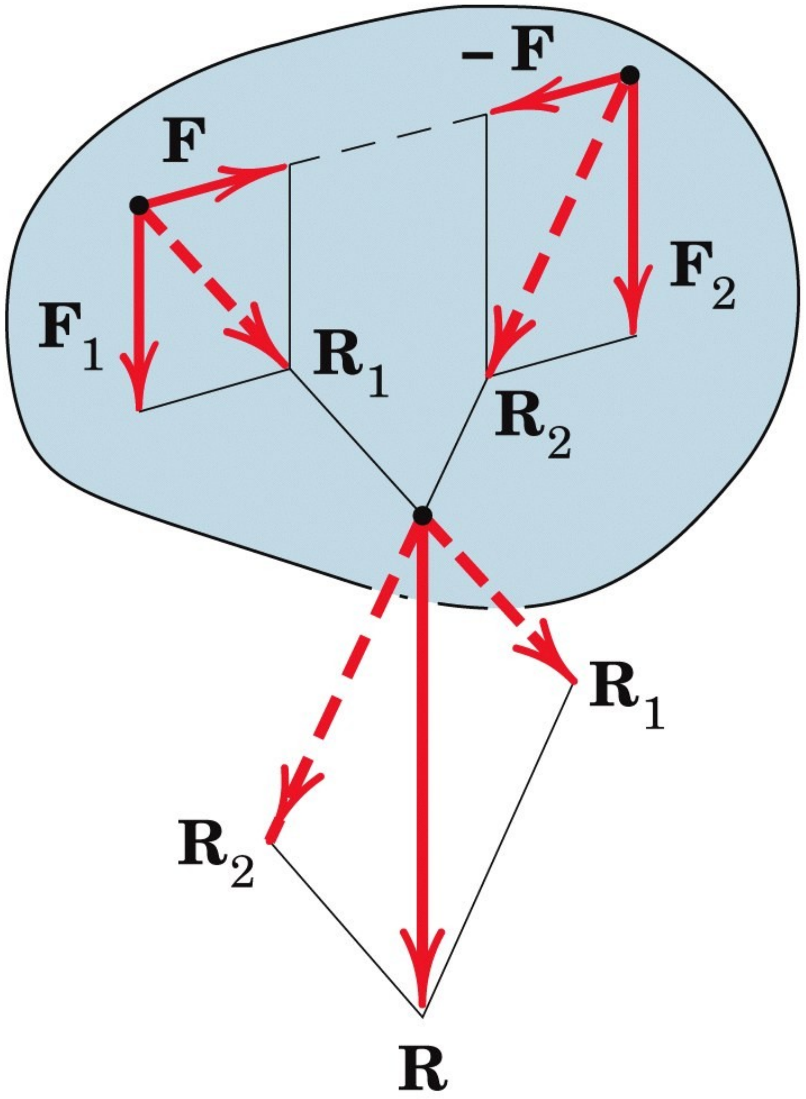


Figure 2-4

Rectangular components of a force

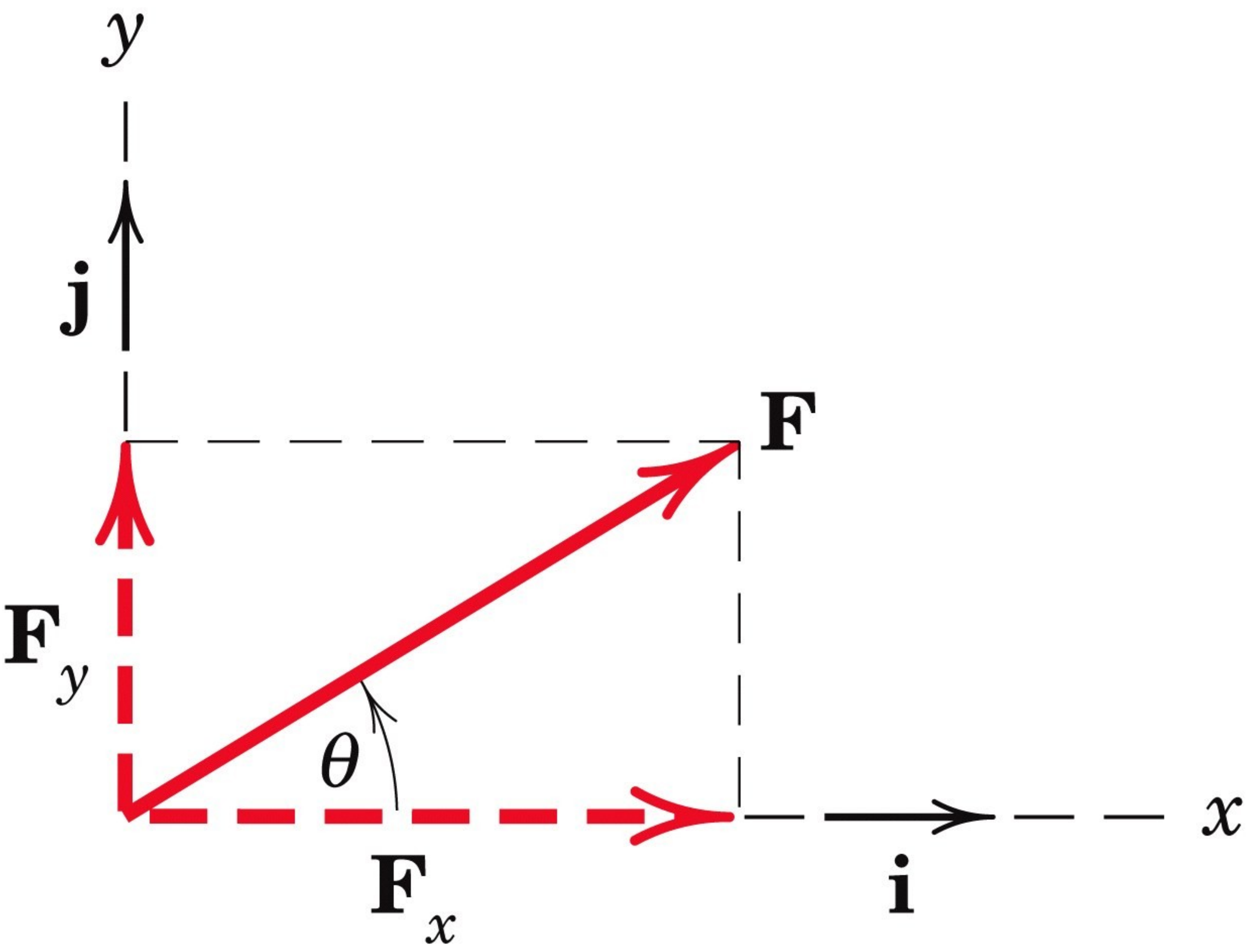
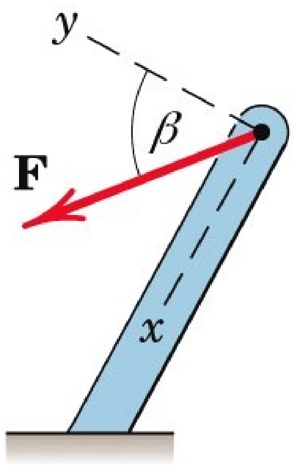
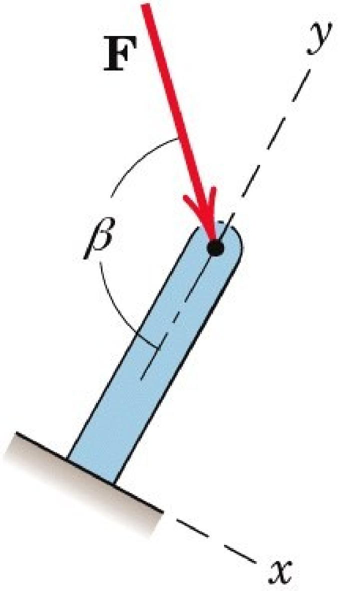


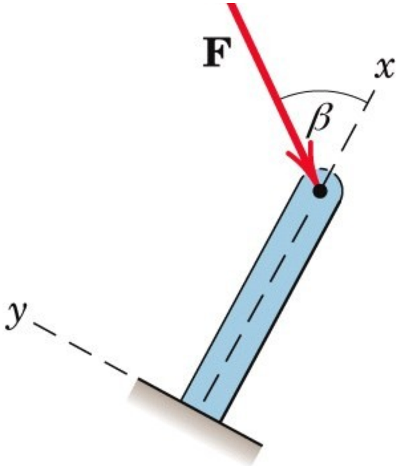
Figure 2-5



$$F_x = F \sin \beta$$
$$F_y = F \cos \beta$$

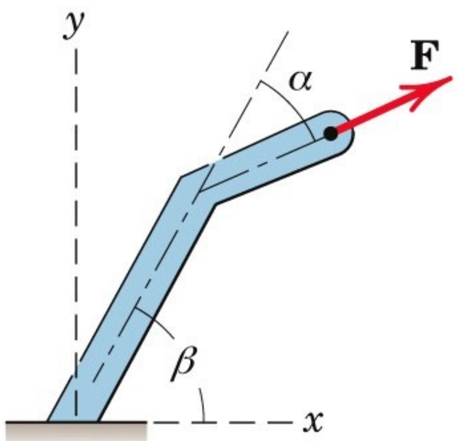


$$F_x = F \sin(\pi - \beta)$$
$$F_y = -F \cos(\pi - \beta)$$

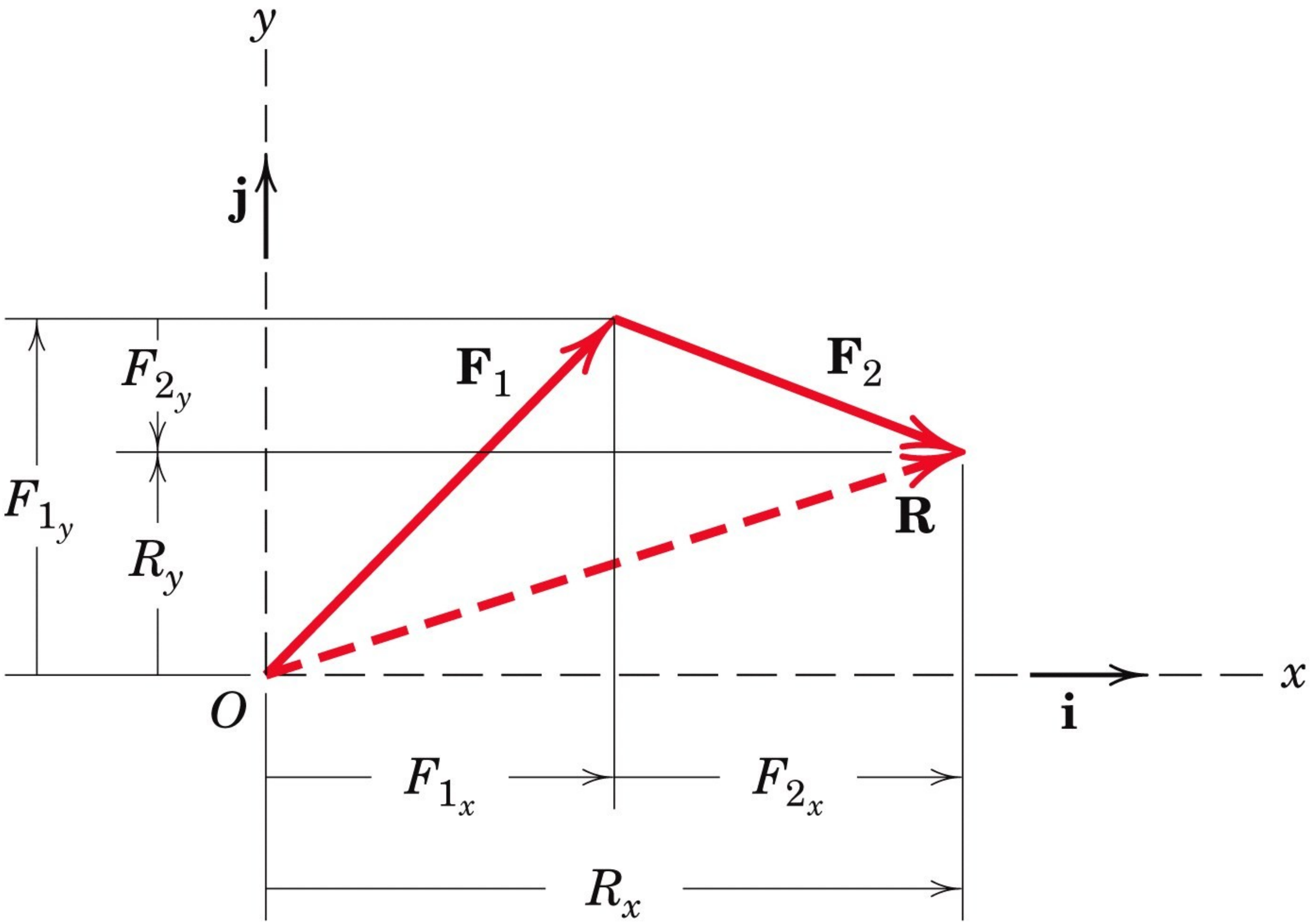


$$F_x = -F \cos \beta$$
$$F_y = -F \sin \beta$$

Figure 2-6



$$F_x = F \cos(\beta - \alpha)$$
$$F_y = F \sin(\beta - \alpha)$$



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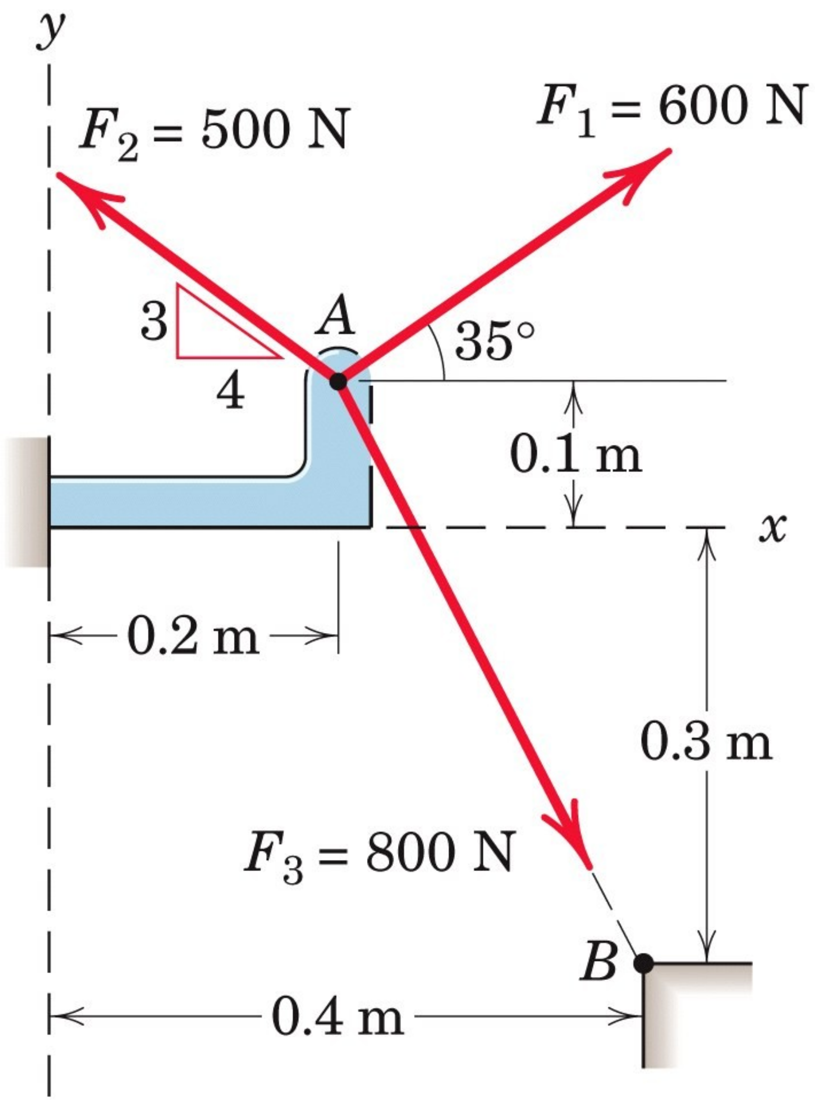
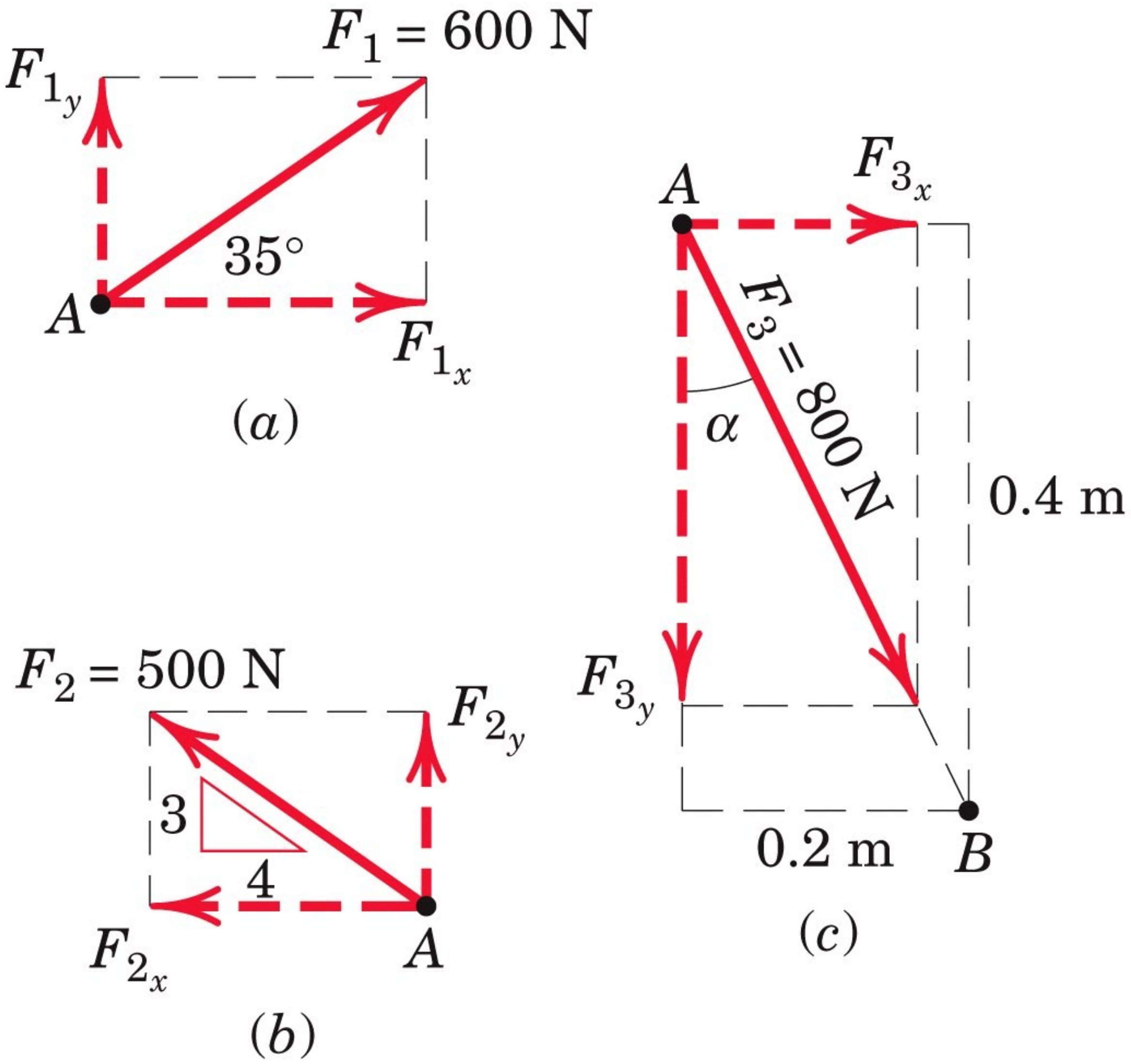
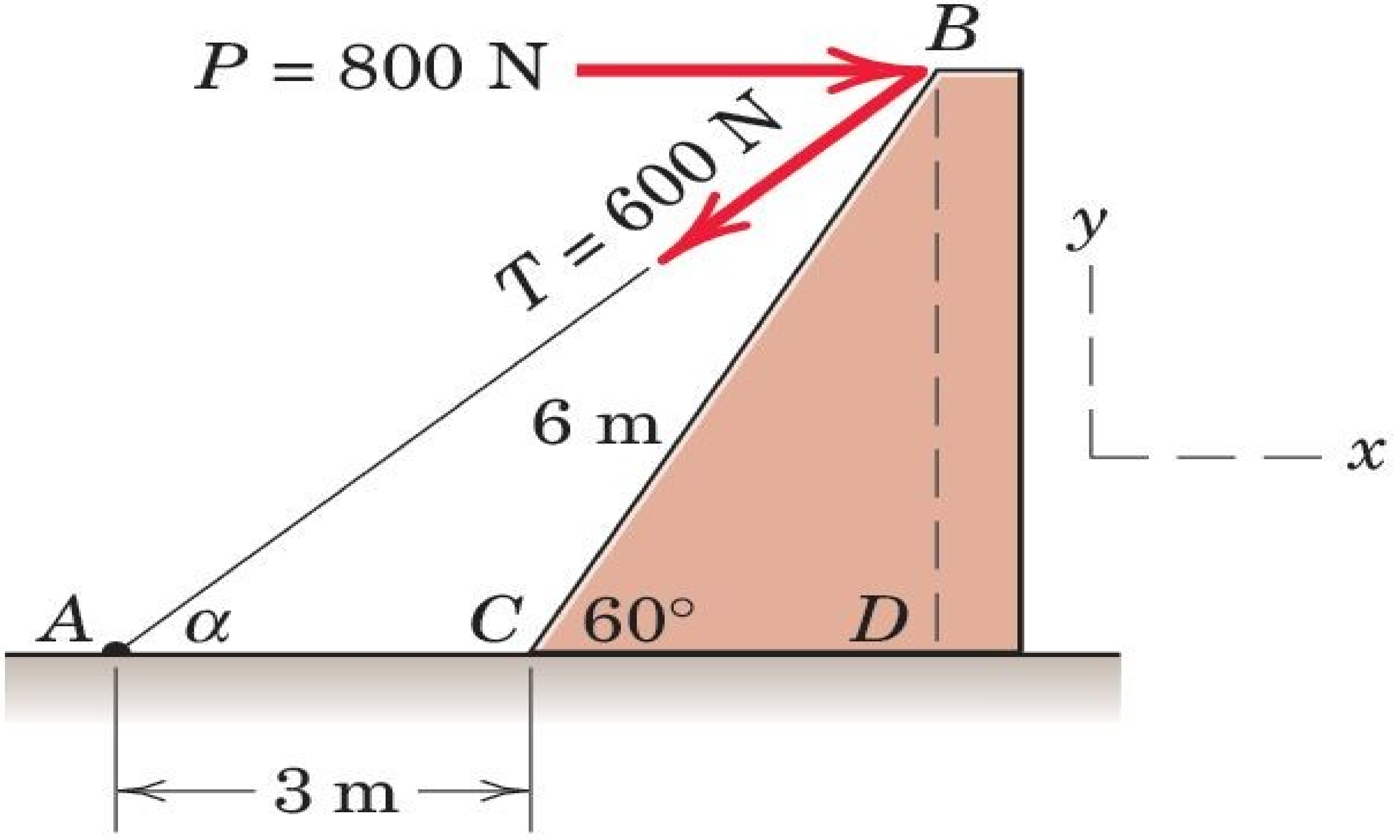


