UMP OPEN COURSEWARE

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

CHAPTER 6

FRICTION

Expected Outcome:

- Able to analyze and solve problems involving dry friction using the concept of equilibrium of a particle or a rigid body

Application

Friction is both problematic and useful in many engineering applications, such as in tires and brakes.

Introduction

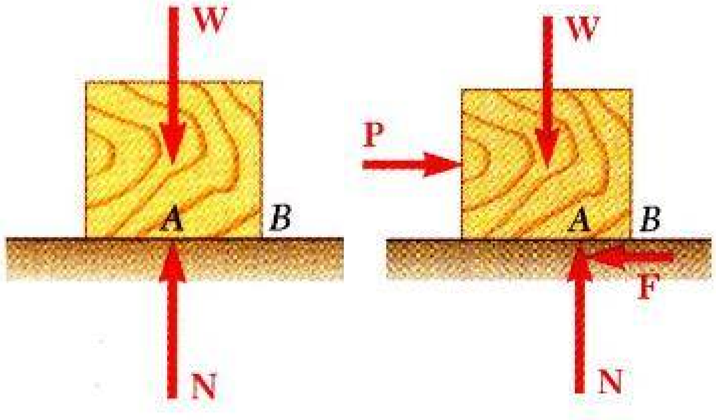
- In preceding chapters, it was assumed that surfaces in contact were either *frictionless* (surfaces could move freely with respect to each other) or *rough* (tangential forces prevent relative motion between surfaces).

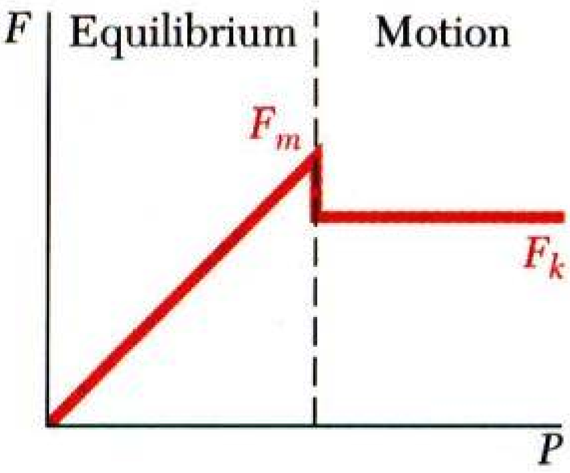
- Actually, no perfectly frictionless surface exists. For two surfaces in contact, tangential forces, called *friction forces*, will develop if one attempts to move one relative to the other.

- Types of friction:
- *dry* or *Coulomb friction*
- *fluid friction*

In this chapter, only dry friction will be consider

The Laws of Dry Friction. Coefficients of Friction





- Block of weight **W** is placed on a horizontal surface. Forces acting on the block are its weight and reaction of surface **N**.

- Small horizontal force **P** is applied. For the block to remain stationary, in equilibrium, a horizontal component **F** of the surface reaction is required. **F** is a *static-friction force*.

- As **P** increases, the static-friction force **F** increases as well until it reaches a maximum value F_m. μ_S is coefficient of static friction.

$$F_m = \mu_s N$$

- Further increase in **P** causes the block to begin to move as **F** drops to a smaller *kinetic-friction force* $\mathbf{F}_k$. μ_K is coefficient of kinetic friction.

$$F_k = \mu_k N$$

The Laws of Dry Friction. Coefficients of Friction

Table 8.1. Approximate Values of Coefficient of Static Friction for Dry Surfaces

Metal on metal	0.15–0.60
Metal on wood	0.20–0.60
Metal on stone	0.30–0.70
Metal on leather	0.30–0.60
Wood on wood	0.25–0.50
Wood on leather	0.25–0.50
Stone on stone	0.40–0.70
Earth on earth	0.20–1.00
Rubber on concrete	0.60–0.90