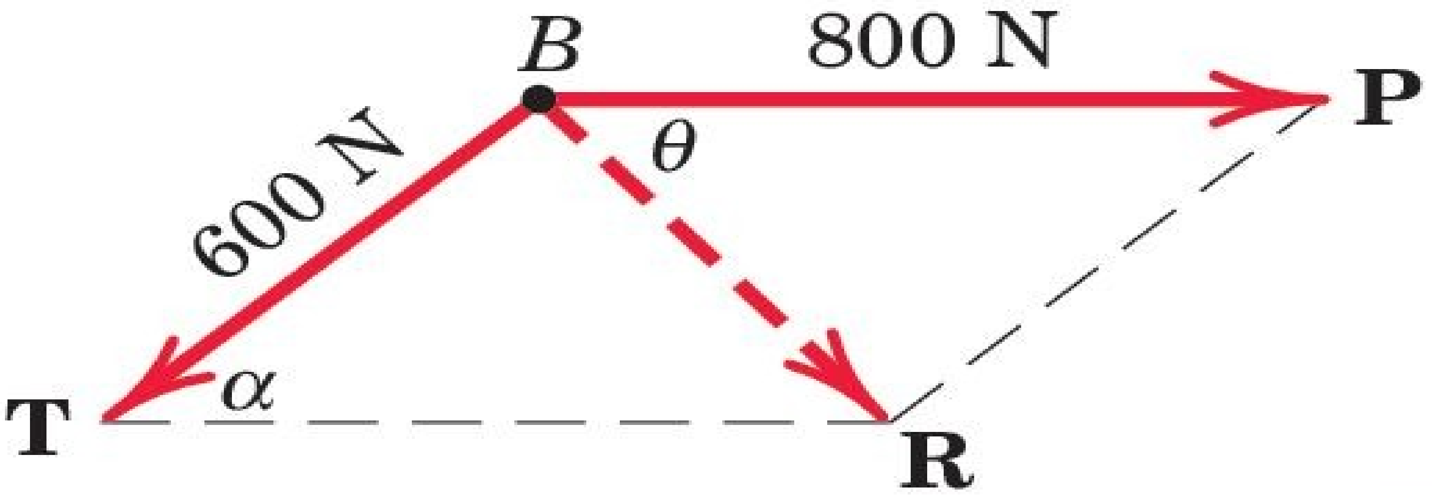
Sample Problem 2-1a



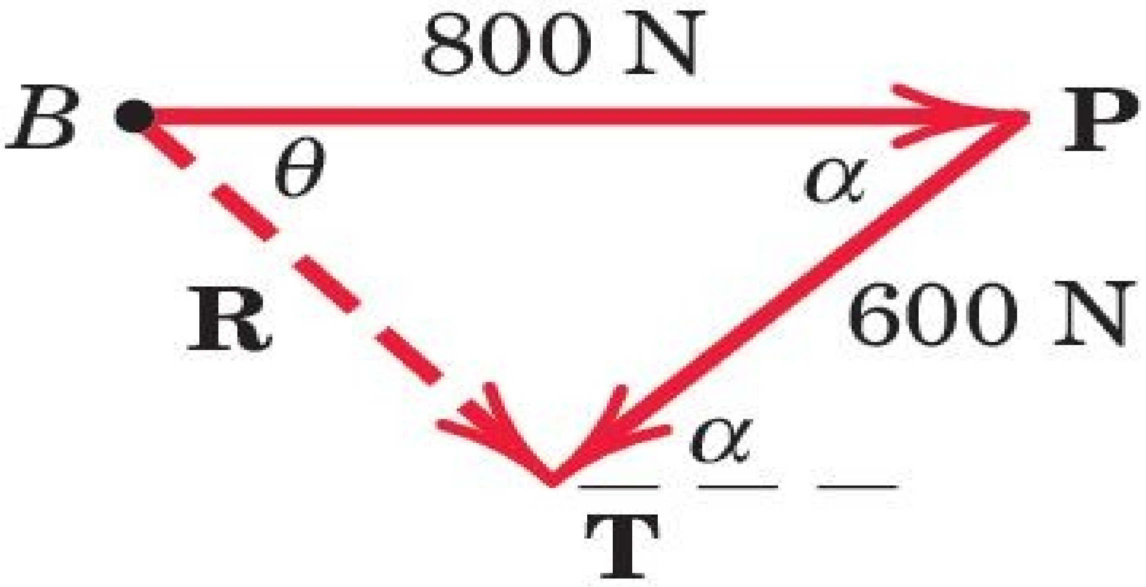
Sample Problem 2-1b



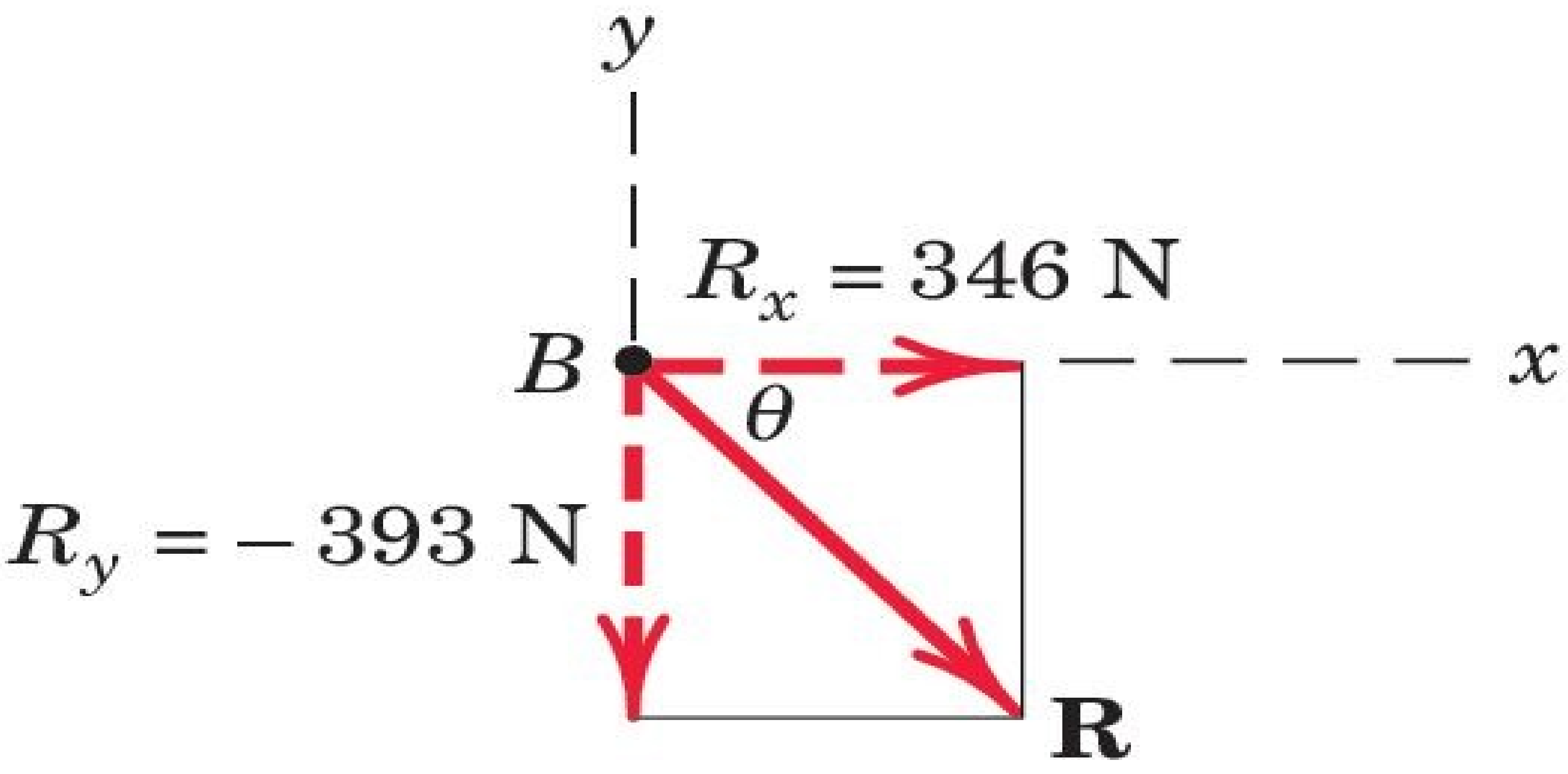
P = 800 N
B
T = 600 N
y
x
6 m
A
α
C
60°
D
3 m



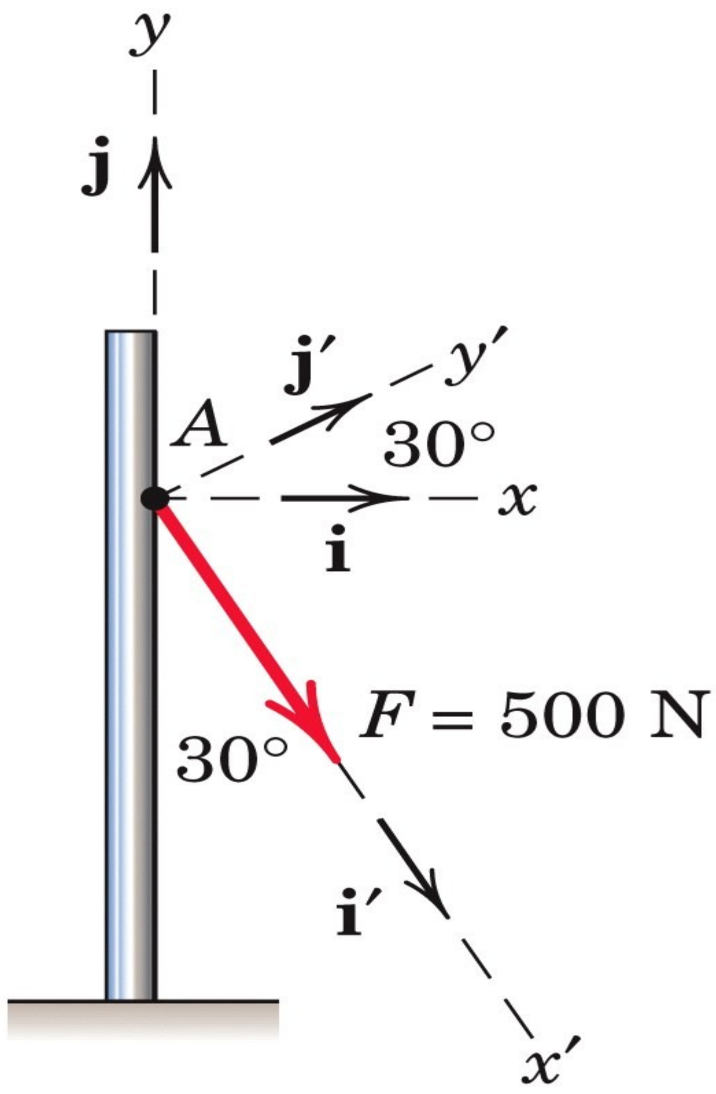
(a)



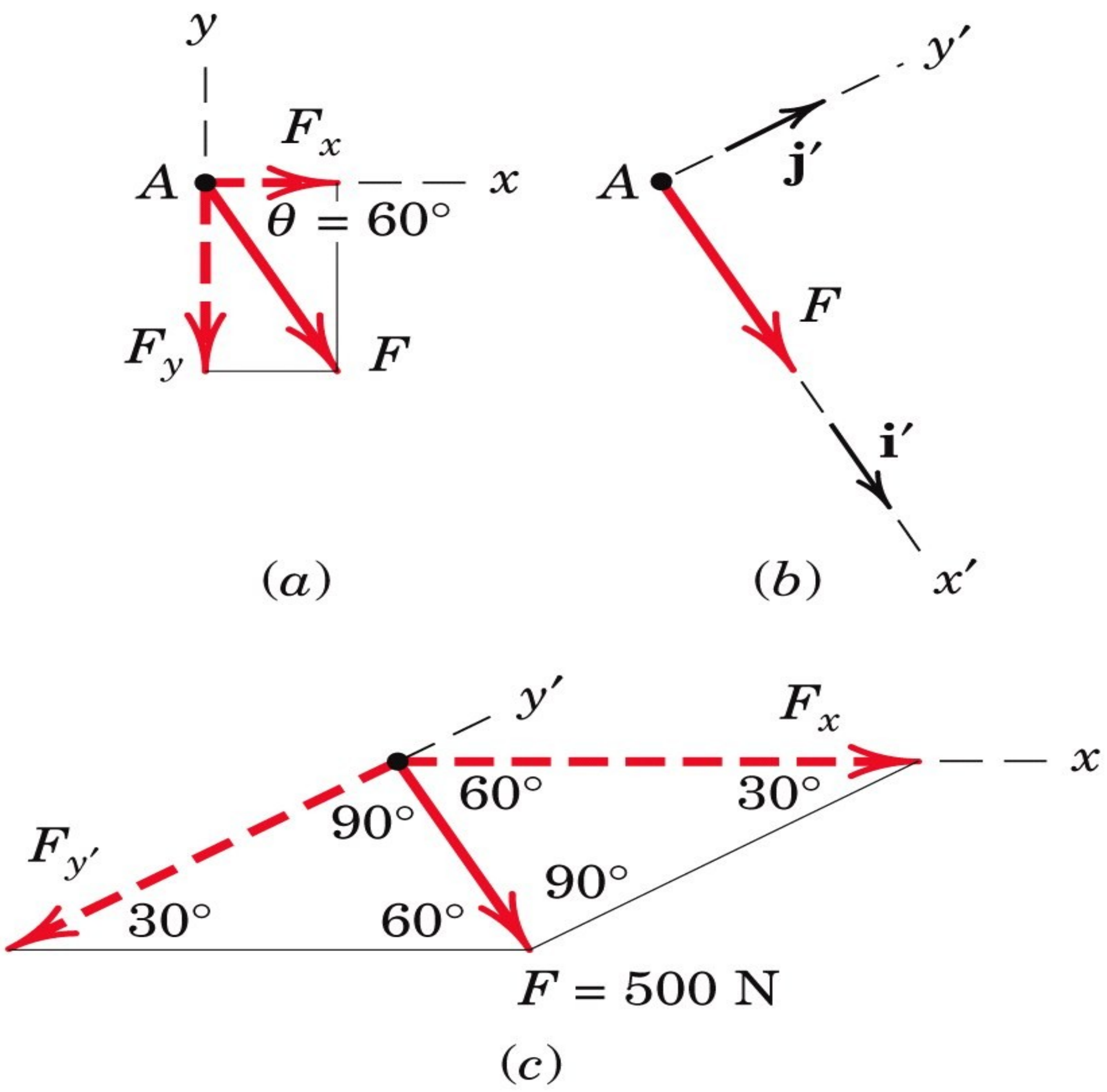
(b)



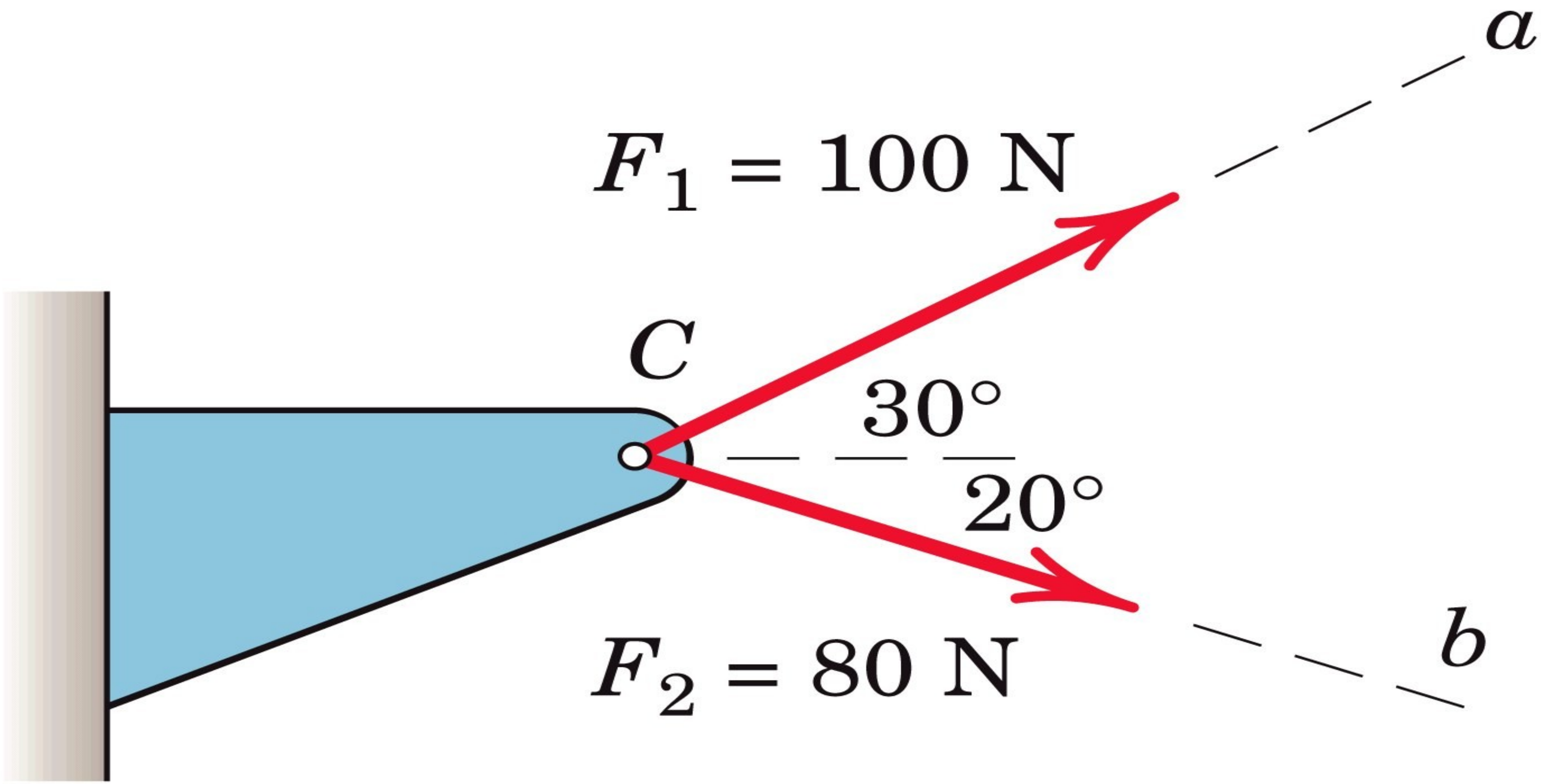
(c)



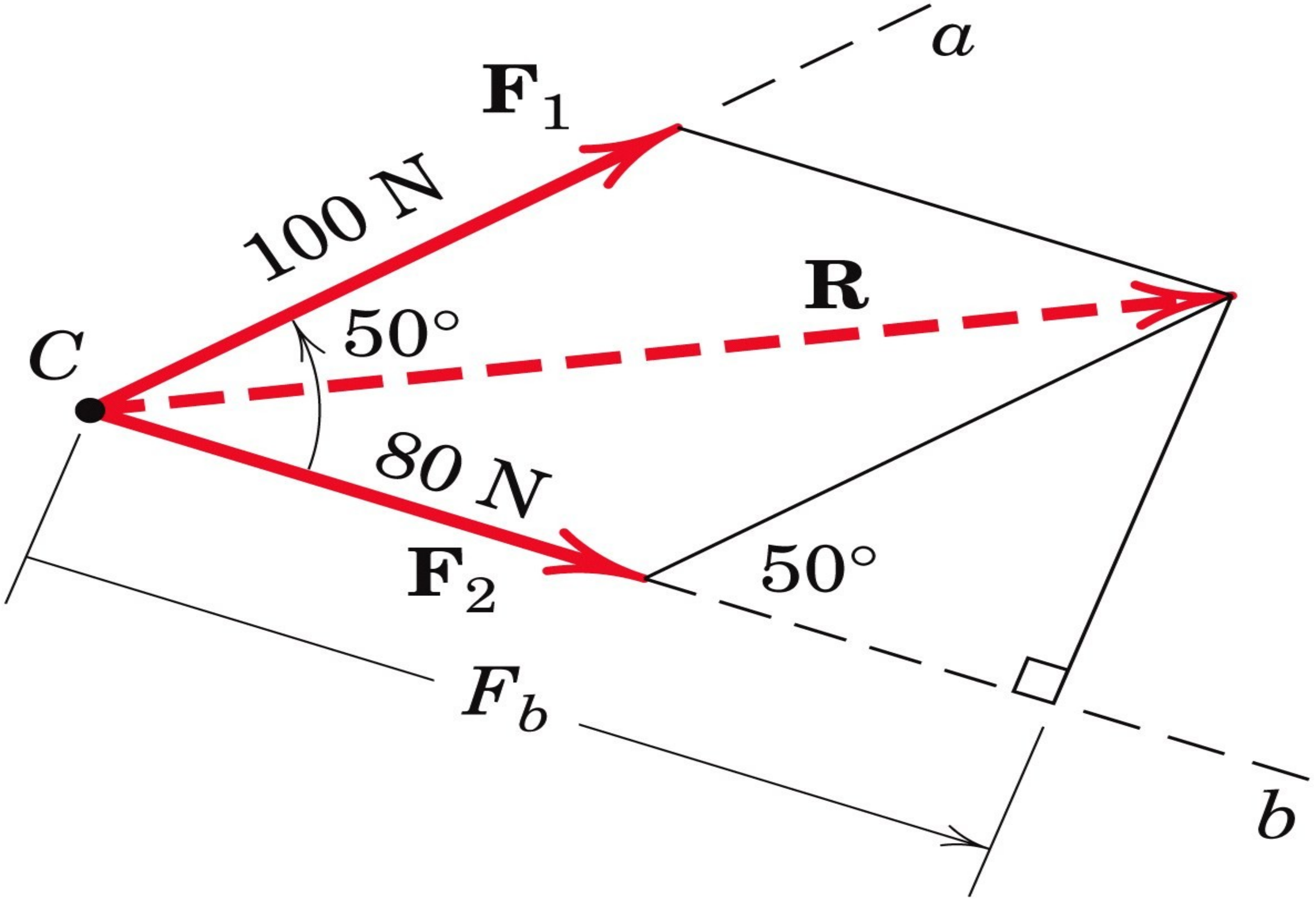
Sample Problem 2-3a



Sample Problem 2-3b

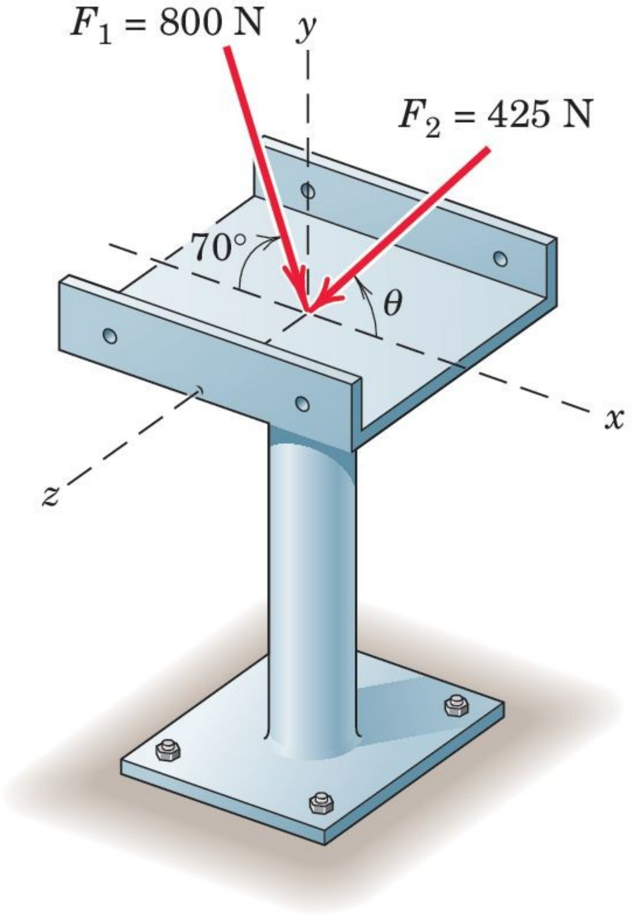


Sample Problem 2.4a



Sample Problem 2-4b

2/6 Two forces are applied to the construction bracket as shown. Determine the angle θ which makes the resultant of the two forces vertical. Determine the magnitude R of the resultant.



ΣFx = 0

F1 x cos70 – F2 x cosθ = 0

800 x cos70 – 425 x cosθ = 0

cosθ = 273.62/425 = 0.64

Θ = 49.92

ΣFy = - RY

-F1 x sin70 – F2 x sinθ = - Ry = - R

-800 x sin70 – 425 x sin49.92 = -R

R = 751.75 +325.19

R = 1076.94 N

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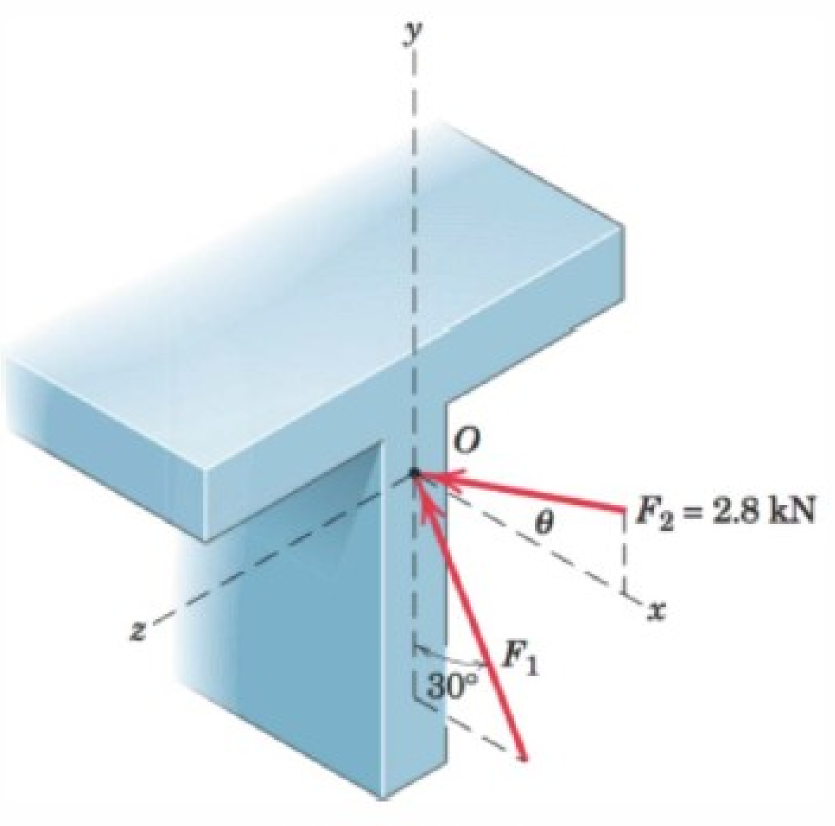
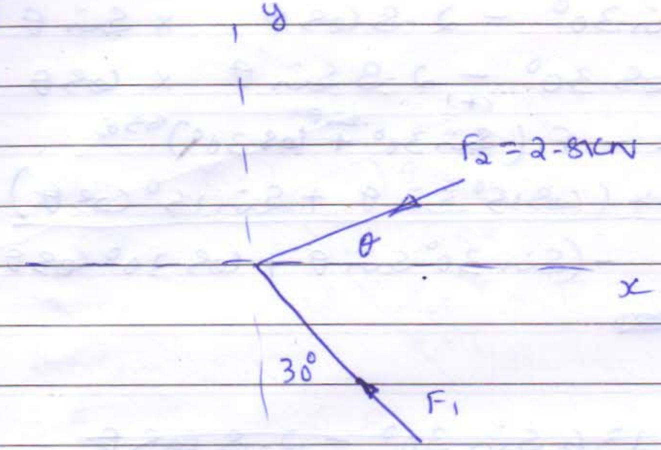
2/17 The two forces shown act in the X-Y plane of the T-beam cross section. If it is known that the resultant R of the two forces has a magnitude of 3.5 kN and a line of action that lies 15° above the negative x-axis, determine the magnitude of F1 and the inclination θ of F2.



Problem 2/17

DATE

2/17



Data, Given

$R = 3.5$ kN

$\alpha = 15^\circ$ above −ve x-axis

To find

$F_1 = ?$

$\theta = ?$

2/17 cont..

Solution

$\vec{F_1} = -F_1 \sin 30^\circ\, i + F_1 \cos 30^\circ\, j$

$\vec{F_2} = -F_2 \cos\theta\, i - F_2 \sin\theta\, j$

$\vec{R} = (-F_1 \sin 30^\circ - 2.8 \cos\theta)\, i + (F_1 \cos 30^\circ - 2.8 \sin\theta)\, j$

$= R_x\, i + R_y\, j$

$\therefore R_x = -3.5 \cos 15^\circ\, i$

$R_y = +3.5 \sin 15^\circ\, j$

$\therefore -3.5 \cos 15^\circ = -F_1 \sin 30^\circ - 2.8 \cos\theta \quad \times \cos 30^\circ$

$+3.5 \sin 15^\circ = F_1 \cos 30^\circ - 2.8 \sin\theta \quad \times \sin 30^\circ$

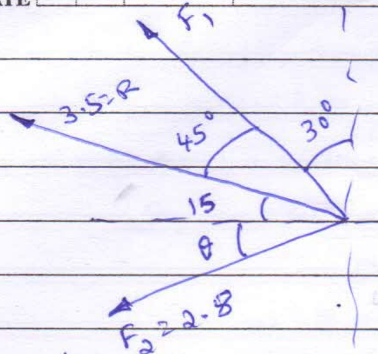
$-3.5 \cos 15^\circ \times \cos 30^\circ + 3.5 \sin 15^\circ \times \sin 30^\circ = -F_1 \sin 30^\circ \times \cos 30^\circ + F_1 \cos 30^\circ \times \sin 30^\circ - 2.8 \cos\theta \times \cos 30^\circ - 2.8 \sin\theta \times \sin 30^\circ$

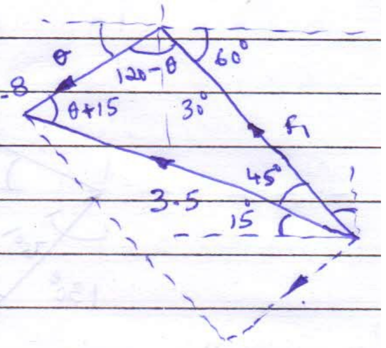
$\therefore 3.5(\sin 15^\circ \times \sin 30^\circ - \cos 15^\circ \times \cos 30^\circ) = -2.8(\cos\theta \cos 30^\circ + \sin\theta \sin 30^\circ)$

$\therefore \dfrac{-2.4748}{-2.8} = 0.866 \cos\theta + 0.5 \sin\theta$

$0.8838 = 0.866 + 0.5 \tan\theta$

DATE





law of triangle of forces.

$$\frac{3.5}{\sin(120-\theta)} = \frac{2.8}{\sin 45} = \frac{F_1}{\sin(\theta+15)}$$

$$\sin(120-\theta) = \frac{3.5 \sin 45}{2.8}$$

$\sin(120-\theta) = 0.8839$

$120-\theta = \sin^{-1} 0.8839$

$-\theta = 62.114 - 120$

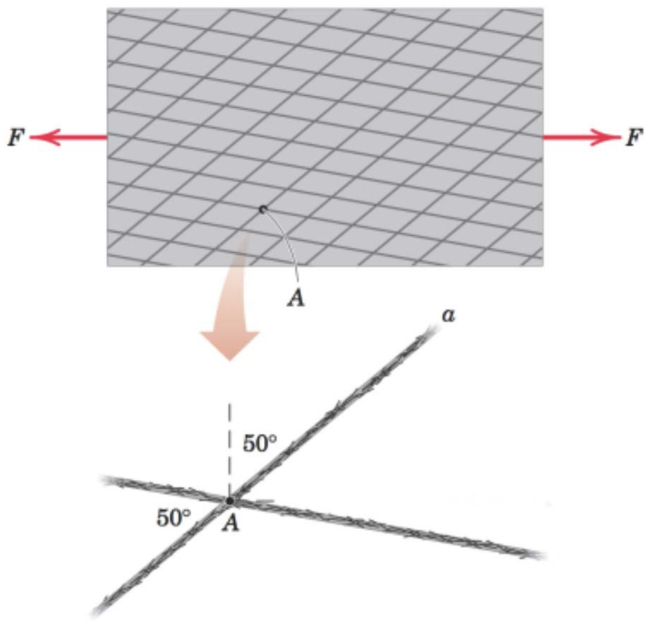
$-\theta = -57.885$

$\therefore \theta = 57.885$

$$\therefore F_1 = \frac{2.8 \times \sin(57.885+15)}{\sin 45}$$

$F_1 = 3.784$ kN

2/22 A sheet of an experimental composite is subjected to a simple tension test to determine its strength along a particular direction. The composite is reinforced by the Kevlar fibers shown, and a close-up showing the direction of the applied tension force F in relation to the fiber directions at point A is shown. If the magnitude of F is 2.5 kN, determine the components Fa,. and Fb of the force F along the oblique axes a and b. Also determine the projections Pa and Pb of F onto the a-b axes.



Given

F = 2.5 kN

To find

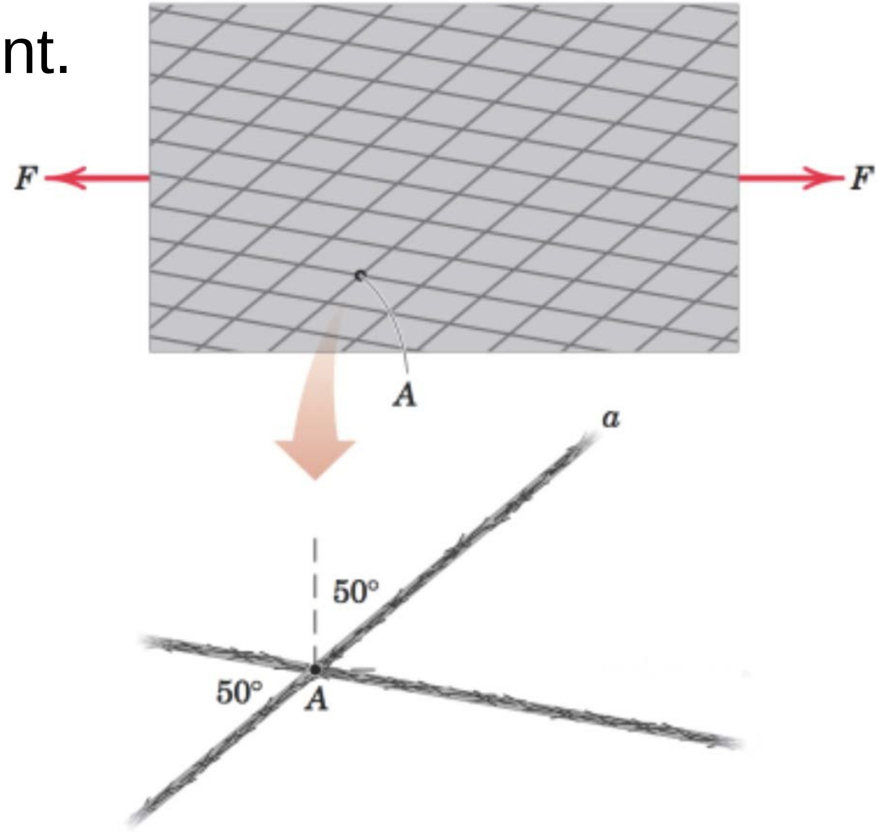
Fa, Fb, Pa and Pb

Solution

Angle b/w a and force F = 90 – 50 = 40

Angle b/w b and force F = 50 - 40 = 10

2/22 cont.