- Maximum static-friction force:

$$F_m = \mu_s N$$

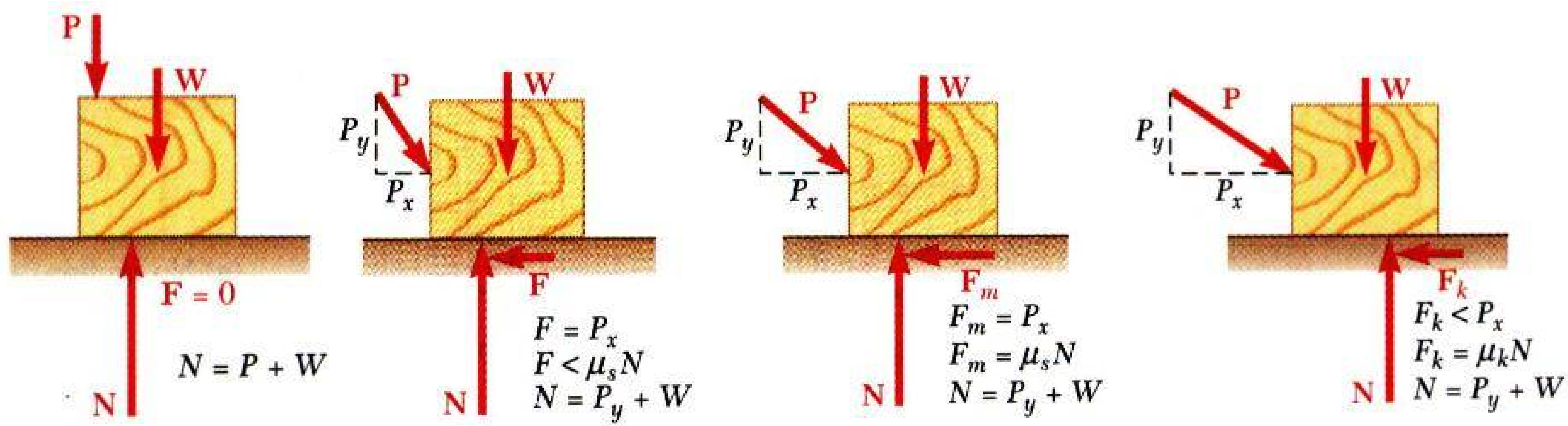
- Kinetic-friction force:

$$F_k = \mu_k N$$

$$\mu_k \cong 0.75 \mu_s$$

- Maximum static-friction force and kinetic-friction force are:
  - proportional to normal force
  - dependent on type and condition of contact surfaces
  - independent of contact area

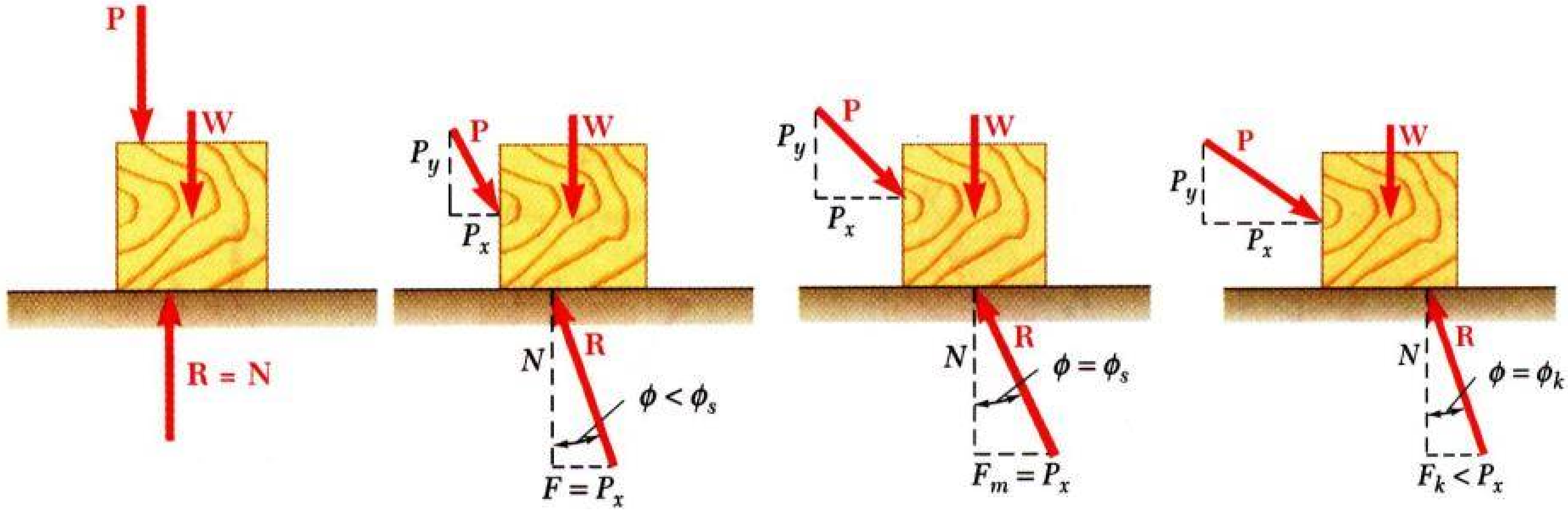
The Laws of Dry Friction. Coefficients of Friction