Fb = 2.5 x sin40/sin50 = 2.10

Projection

Pa = F x Cos 40 = 2.5 x 0.766

Pa = 1.915 kN

Pb = F x Cos 10 = 2.5 x 0.98

Pb = 2.46 kN

Components - Sine Rule

Fa/sin10 = Fb/sin40 = F/sin50

Fa = 2.5 x sin10/sin50 = 0.567 kN

Fb = 2.5 x sin40/sin50 = 2.10 kN

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Moment

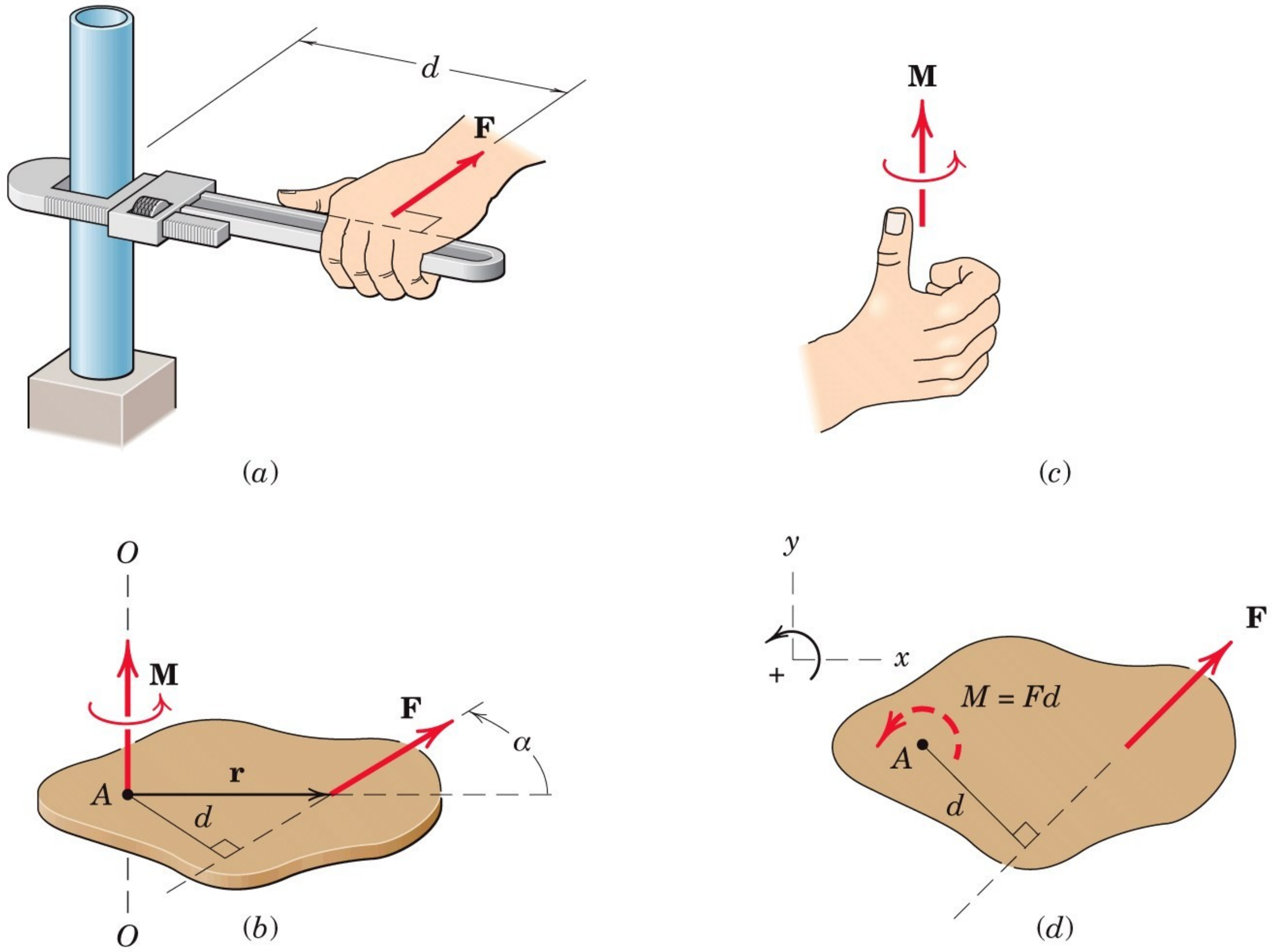


Figure 2-8

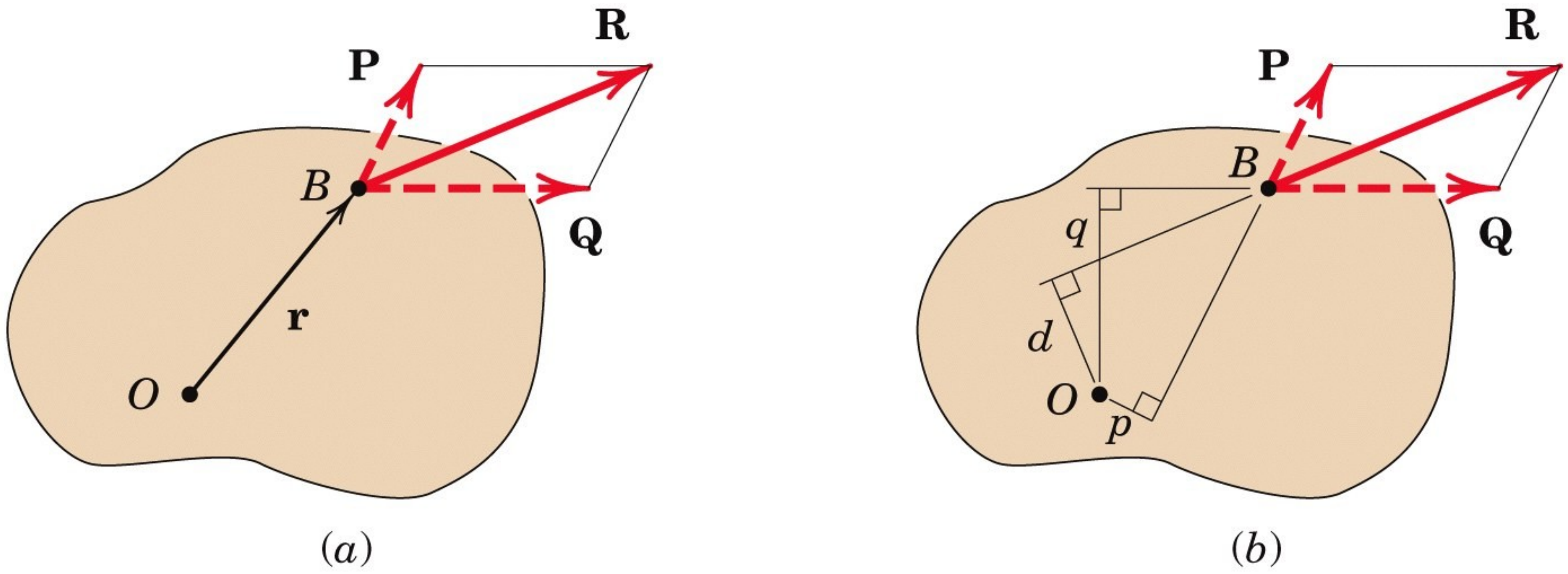
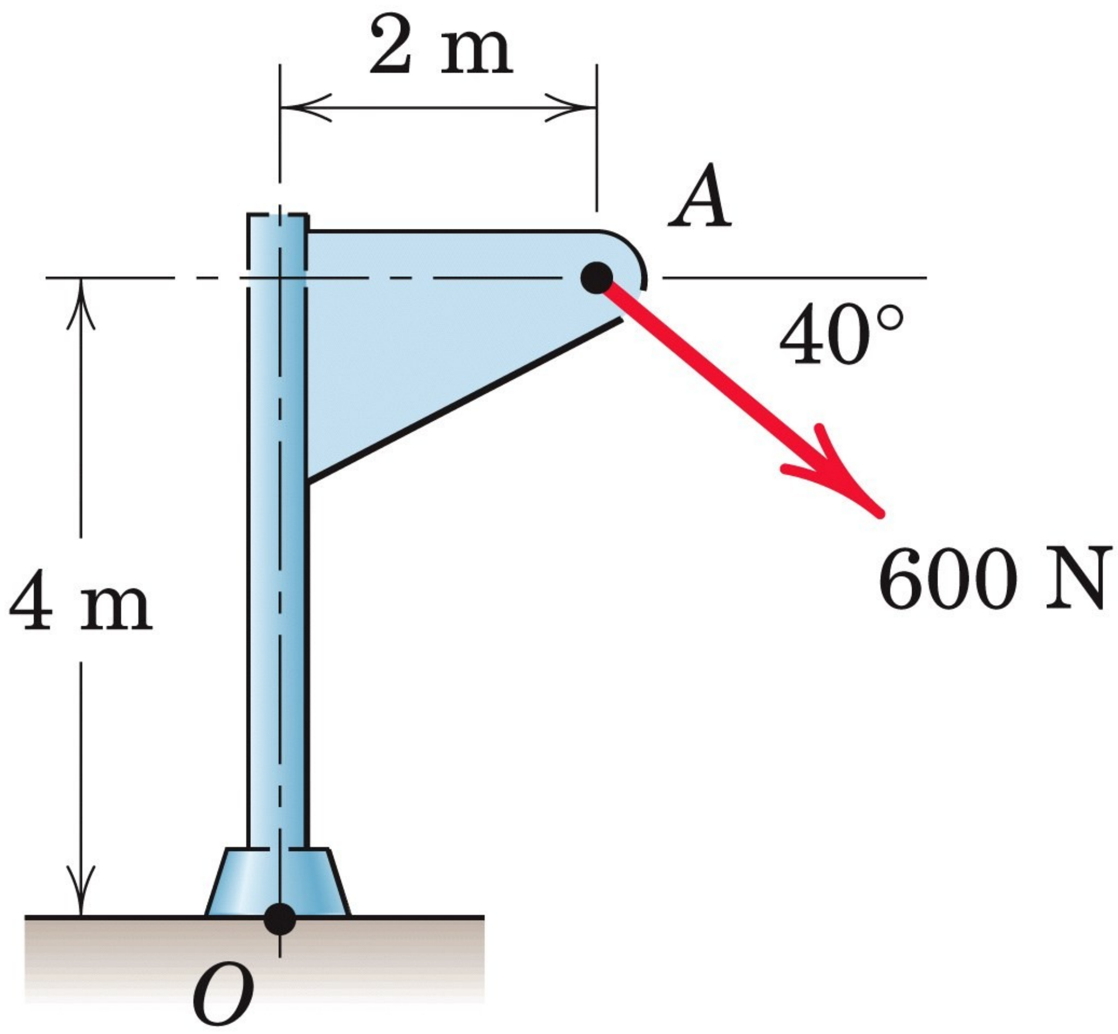
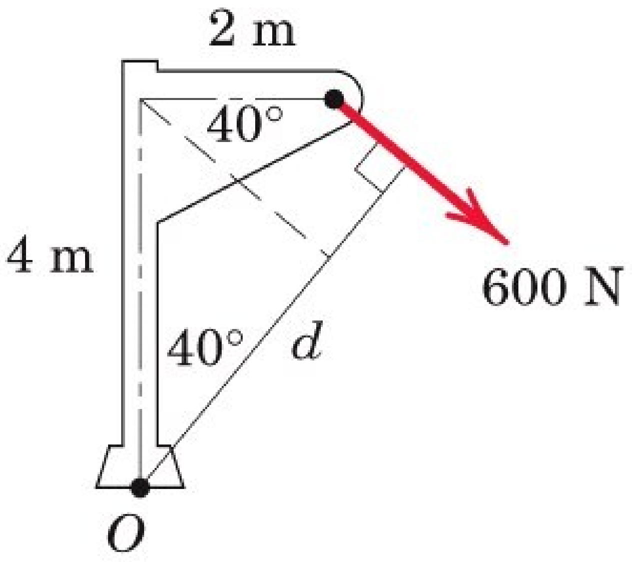
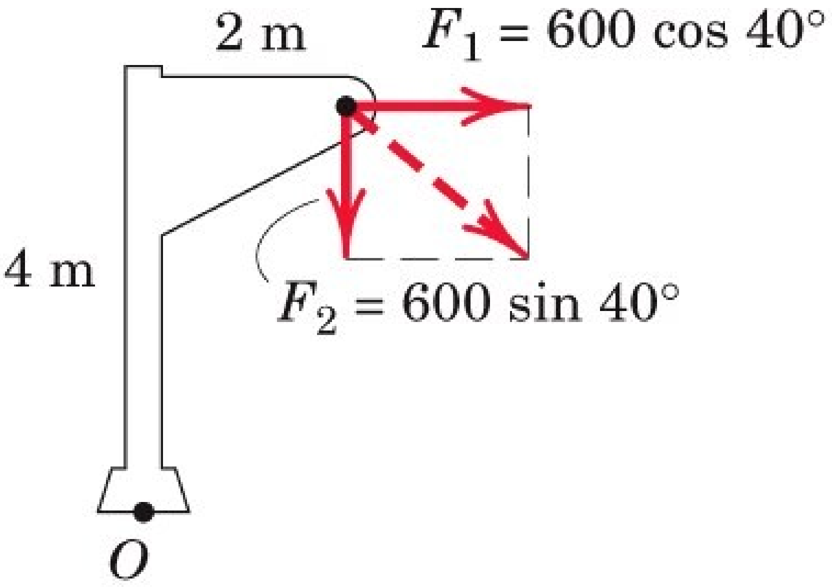


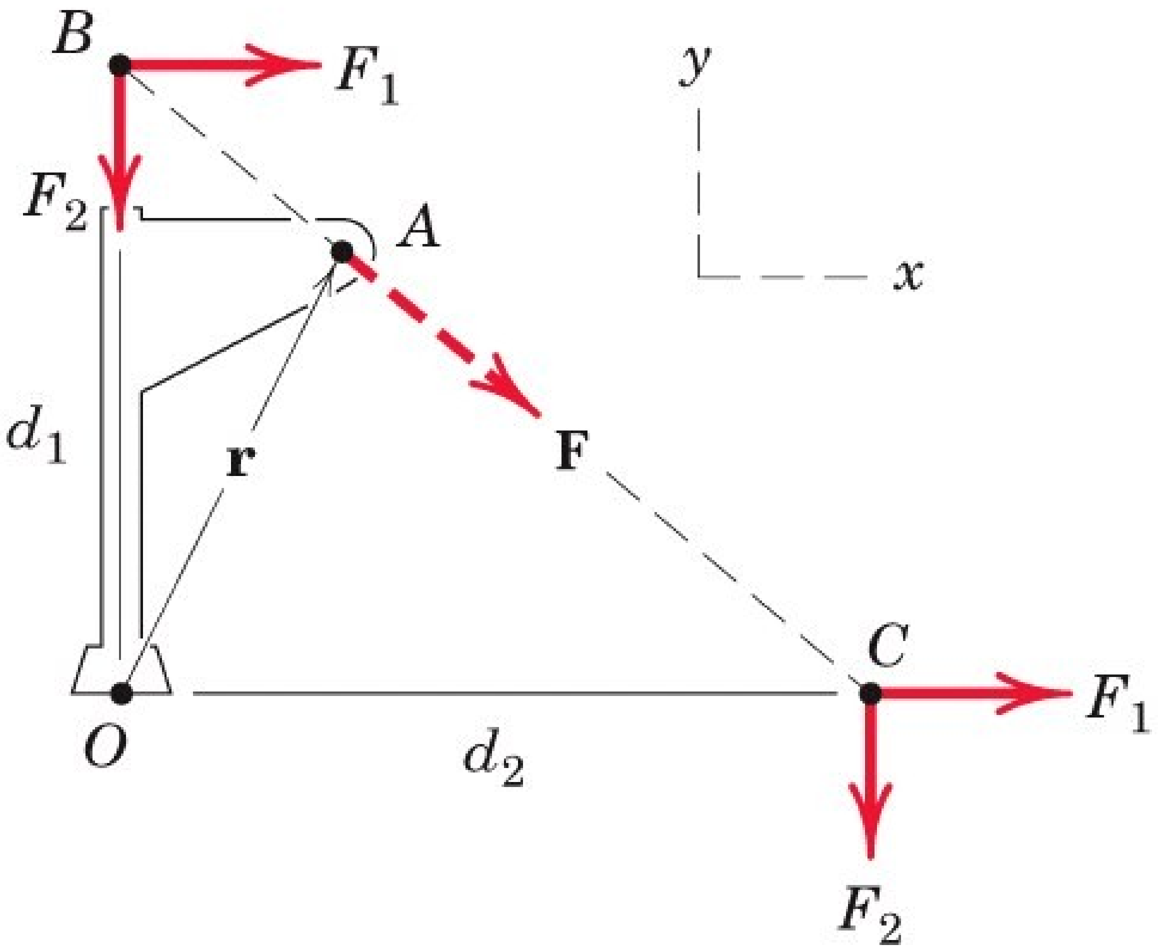
Figure 2-9



Sample Problem 2-5a

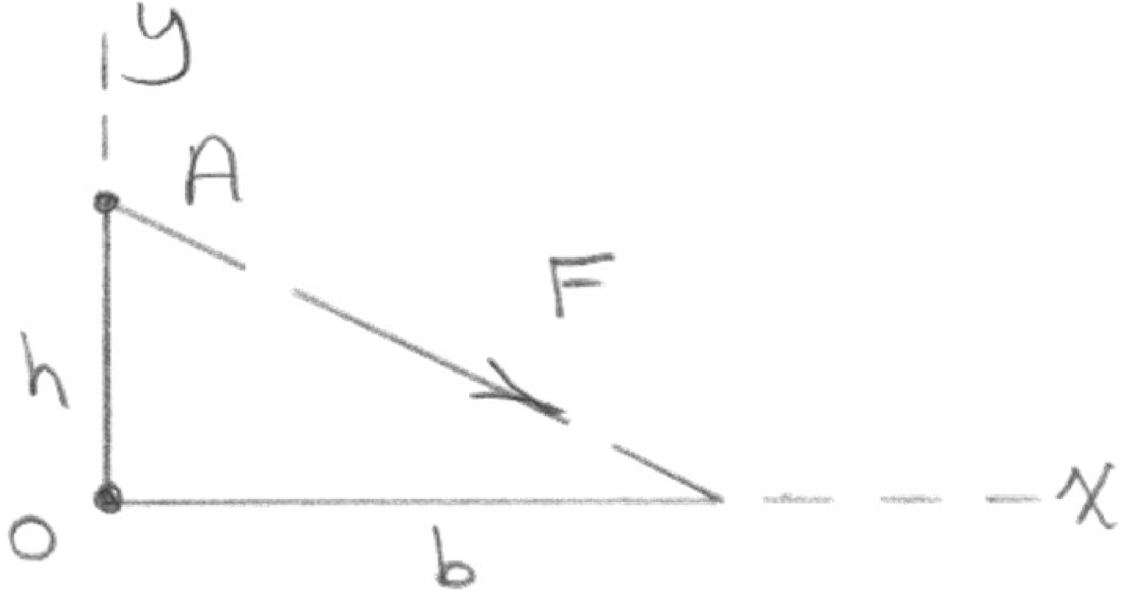






Sample Problem 2-5b

2/32 The force of magnitude F acts along the edge of the triangular plate. Determine the moment of F about point 0.



Given

F = Force

To find

Mo = ?

Solution

$\tan\theta = h/b$

$Mo = -F \times \sin\theta \times b = -F \times h \times b / \sqrt{(h^2 + b^2)}$

Or

$Mo = -F \times \cos\theta \times h = -F \times b \times h / \sqrt{(h^2 + b^2)}$

2/41 A 150-N pull T is applied to a cord, which is wound securely around the inner hub of the drum. Determine the moment of T about the drum center C. At what angle θ should T be applied so that the moment about the contact point P is zero?

Given

T = 150 N, r1 = 125mm, r2 = 200 mm

To find

Mc = ?

Θ = ? For Mp = 0

Solution

Mc = 150 x 125 = 18750 N - mm

Cos θ = 125/200

Θ = 51.31

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2/41 A 150-N pull T is applied to a cord, which is wound securely around the inner hub of the drum. Determine the moment of T about the drum center C. At what angle θ should T be applied so that the moment about the contact point P is zero?

Given

T = 150 N, r1 = 125mm, r2 = 200 mm

To find

Mc = ?

Θ = ? For Mp = 0

Solution

Mc = 150 x 125 = 18750 N - mm

Cos θ = 125/200

Θ = 51.31

2/49 In order to raise the flag pole OC, a light frame OAB is attached to the pole and a tension of 3.2 kN is developed in the hoisting cable by the power winch D. Calculate the moment M0 of this tension about the hinge point 0.

Given

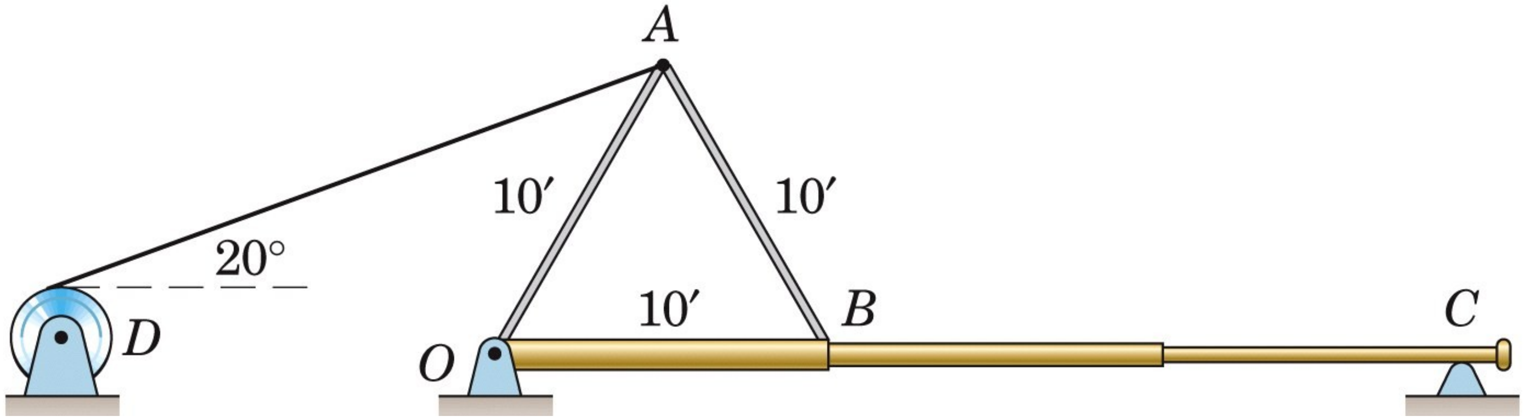
F = Force

To find

Mo = ?

Solution

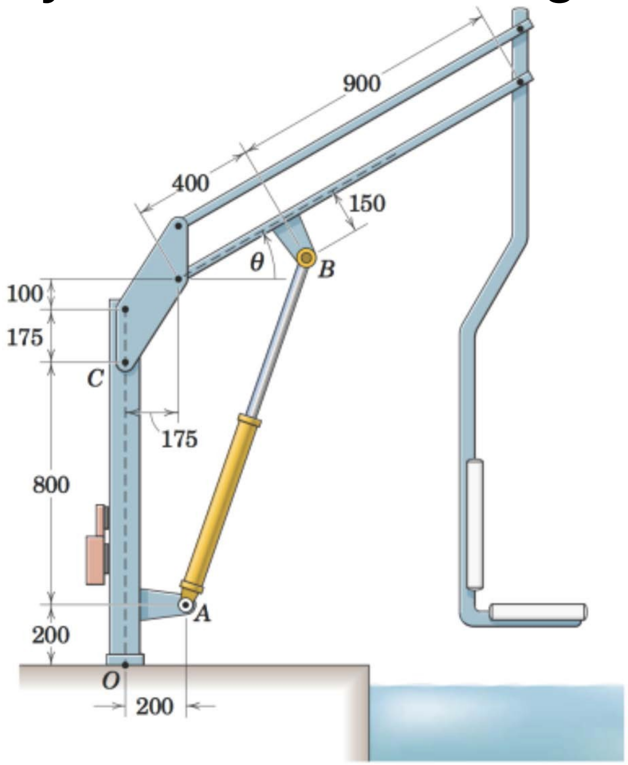
$\theta = 60^0$



Mo = 3.2 x cos 20 x 3 x sin 60 – 3.2 x sin 20 x 3 x cos 60

Mo = 7.812 – 1.641 = 6.17 kN - m

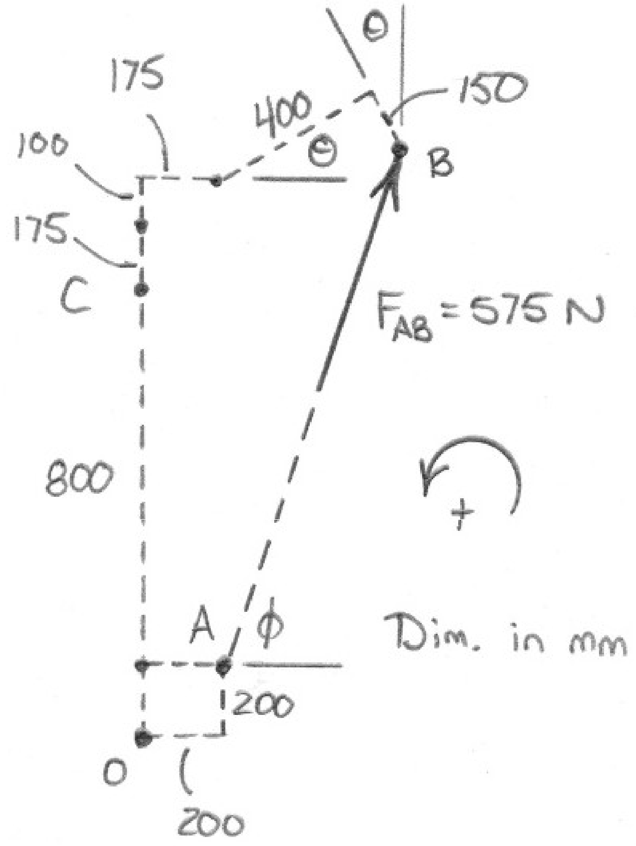
2/56 The mechanism shown is used to lower disabled persons into a whirlpool tub for therapeutic treatment. In the unloaded configuration, the weight of the boom and hanging chair induces a compressive force of 575 N in hydraulic cylinder AB . Compressive means that the force which cylinder AB exerts on point B is directed from A toward B.) If 8 = 30°, determine the moment of this cylinder force acting on pin B about (a) point 0 and (b) point C.



2/56

$$\phi = \tan^{-1}\left(\frac{800 + 175 + 100 + 400\sin\theta - 150\cos\theta}{175 + 400\cos\theta + 150\sin\theta - 200}\right) = 70.9^\circ$$

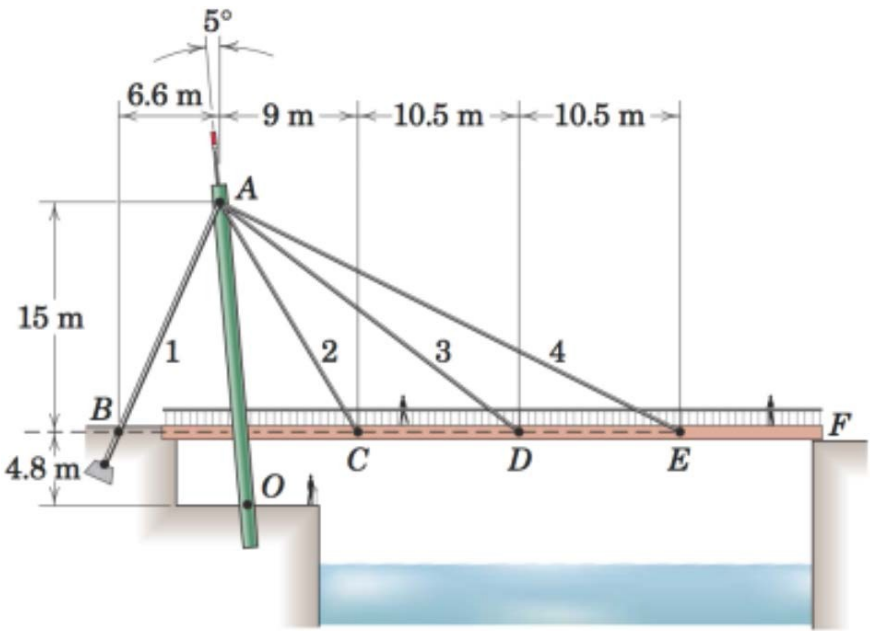
$\theta = 30^\circ$



$$M_O = 575 \sin\phi\,(0.200) - 575 \cos\phi\,(0.200) \longrightarrow \underline{M_O = 71.1 \text{ N·m CCW}}$$

$$M_C = 575 \sin\phi\,(0.200) + 575 \cos\phi\,(0.800) \longrightarrow \underline{M_C = 259 \text{ N·m CCW}}$$

2/57 The asymmetrical support arrangement is chosen for a pedestrian bridge because conditions at the right end F do not permit a support tower and anchorages. During a test, the tensions in cables 2, 3, and 4 are all adjusted to the same value T. If the combined moment of all four cable tensions about point 0 is to be zero, what should be the value T1 of the tension in cable 1? Determine the corresponding value of the compression force P at 0 resulting from the four tensions applied at A Neglect the weight of the tower.



Given T = T2, T3, T4 ; Mo = 0

To find T1 = ?, P = ?

Solution

Tan θ1 = 15/6.6 , θ1 = 66.25

Tan θ2 = 15/9 , θ2 = 59

Tan θ3 = 15/(9+10.5) , θ3=37.57

Tan θ4 = 15/(9+10.5+10.5) ,

θ4 = 26.57

2/57 Conti…….

$M_o = 0$

$M_o = [T\times(\cos\theta_2+\cos\theta_3+\cos\theta_4) - T_1\times\cos\theta_1]\times4.8 - T_1\times\sin\theta_1(6.6+19.8\times\tan5) + T \times [\sin\theta_2\times(9-19.8\times\tan5) + \sin\theta_3\times(9-19.8\times\tan5+10.5) + \sin\theta_4\times(9-19.8\times\tan5+10.5+10.5)]$

$= 10.6T – 1.93T_1 – 7.63T_1 + T[6.23 + 10.8 + 12.64)$

$T_1 = 40.27T/9.56$

$T_1 = 4.21T$

$\Sigma f_y = 0$

$P \times \cos5 = T_1 \times \sin\theta_1 + T \times [\sin\theta_2 + \sin\theta_3 + \sin\theta_4]$

$P = 4.21T \times 0.92 + [0.86 + 0.61 + 0.45] \times T$

$P = 5.8T$

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Unit - 1
Couple

ENGINEERING MECHANICS STATICS

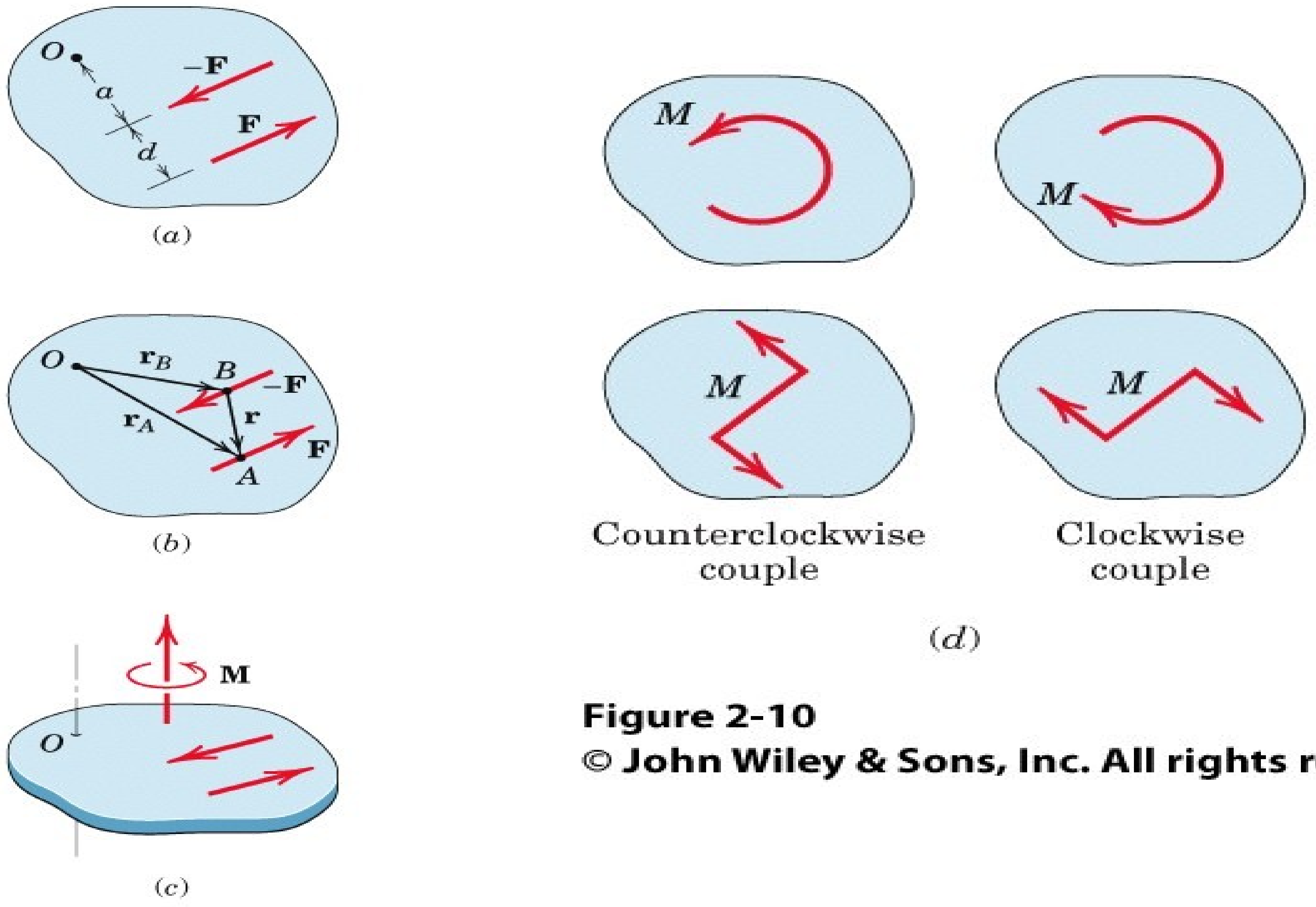


Figure 2-10

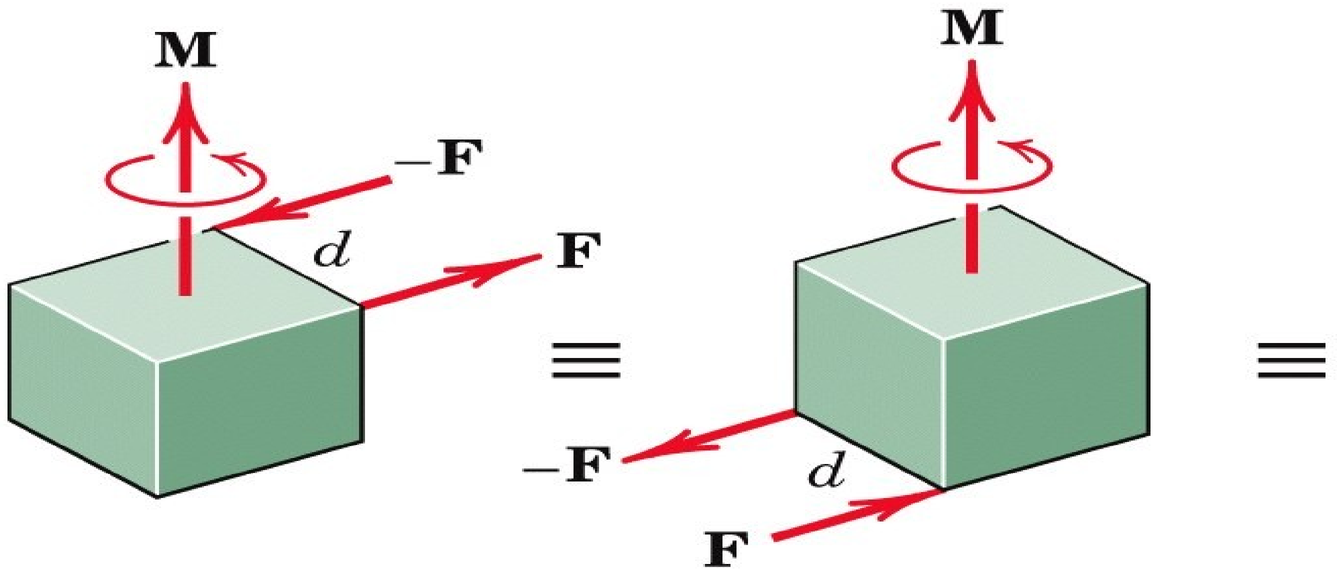
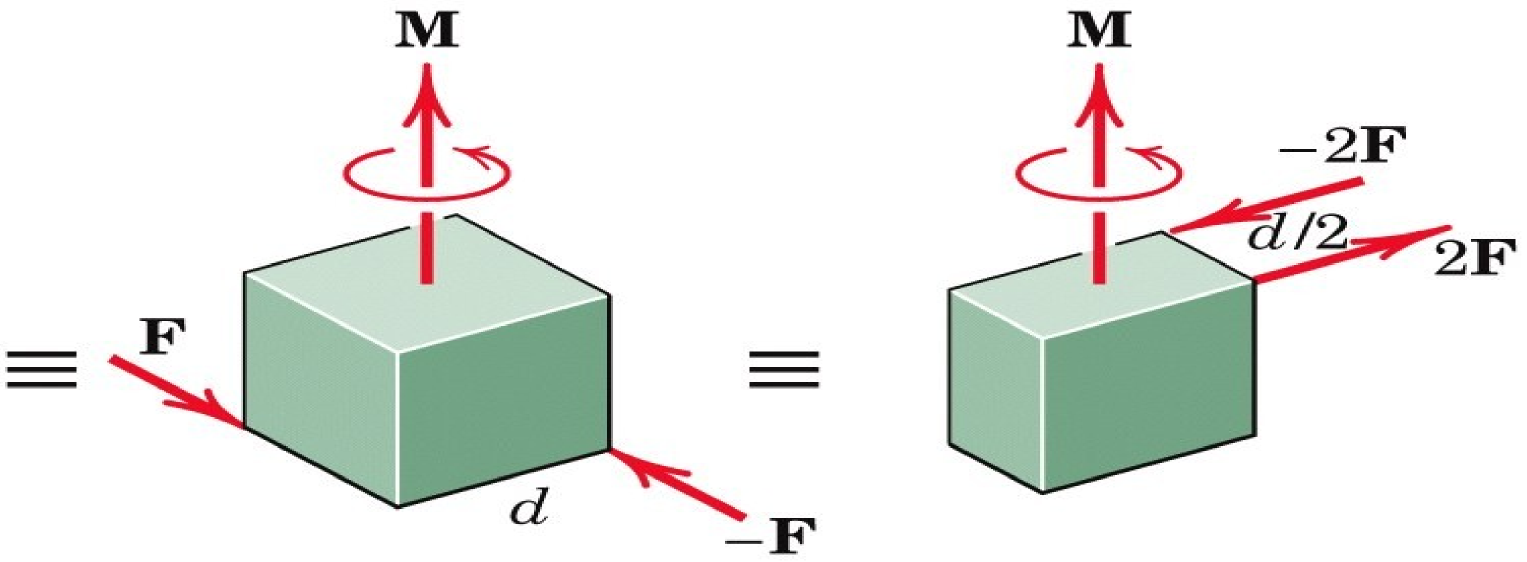


Figure 2-11



Characteristics of couple

1. The net force acting because of a couple is zero.

2. The moment produced by a couple is same at any point.

3. A couple can be balanced by an opposite couple or opposite moment.

4. A couple can not be replaced by a single force.

Force couple system

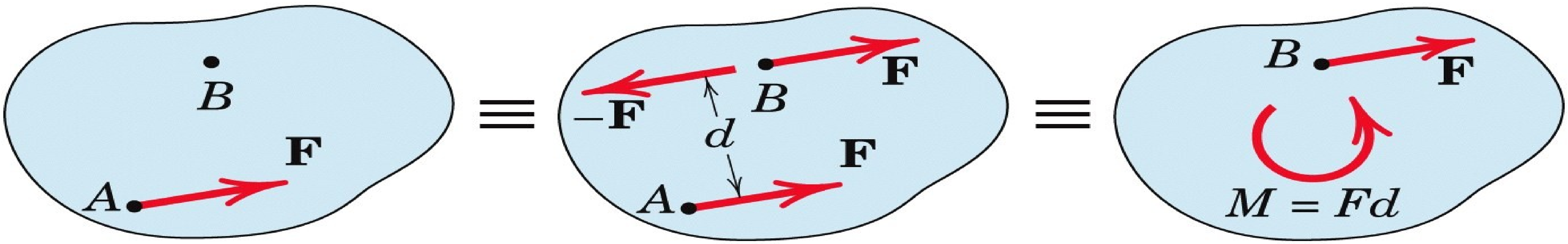
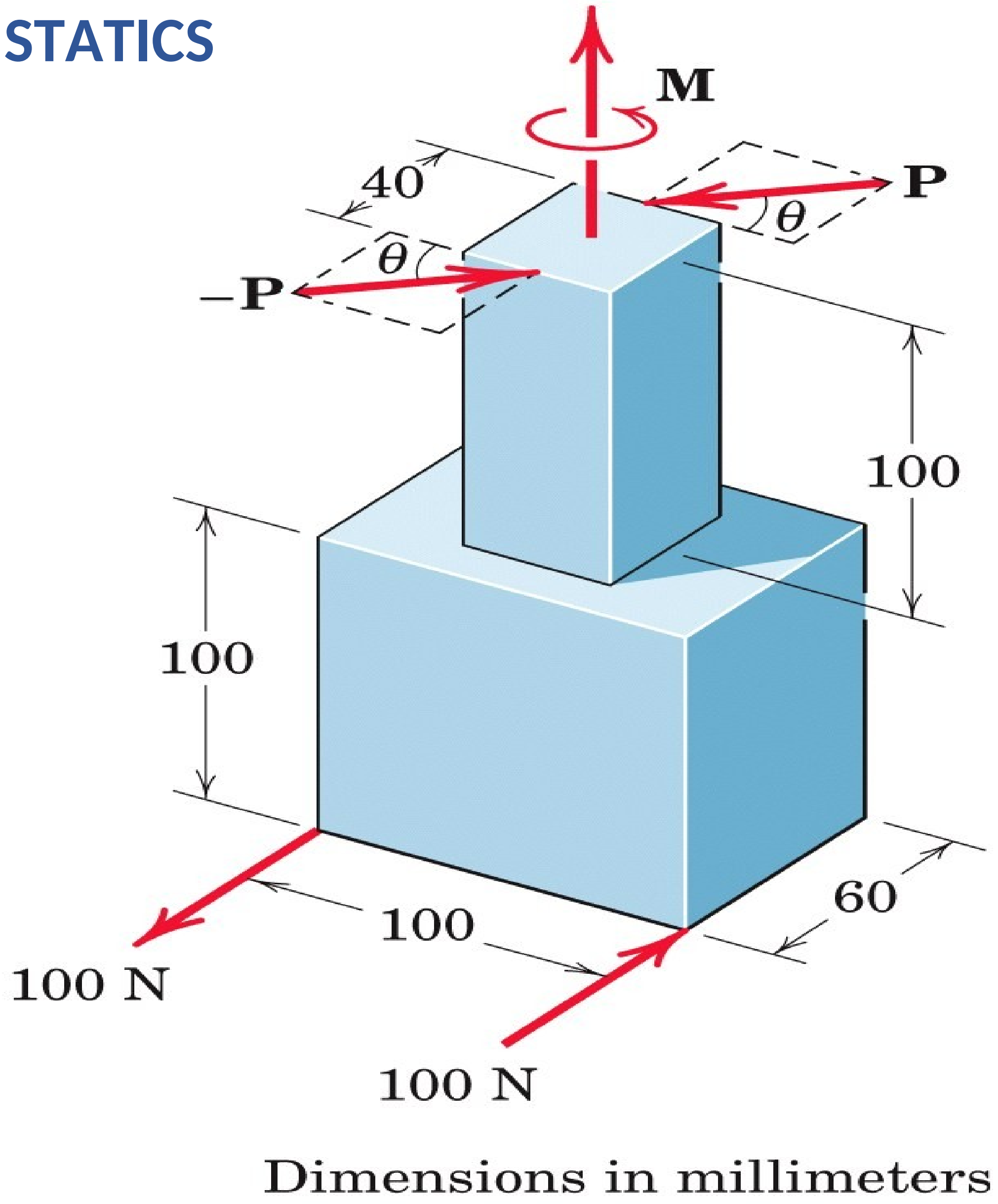
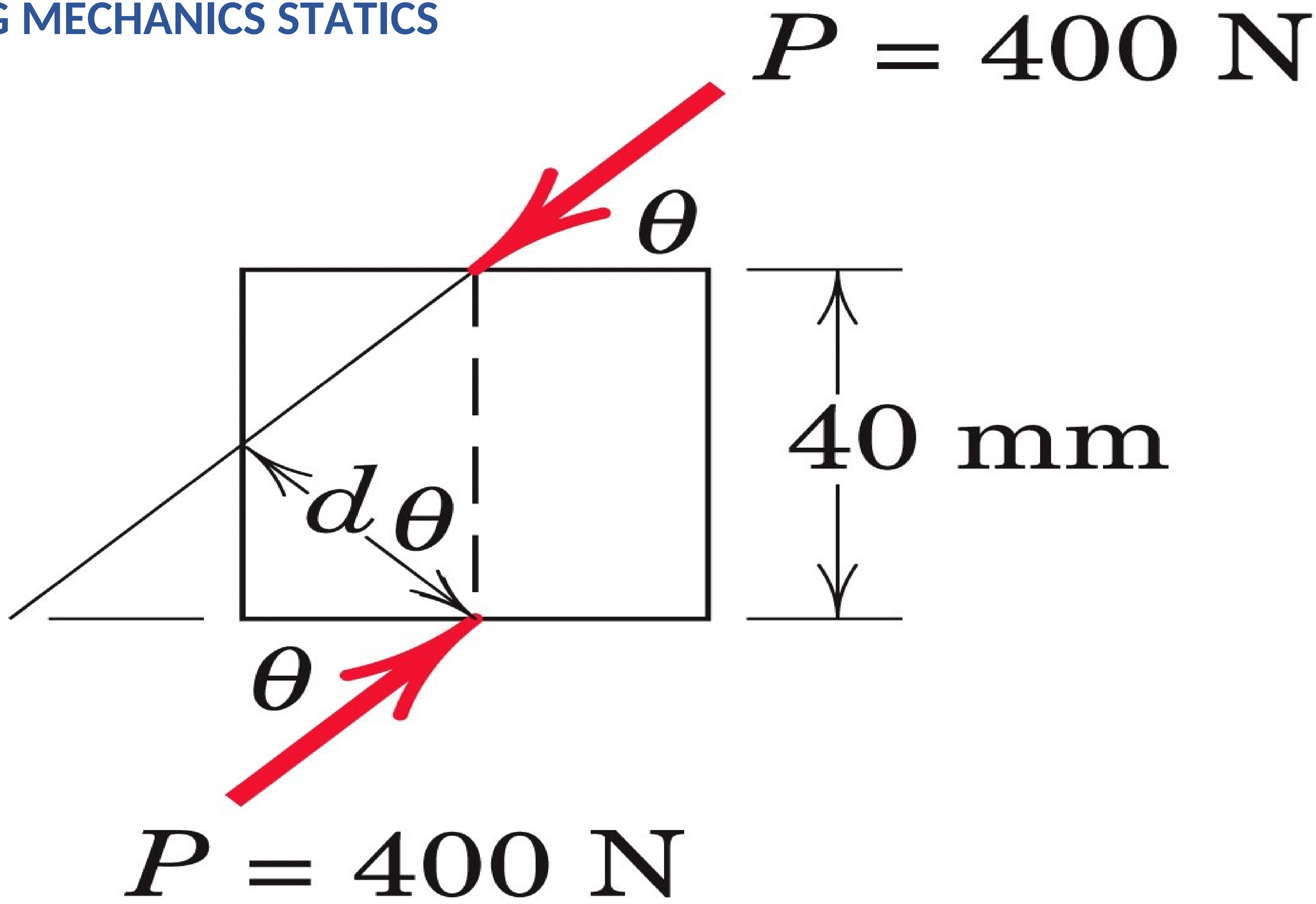


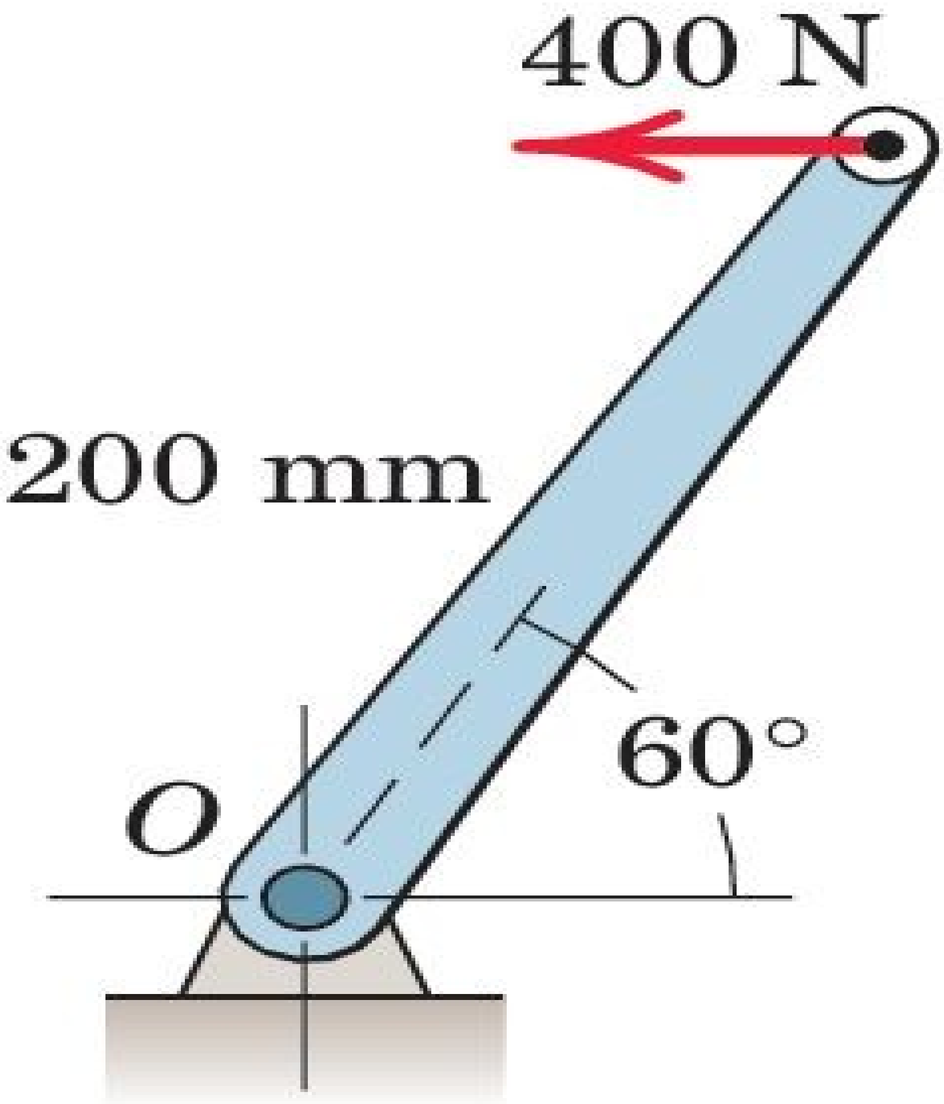
Figure 2-12

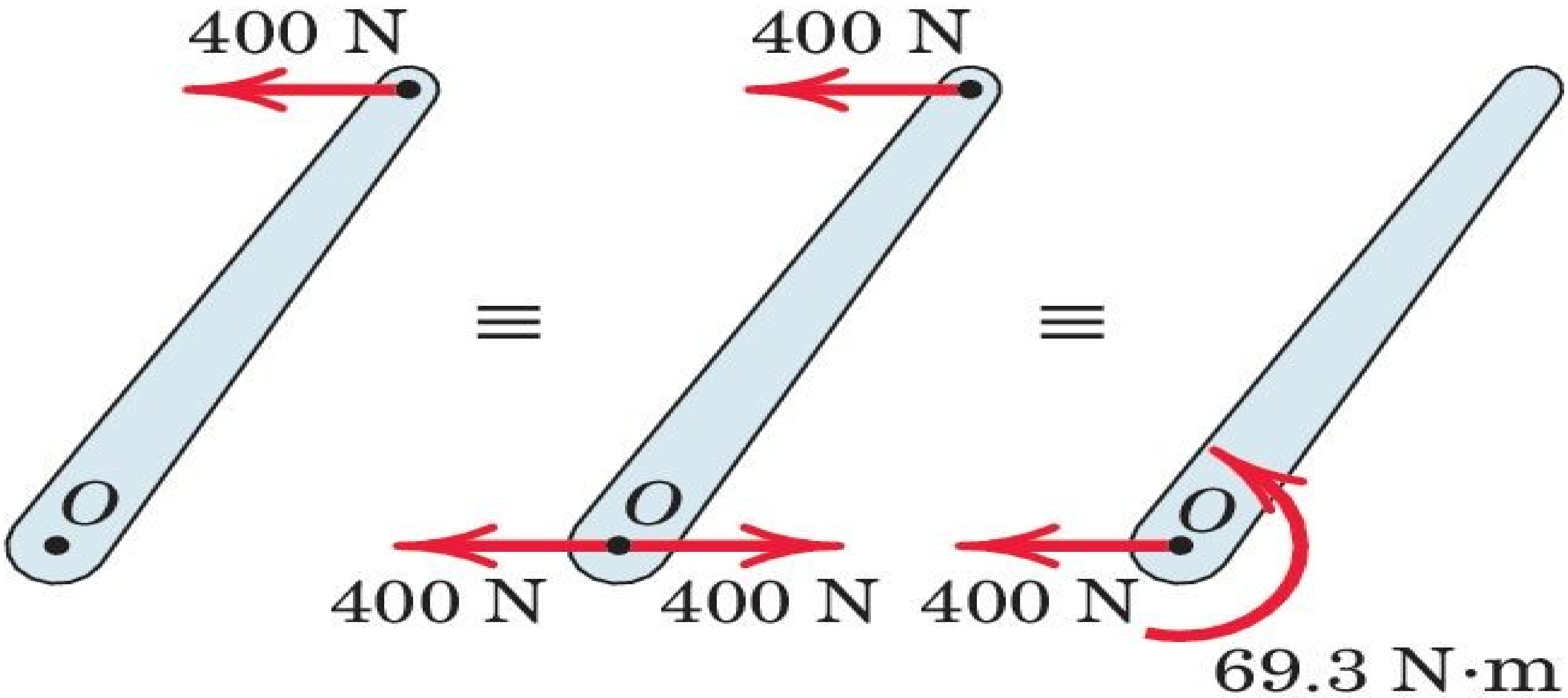


Sample Problem 2-7a



Sample Problem 2-7b


400 N
200 mm
60°
O


400 N
O
≡
400 N
O
400 N
400 N
≡
O
400 N
69.3 N·m

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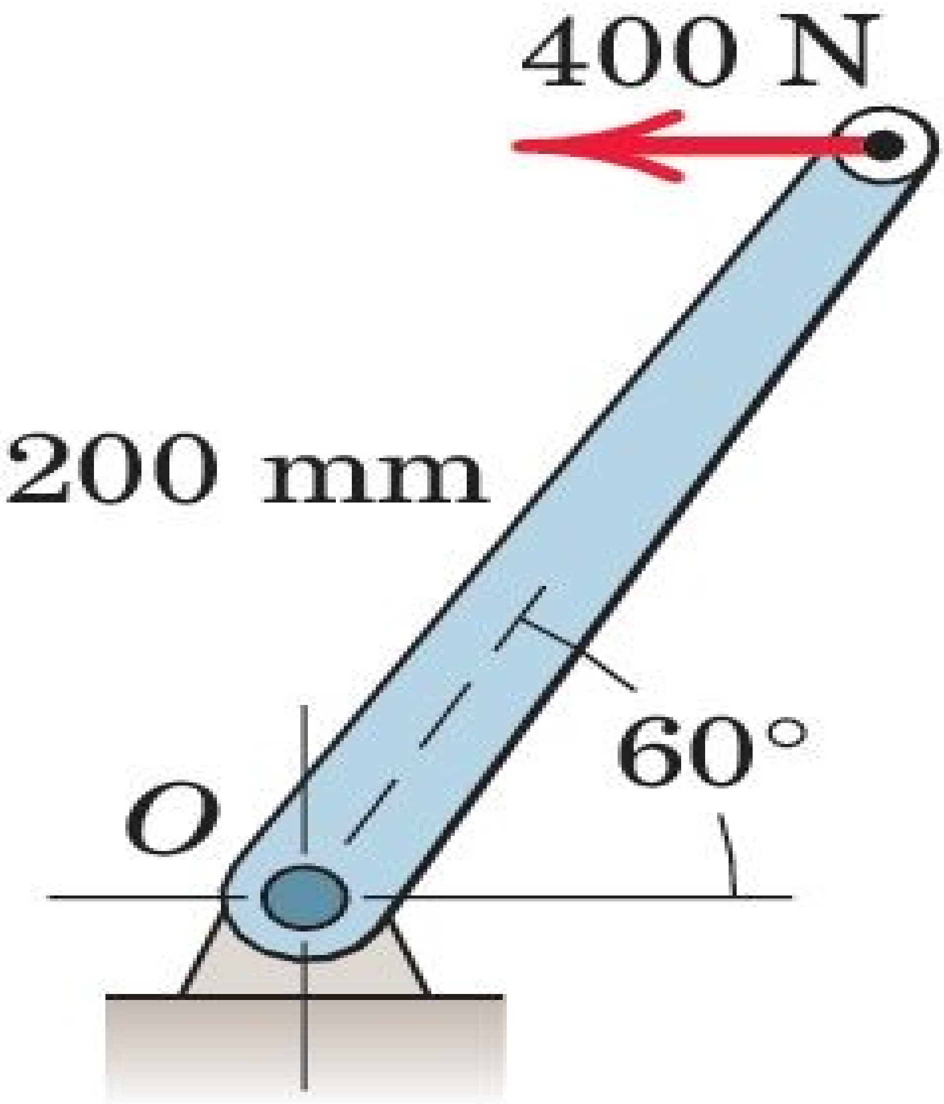
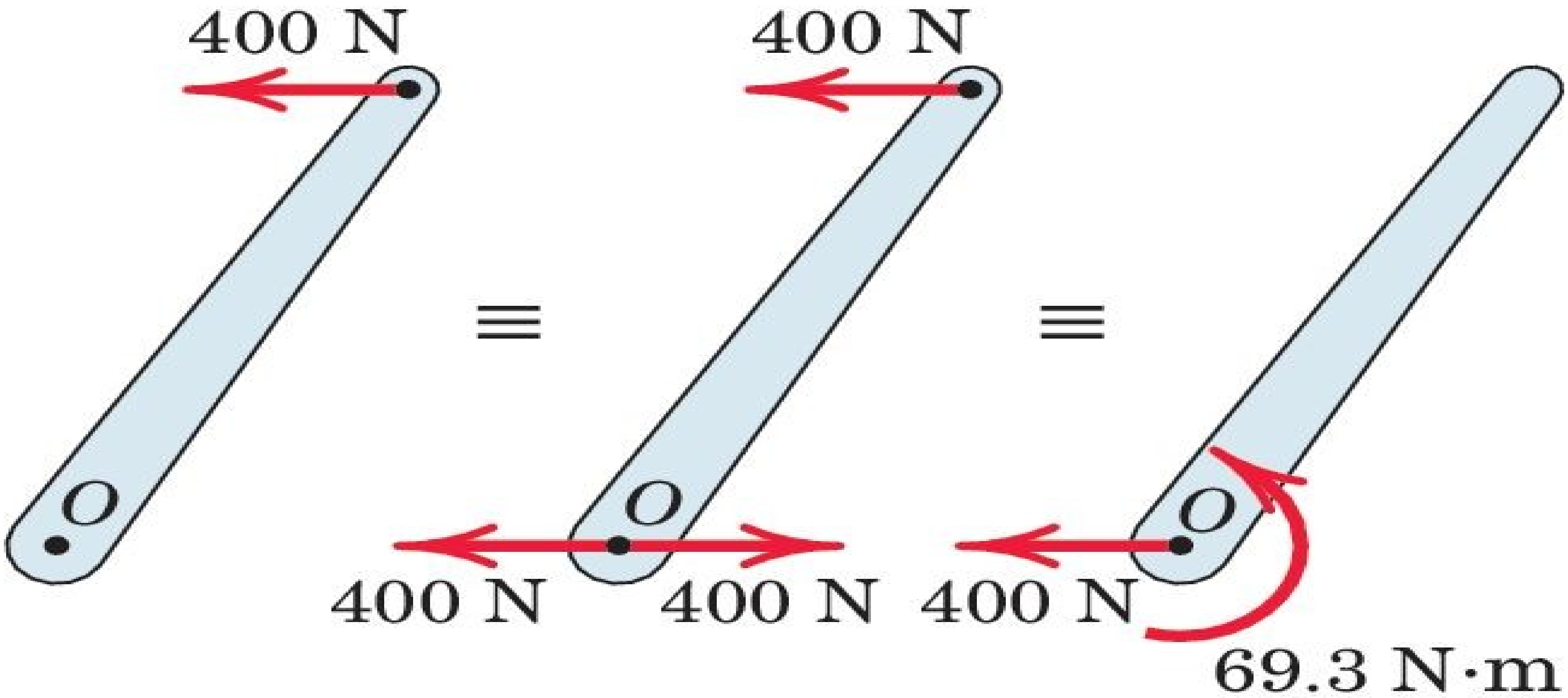
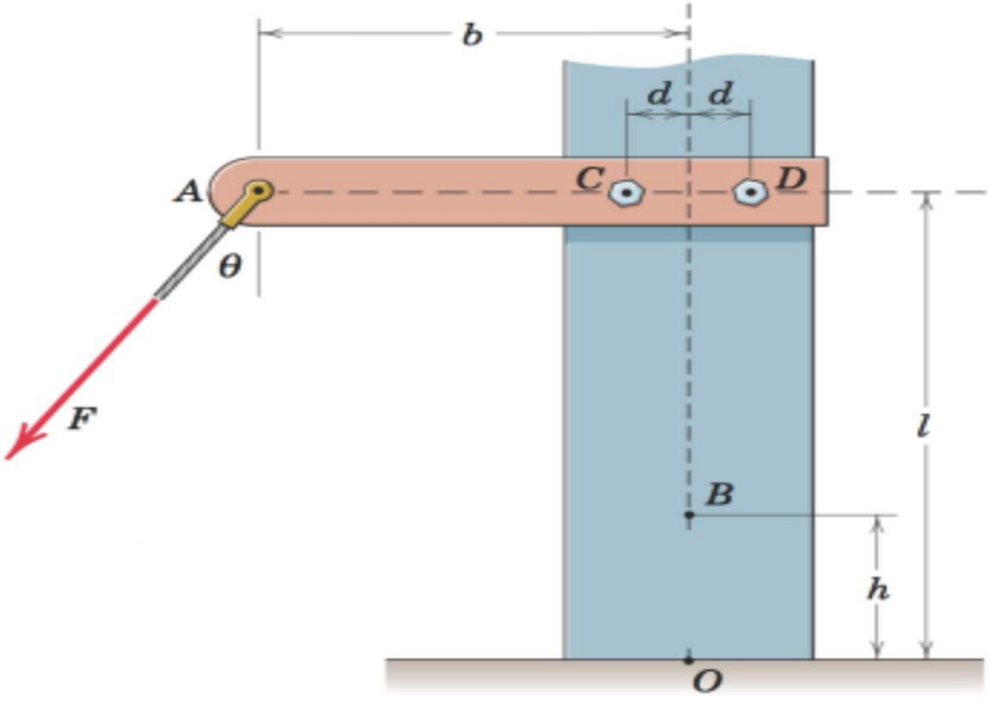
Unit - 1
Couple


400 N
200 mm
60°
O



400 N
400 N
≡
≡
O
O
O
400 N
400 N
400 N
69.3 N·m

2/68 The force F is applied at the end of arm ACD, which is mounted to a vertical post. Replace this single force F by an equivalent force-couple system at B. Next, redistribute this force and couple by replacing it with two forces acting in the same direction as F, one at C and the other at D, and determine the forces supported by the two hex-bolts. Use values of F = 425 N, $\theta = 30^0$ b = 1.9 m, d = 0.2 m, h = 0.8 m, and l = 2.75 m.



Given

To find : Force couple system at B, Fc, Fd

Solution

FB = -Fsinθi – Fcosθj

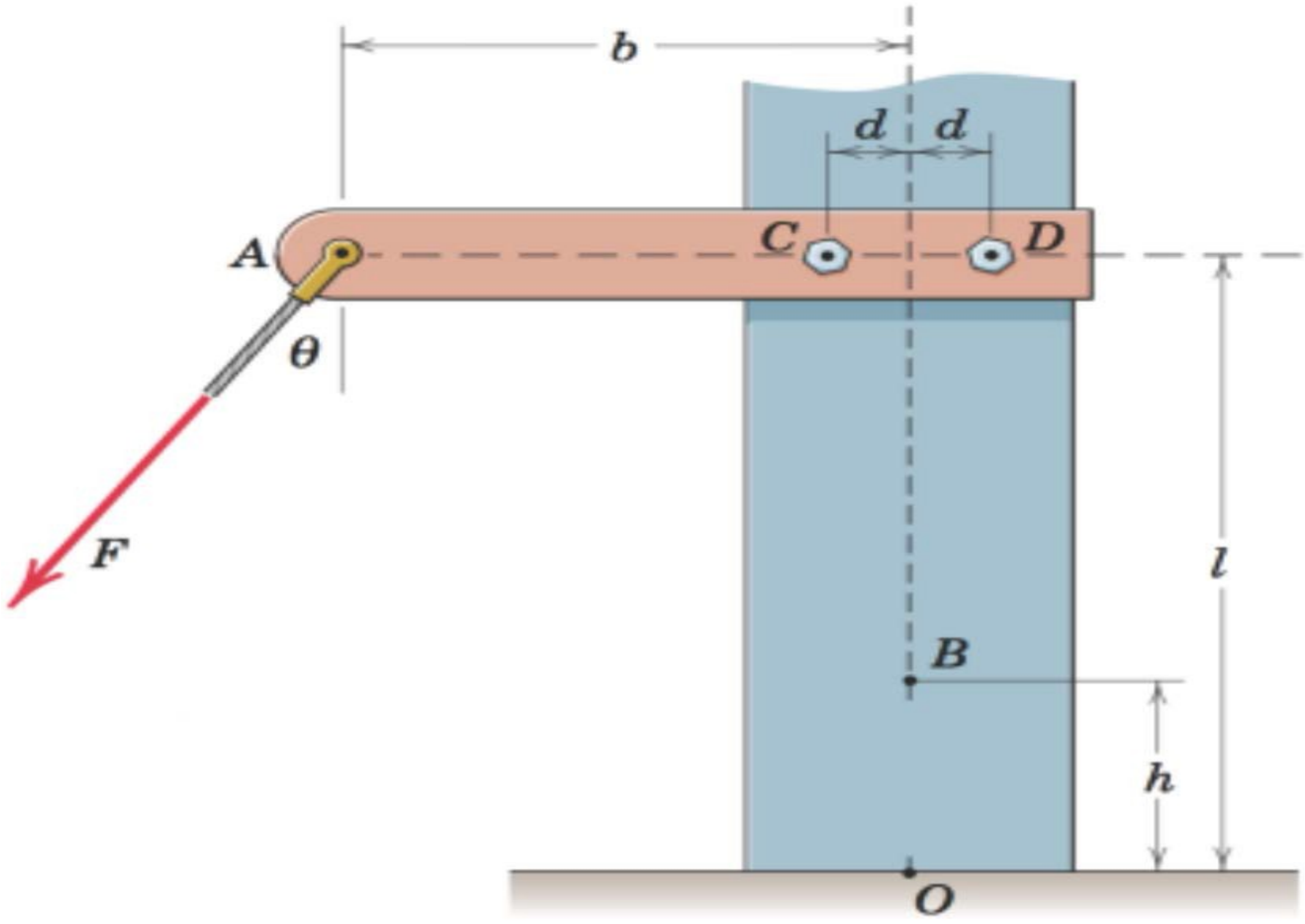
= - 425xsin30i – 425xcos30j

= - 212.5i – 368.06j kN

MB = Fsinθx(l-h) + Fcosθxb

1114.27=212.5x(2.75-0.8)+368.06x1.9

2/68 Conti……



$\Sigma F = 0$

Fc - Fd = F = 425

MB = Fcxcosθxd + Fcxsinθx(l-h) + Fdxcosθxd - FdxSinθx(l-h)

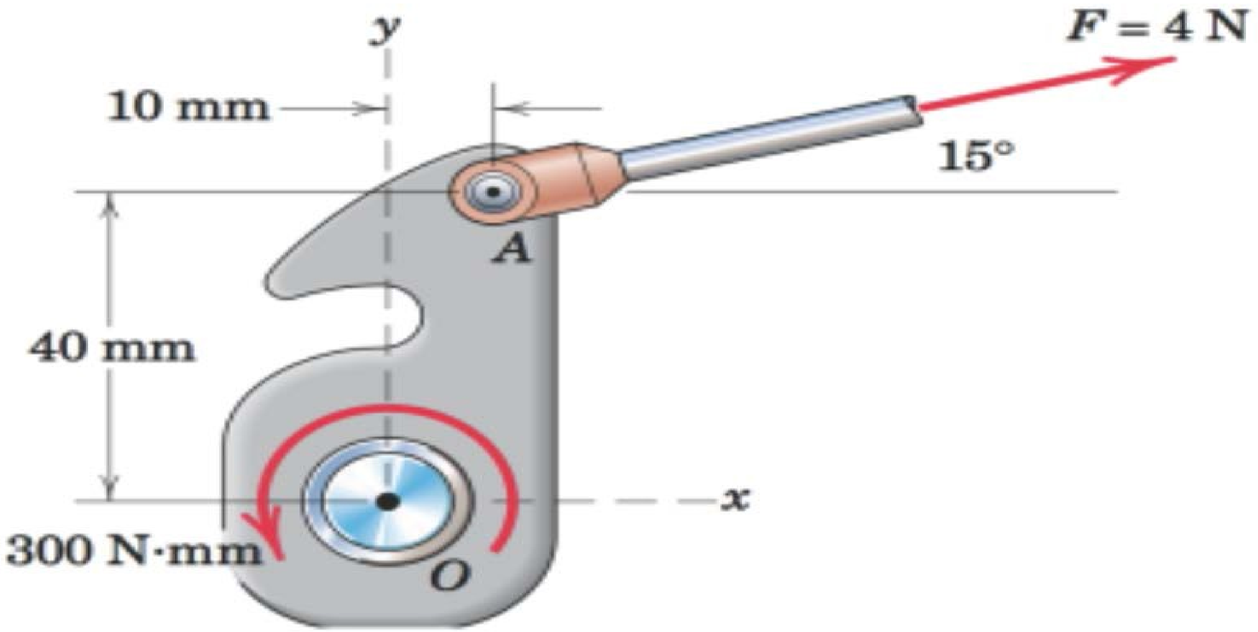
1114.27 = (F + Fd) x cos30 x 0.2 + (F + Fd) x sin30 x (2.75–0.8) + Fd x cos30 x 0.2 – Fd x sin30 x (2.75 – 0.8)

Fd=(1114.27–73.61–414.38)/(0.173+0.97+0.173–0.97)= 1807

Fc = 425 + 1807 = 2232 N

ENGINEERING MECHANICS STATICS

2/76 The device shown is a part of an automobile seatback-release mechanism. The part is subjected to the 4-N force exerted at A and a 300-N · mm restoring moment exerted by a hidden torsional spring. Determine the y-intercept of the line of action of the single equivalent force.



Given F = 4 N,

M = 300 N-mm

Θ = 15^0

X1 = 10 mm, Y1 = 40 mm

To find : Y-intercept

Solution

Mo = M + FsinθX1 - FcosθY1

- FcosθxY = 300 + 4xsin15x10 – 4xcos15x40

Y = (300 + 10.35 – 154.55) / (- 4xcos15)

Y = 155.8 / - 3.86 = - 40.36 mm

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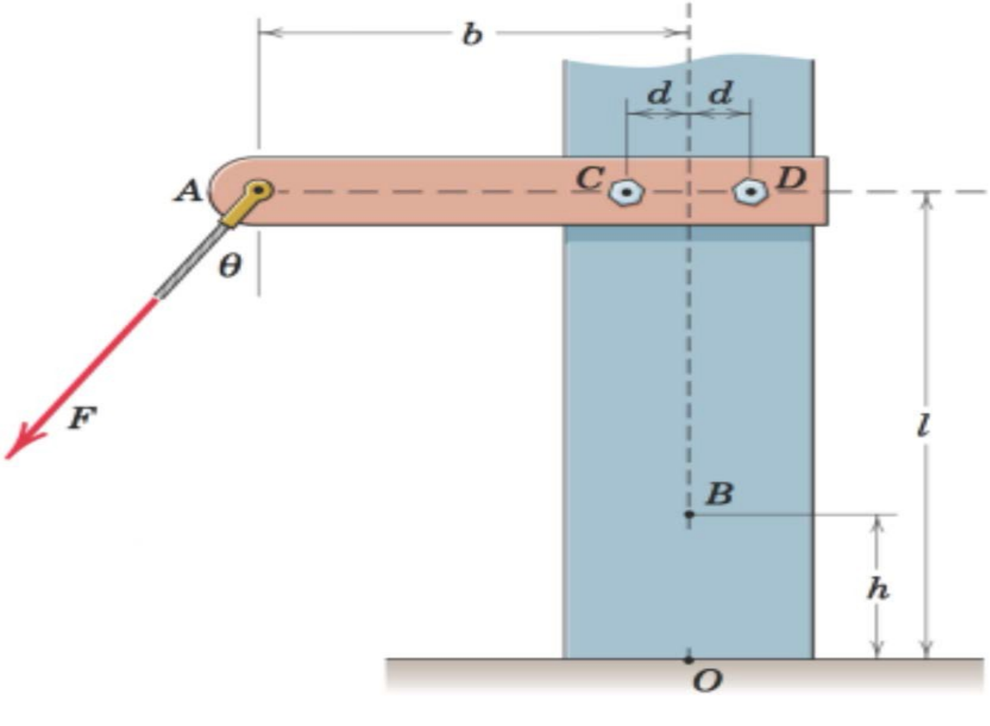
2/68 The force F is applied at the end of arm ACD, which is mounted to a vertical post. Replace this single force F by an equivalent force-couple system at B. Next, redistribute this force and couple by replacing it with two forces acting in the same direction as F, one at C and the other at D, and determine the forces supported by the two hex-bolts. Use values of F = 425 N, $\theta = 30^0$ b = 1.9 m, d = 0.2 m, h = 0.8 m, and l = 2.75 m.



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Solution

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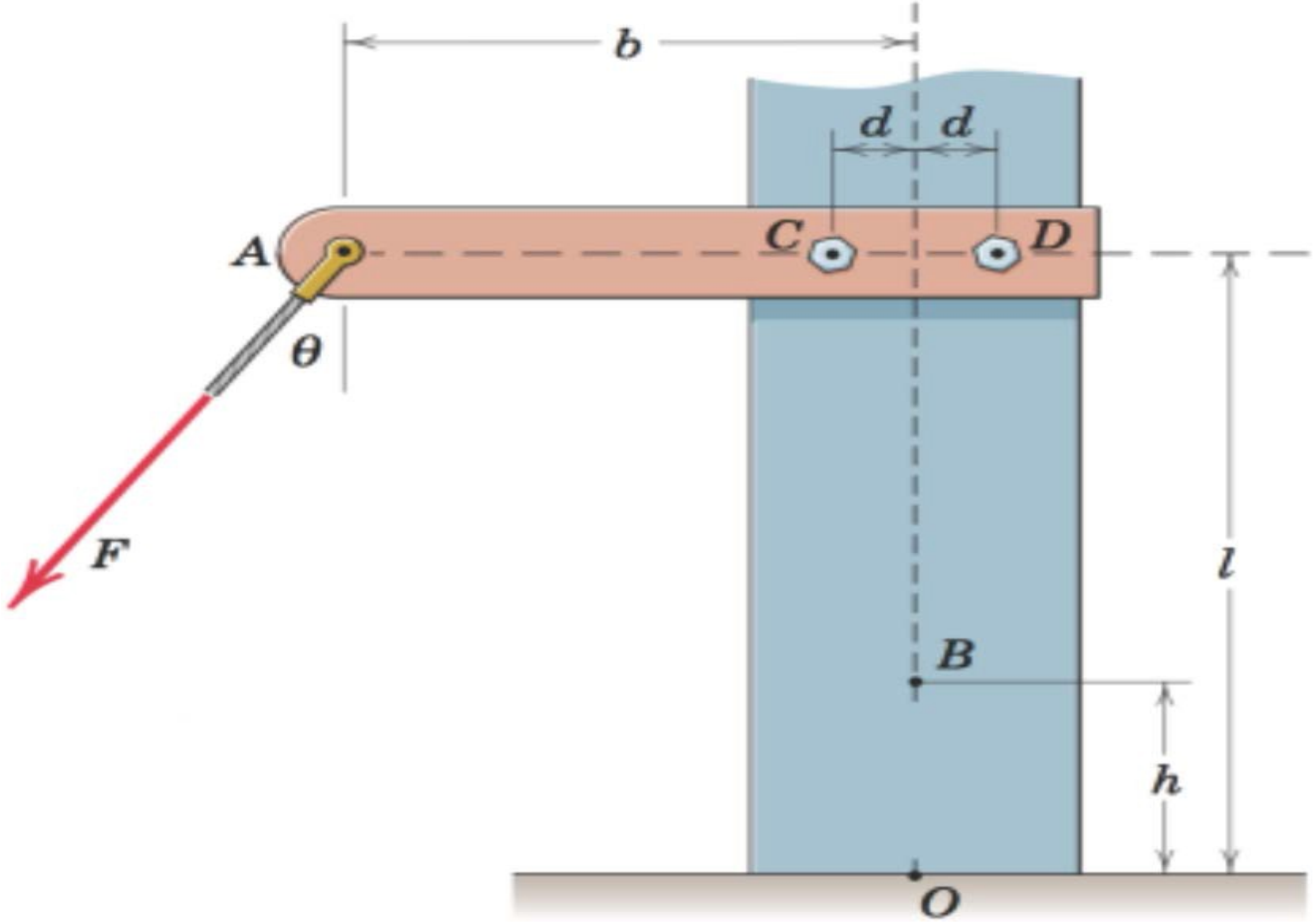
= - 425xsin30i – 425xcos30j

= - 212.5i – 368.06j kN

MB = Fsinθx(l-h) + Fcosθxb

1114.27=212.5x(2.75-0.8)+368.06x1.9

2/68 Conti……



$\Sigma F = 0$

$F_c - F_d = F = 425$

$M_B = F_c \times \cos\theta \times d + F_c \times \sin\theta \times (l-h) + F_d \times \cos\theta \times d - F_d \times \sin\theta \times (l-h)$

$1114.27 = (F + F_d) \times \cos 30 \times 0.2 + (F + F_d) \times \sin 30 \times (2.75 - 0.8) + F_d \times \cos 30 \times 0.2 - F_d \times \sin 30 \times (2.75 - 0.8)$

$F_d = (1114.27 - 73.61 - 414.38)/(0.173 + 0.97 + 0.173 - 0.97) = 1807$

$F_c = 425 + 1807 = 2232$ N

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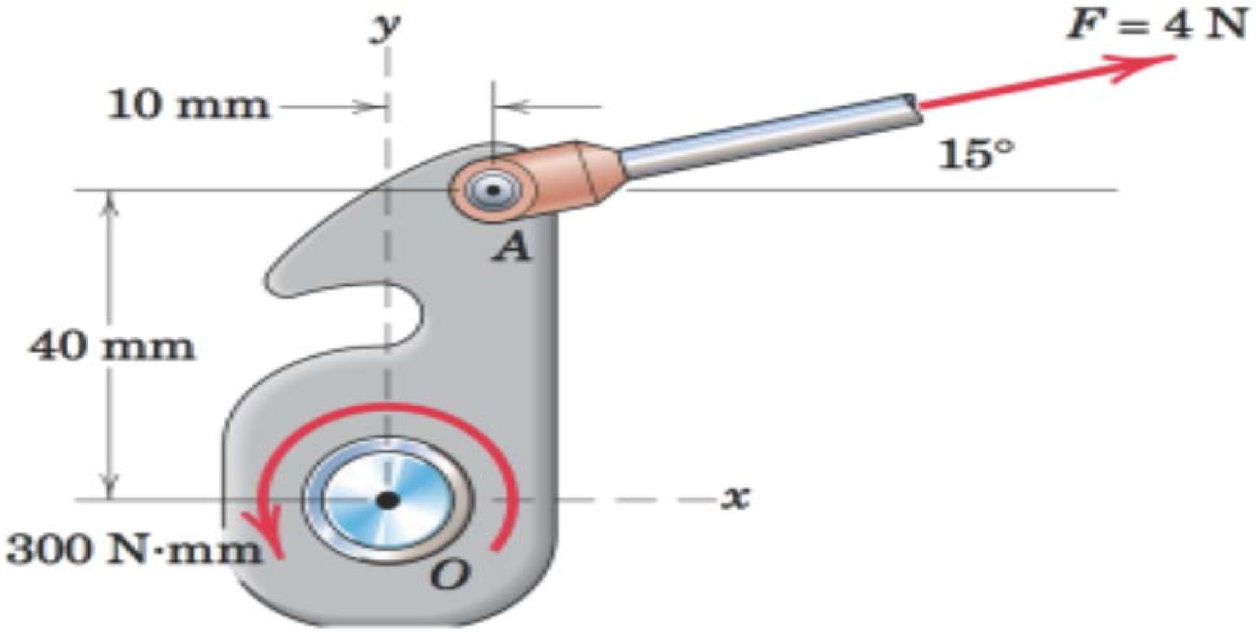
2/76 The device shown is a part of an automobile seatback-release mechanism. The part is subjected to the 4-N force exerted at A and a 300-N · mm restoring moment exerted by a hidden torsional spring. Determine the y-intercept of the line of action of the single equivalent force.



Given F = 4 N,

M = 300 N-mm

$\Theta = 15^0$

X1 = 10 mm, Y1 = 40 mm

To find : Y-intercept

Solution

Mo = M + FsinθX1 - FcosθY1

- FcosθxY = 300 + 4xsin15x10 – 4xcos15x40

Y = (300 + 10.35 – 154.55) / (- 4xcos15)

Y = 155.8 / - 3.86 = - 40.36 mm

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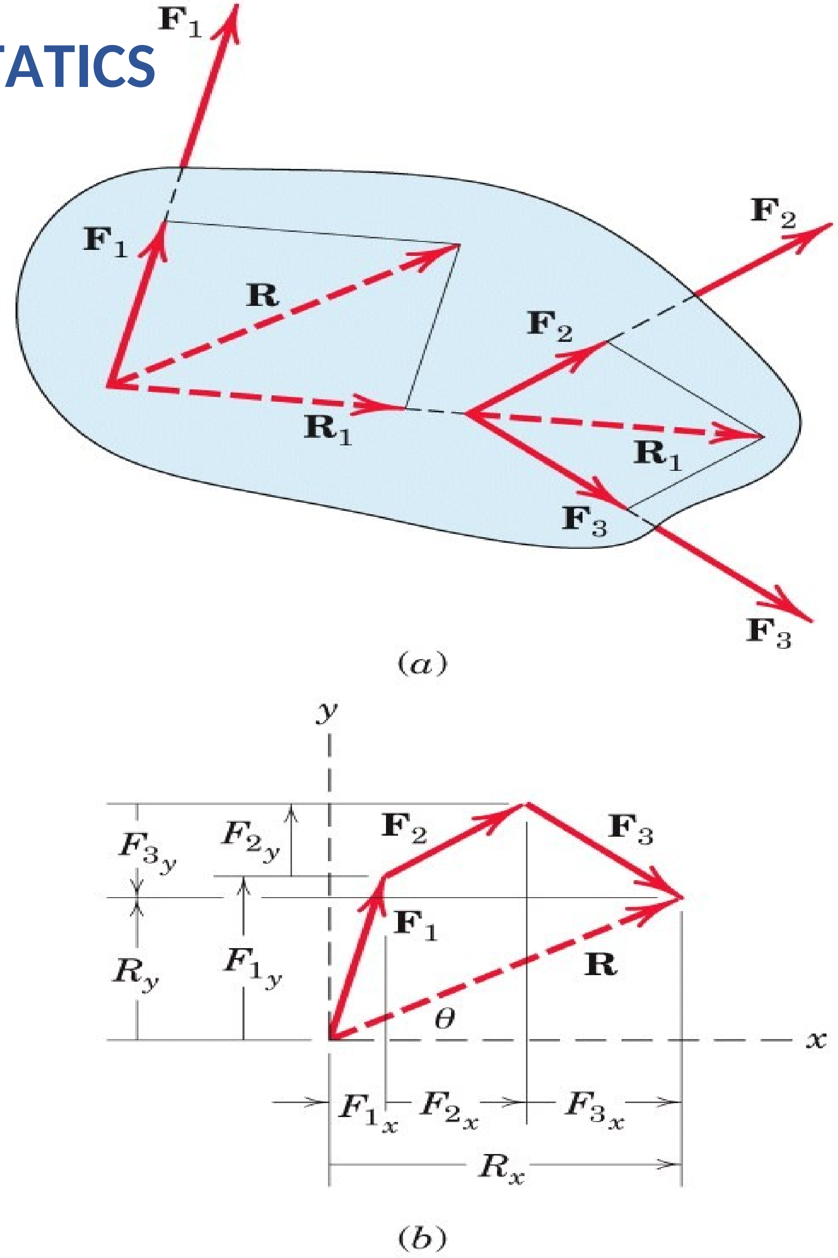
Unit - 1
Resultant



$\mathbf{F}_1$
$\mathbf{F}_1$
$\mathbf{R}$
$\mathbf{R}_1$
$\mathbf{F}_2$
$\mathbf{F}_2$
$\mathbf{R}_1$
$\mathbf{F}_3$
$\mathbf{F}_3$
(a)
y
F_{3_y}
F_{2_y}
$\mathbf{F}_2$
$\mathbf{F}_3$
$\mathbf{F}_1$
R_y
F_{1_y}
$\mathbf{R}$
θ
x
F_{1_x}
F_{2_x}
F_{3_x}
R_x
(b)

Figure 2-13

ENGINEERING MECHANICS STATICS

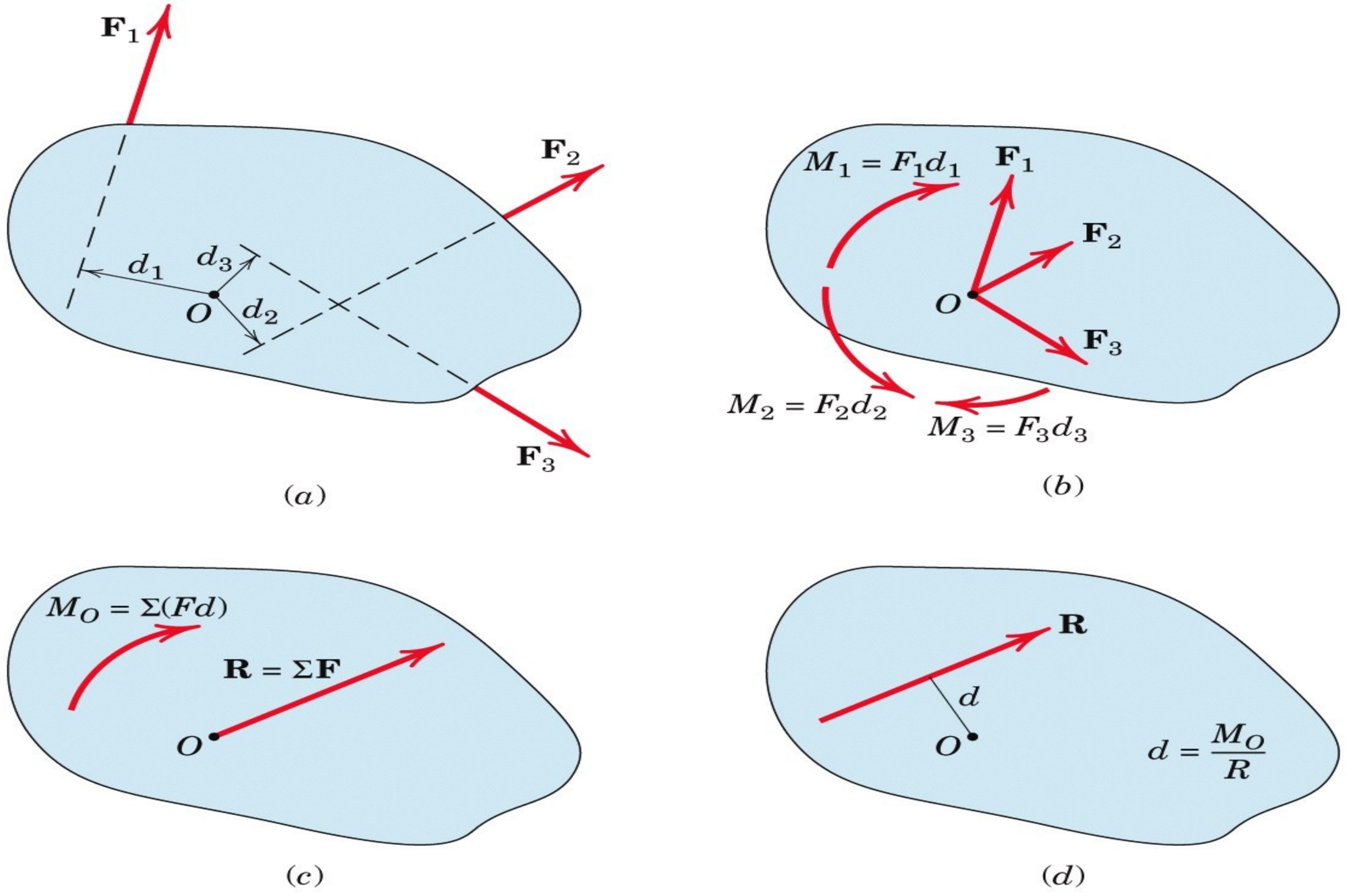


Figure 2-14

ENGINEERING MECHANICS STATICS

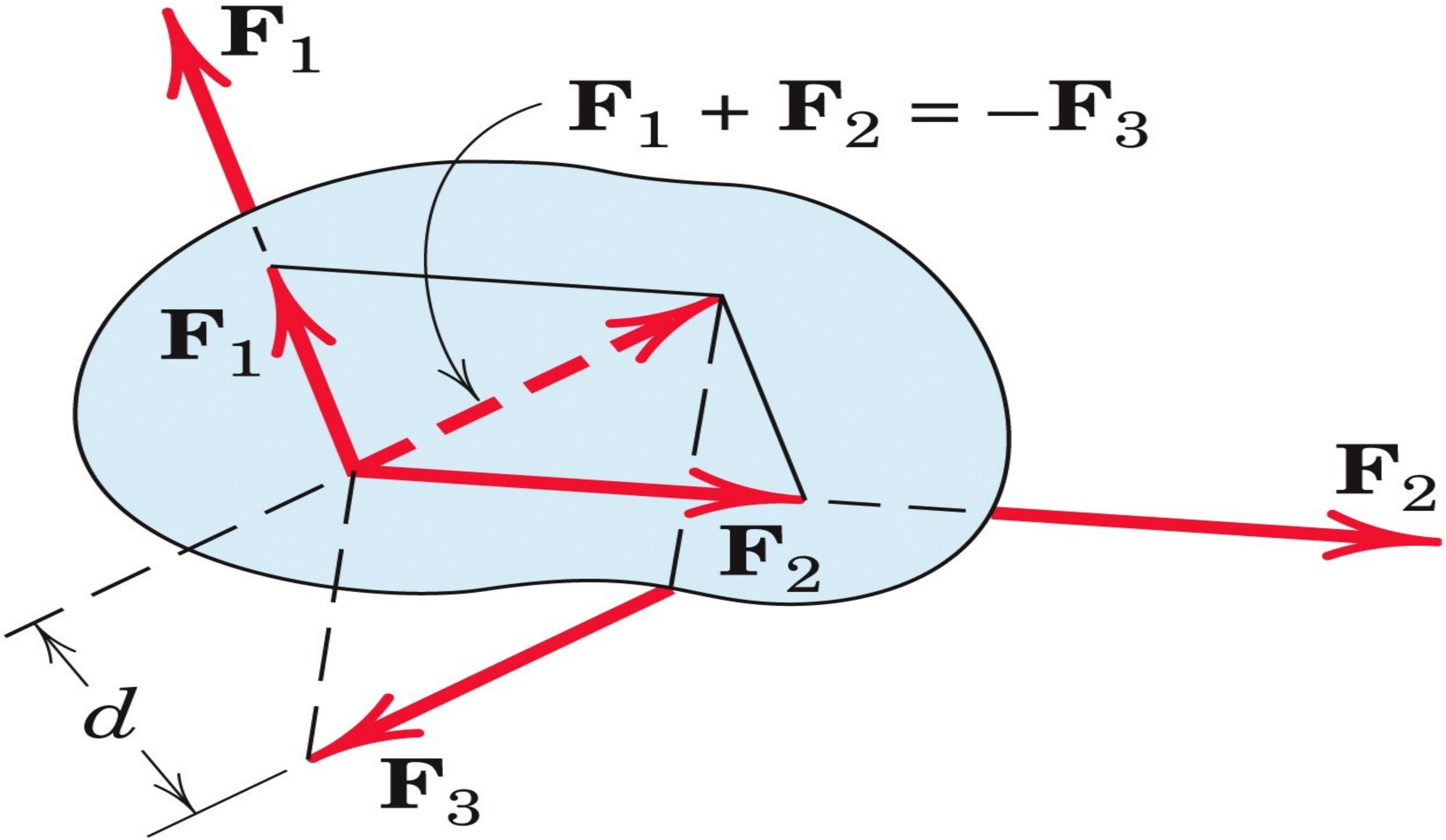


Figure 2-15

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ENGINEERING MECHANICS STATICS

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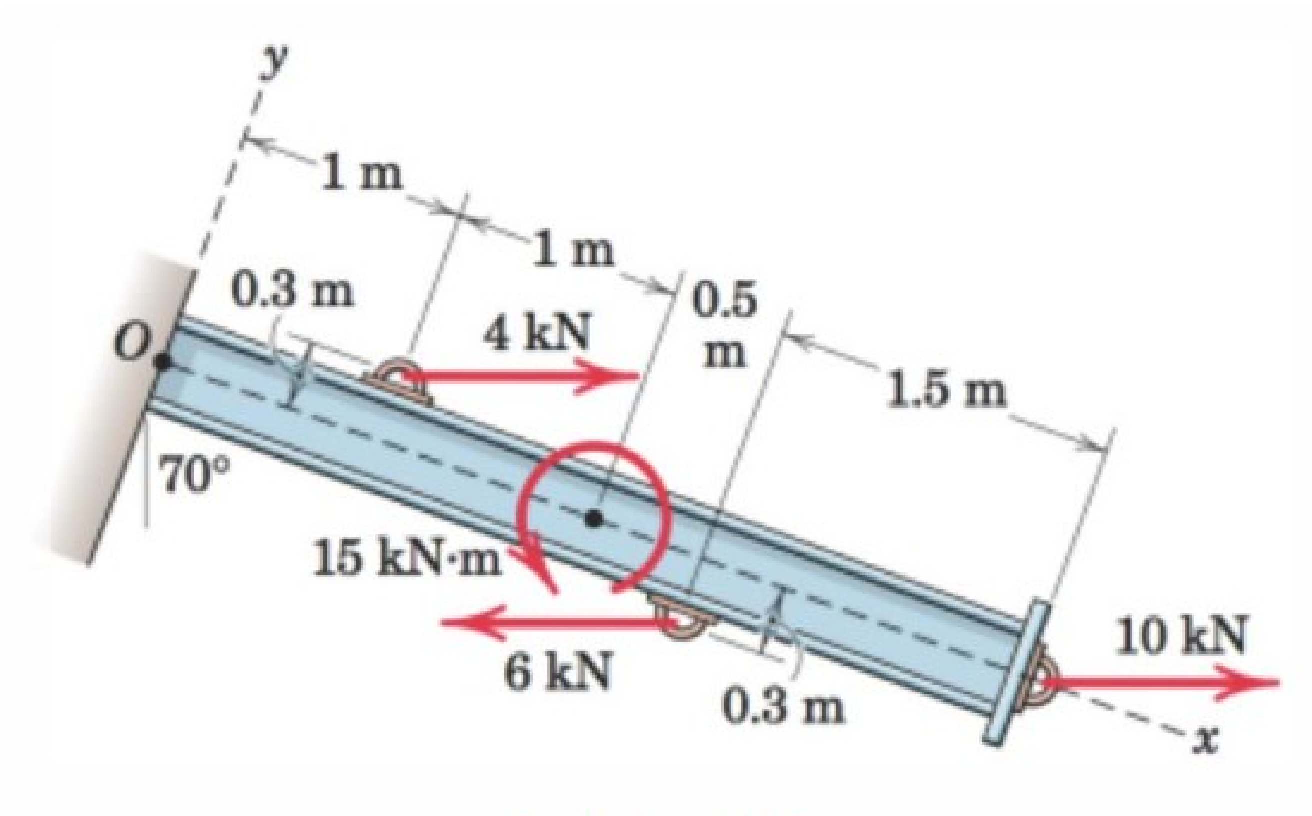
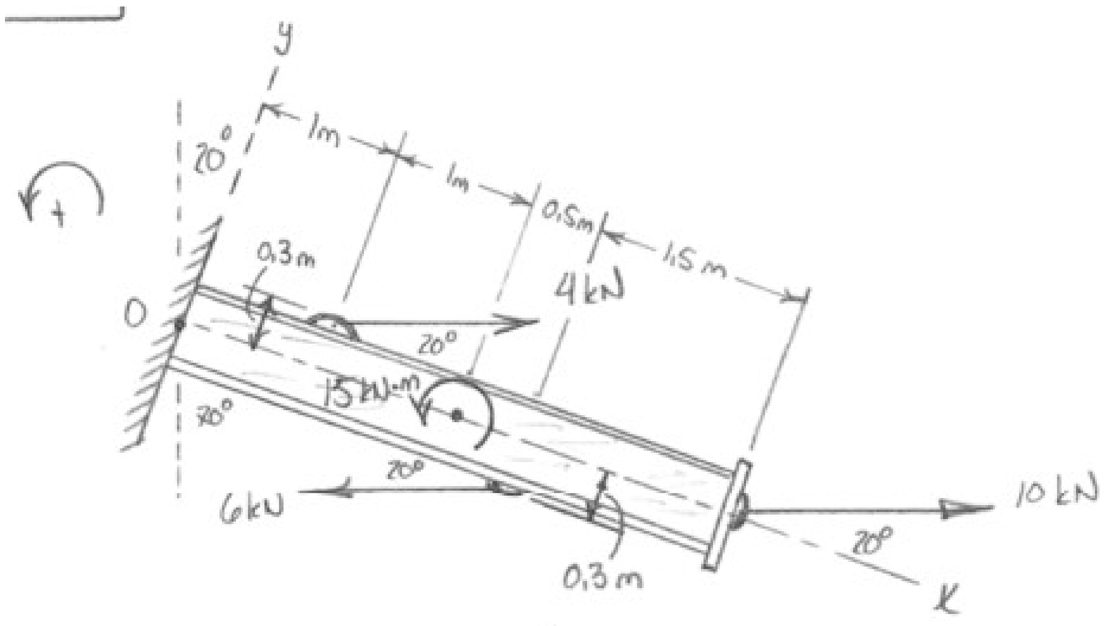
Unit - 1
Resultant

2/81 Replace the three horizontal forces and applied couple with an equivalent force-couple system at 0 by specifying the resultant R and couple M_0. Next, determine the equation for the line of action of the stand-alone resultant force R.



Problem 2/81

2/81 cont..



$R = 10 + 4 - 6 \longrightarrow R = 8\ kN$

$\underline{R} = 8\cos 20°\ \underline{i} + 8\sin 20°\ \underline{j} \longrightarrow \underline{R} = 7.52\ \underline{i} + 2.74\ \underline{j}\ kN$

• Line-of-Action:

$\underline{r} \times \underline{R} = \underline{M}_o \longrightarrow (x\underline{i} + y\underline{j}) \times (7.52\underline{i} + 2.74\underline{j}) = 22.1\ \underline{k}$

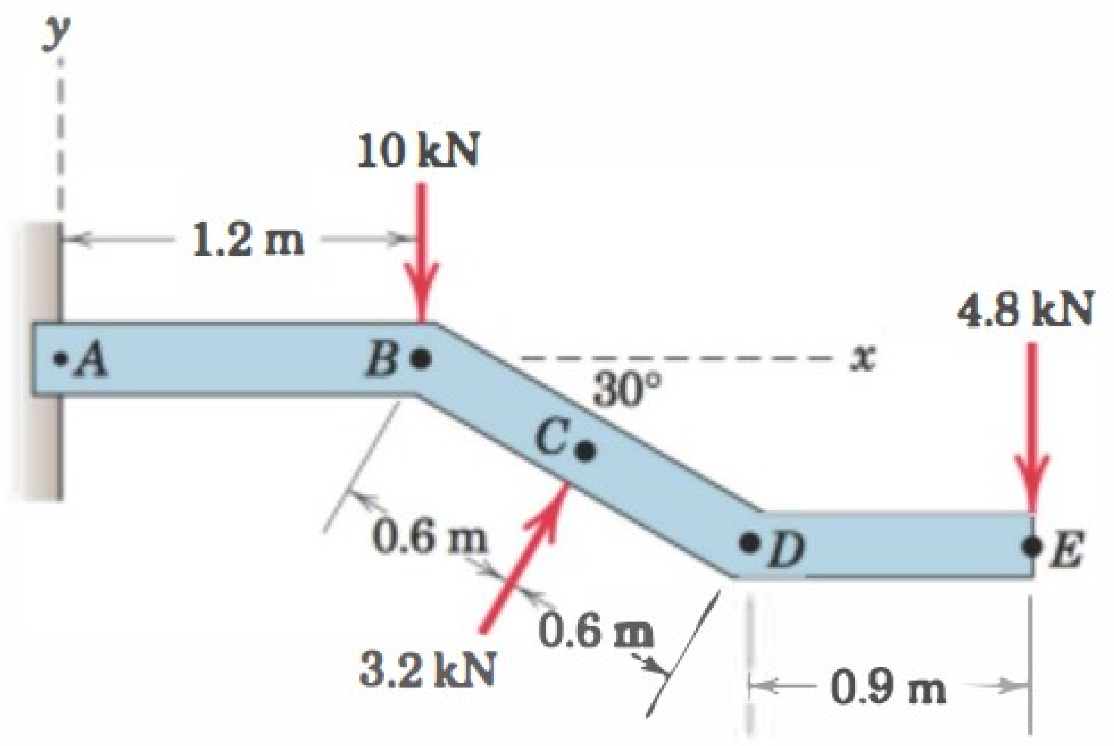
$\underline{k}: \quad 2.74x - 7.52y = 22.1$

$\therefore \quad y = 0.364x - 2.94\ (m)$

Mo = 15 + 4sin20(1) - 6sin20(2.5) + 10sin20(4) – 4cos20(0.3) – 6cos20(0.3)

Mo = 22.1 kN-m CCW

2/91 Replace the three forces which act on the bent bar by a force-couple system at the support point A. Then determine the x-intercept of the line of action of the stand-alone resultant force R.



Problem 2/91

2/91 Equivalent force-couple system at A:

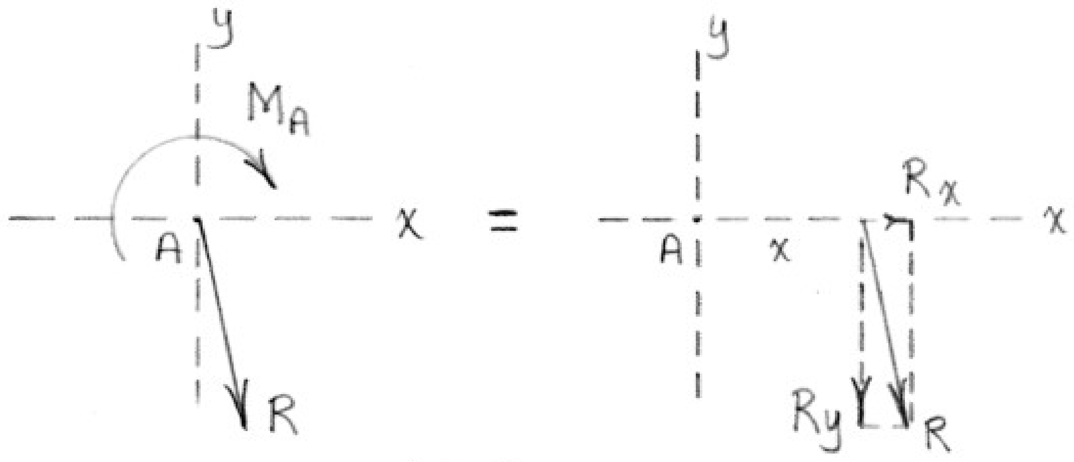
$$\underline{R} = -10\underline{j} - 4.8\underline{j} + 3.2(\sin 30^\circ \underline{i} + \cos 30^\circ \underline{j})$$

$$= \underline{1.6\underline{i} - 12.03\underline{j} \text{ kN}}$$

$$+\circlearrowright M_A = 10(1.2) + 4.8(1.2 + 1.2\cos 30^\circ + 0.9)$$

$$-3.2\sin 30^\circ(0.6\sin 30^\circ) - 3.2\cos 30^\circ(1.2 + 0.6\cos 30^\circ)$$

$$= \underline{21.8 \text{ kN}\cdot\text{m CW}}$$



Condition: $x|R_y| = M_A$

$$x = \frac{21.8}{12.03} = \underline{1.814 \text{ m}}$$

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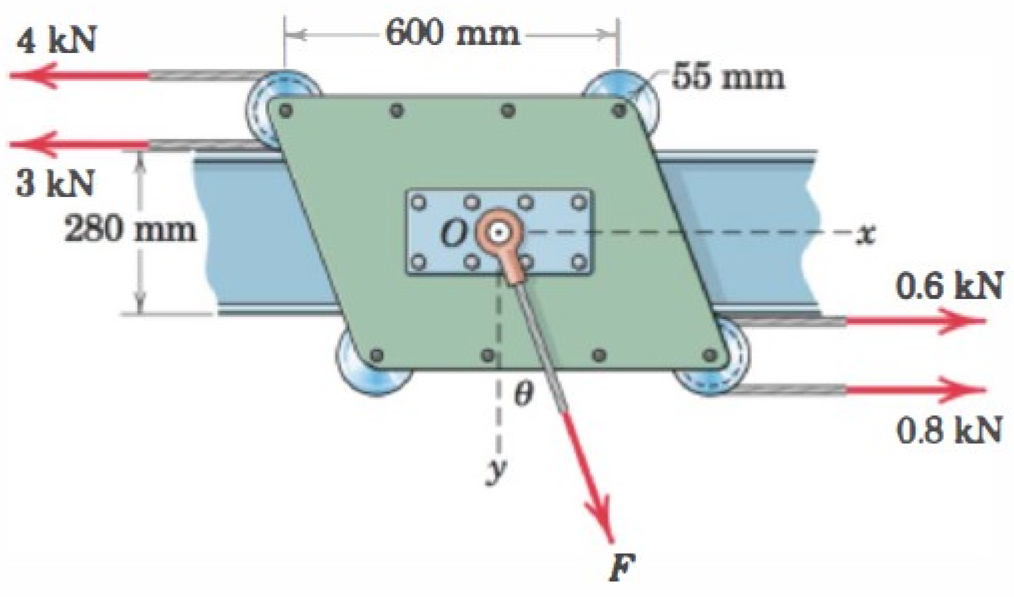
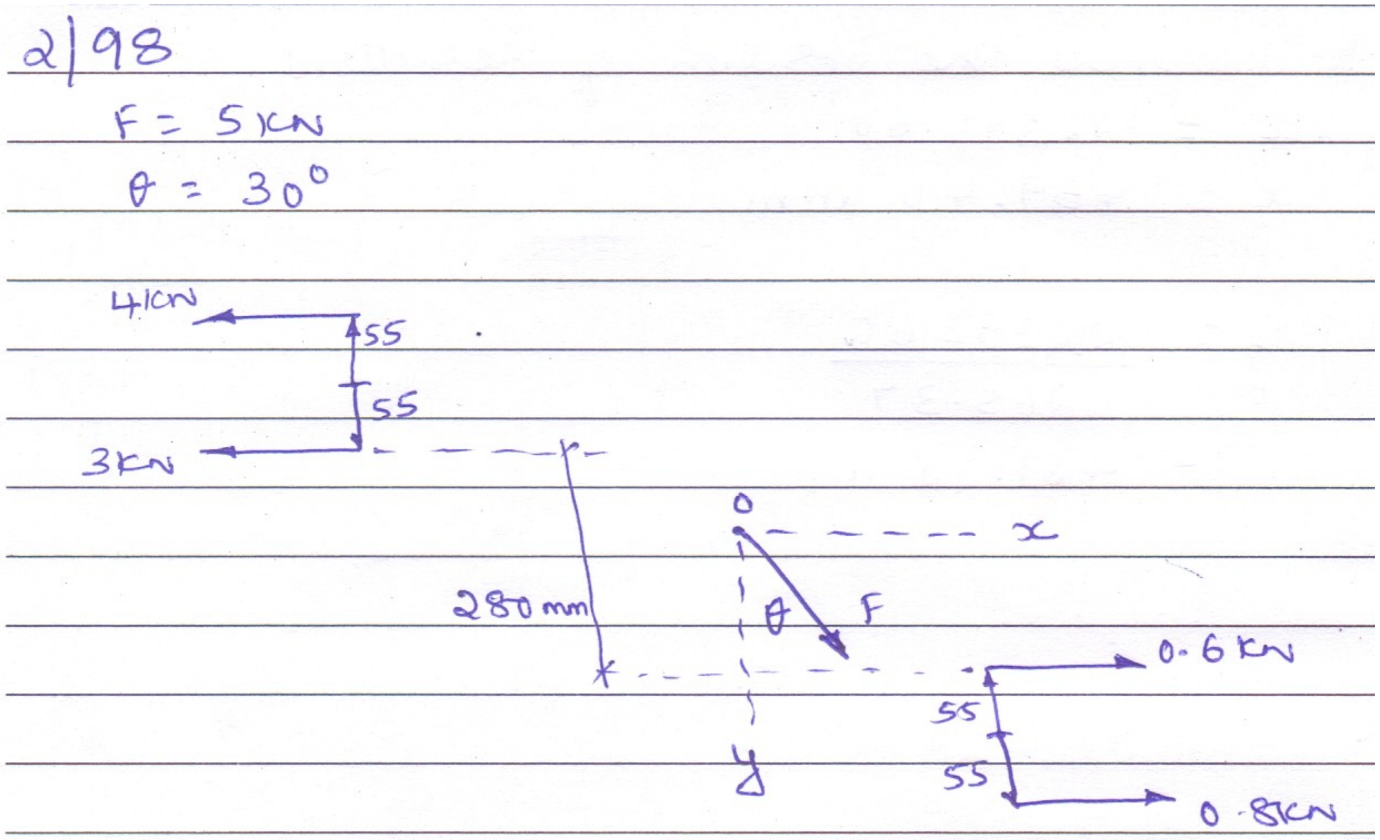
Unit - 1
Numerical on Resultant

2/98 Five forces are applied to the beam trolley as shown. Determine the coordinates of the point on the y-axis through which the stand-alone resultant R must pass if F = 5 kN and θ = 30°.



Problem 2/98



2/98 cont..

$$F_x = -4 - 3 + 0.6 + 0.8 + 5\sin 30^\circ = 3.1\ \text{KN}$$

$$F_y = 5\cos 30^\circ = 4.33\ \text{KN}$$

$$M_O = 4\left(\frac{280}{2} + 55 + 55\right) + 3\left(\frac{280}{2}\right) + 0.6\left(\frac{280}{2}\right) +$$

$$0.8\left(\frac{280}{2} + 55 + 55\right)$$

$$= 1000 + 420 + 84 + 200$$

$$= 1704\ \text{KN-mm}$$

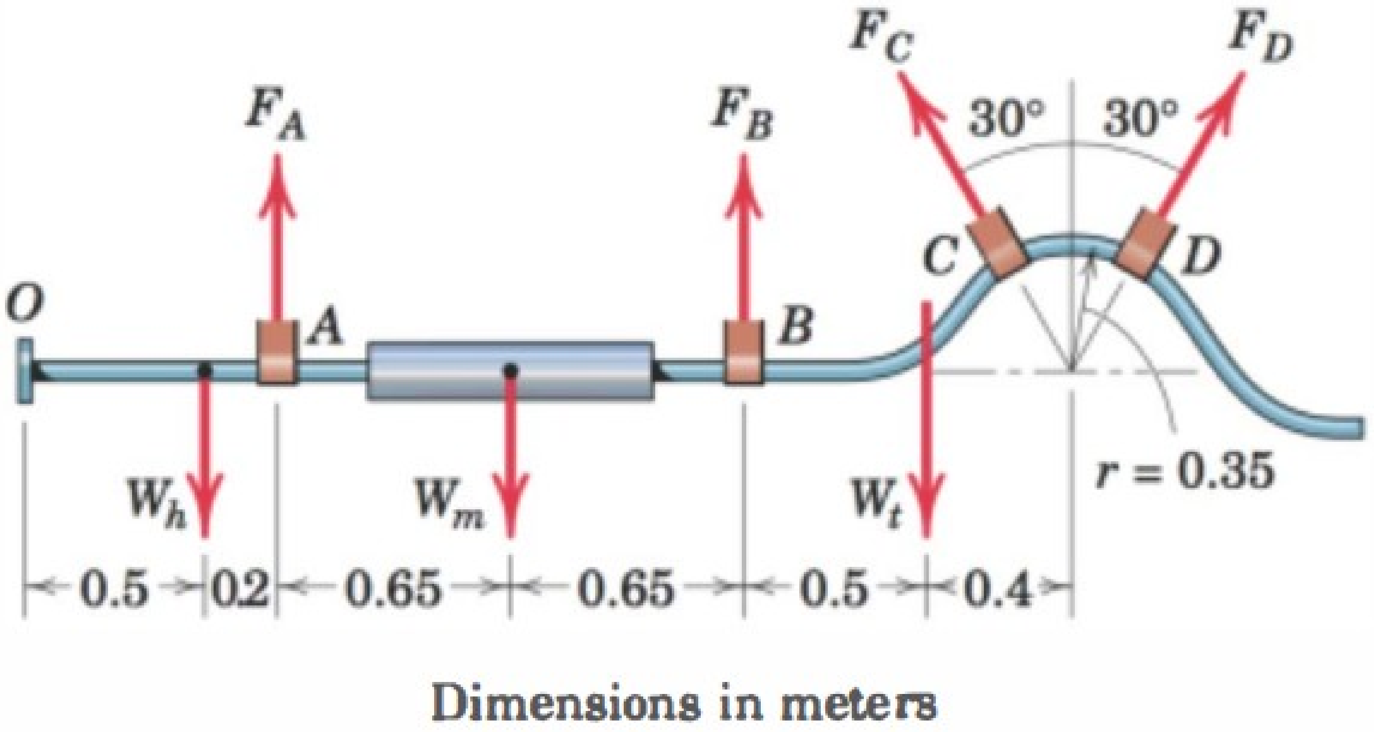
$$x = \frac{M_O}{R_y}$$

$$= \frac{1704}{4.33}$$

$$= 393.53\ \text{mm}$$

$$y = \frac{1704}{3.1} = 549.67\ \text{mm}$$

2/100 An exhaust system for a pickup truck is shown in the figure. The weights Wh, W m• and W1 of the headpipe, muffler, and tailpipe are 10, 100, and 50 , respectively, and act at the indicated points. If the exhaust-pipe hanger at point A is adjusted so that its tension FA is 50 N, determine the required forces in the hangers at points B, C, and D so that the force-couple system at point 0 is zero. Why is a zero force-couple system at 0 desirable?



Problem 2/100

2/100 For a zero force-couple system at point O:

$$\underline{R} = \Sigma \underline{F} = (-F_C \sin 30^\circ + F_D \sin 30^\circ)\underline{i} + (50 - 10 - 100 - 50 + F_B + F_C \cos 30^\circ + F_D \cos 30^\circ)\underline{j} = \underline{0}$$

$$\Rightarrow F_C = F_D = F$$

$$\circlearrowleft M_O = -10(0.5) + 50(0.7) - 100(1.35) + F_B(2) - 50(2.5) + 2F \cos 30^\circ (2.9) = 0$$

$$\underline{F = F_C = F_D = 6.42 \text{ N}}, \quad \underline{F_B = 98.9 \text{ N}}$$

THANK YOU

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