- No friction, ($P_x = 0$)
- No motion, ($P_x < F$)
- Motion impending, ($P_x = F_m$)
- Motion, ($P_x > F_m$)

Angles of Friction

- It is sometimes convenient to replace normal force **N** and friction force **F** by their resultant **R**:



- No friction
- No motion
- Motion impending
- Motion

$$\tan\phi_s = \frac{F_m}{N} = \frac{\mu_s N}{N}$$

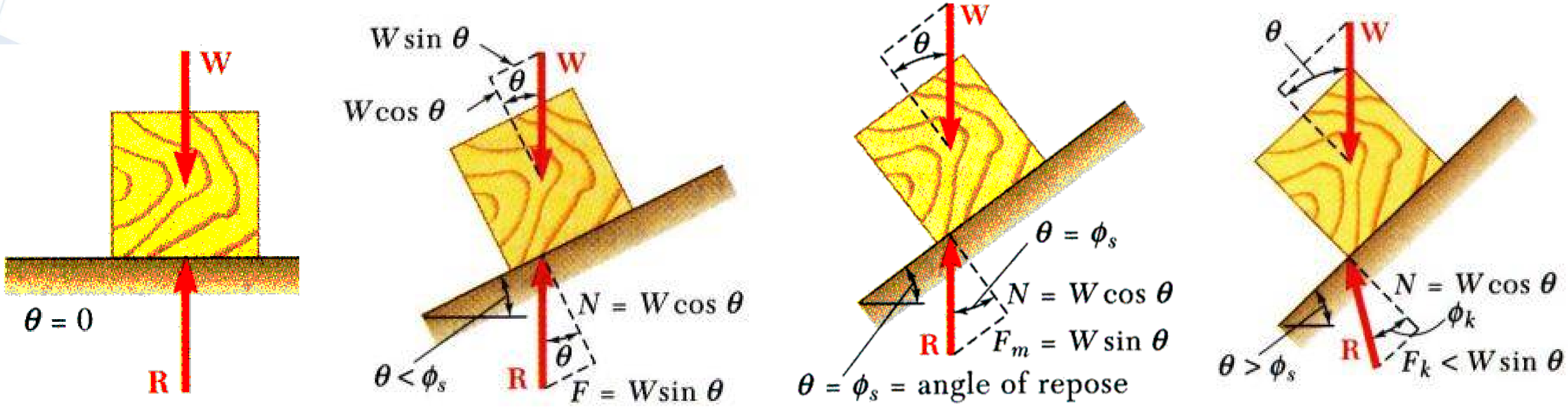
$$\tan\phi_s = \mu_s$$

$$\tan\phi_k = \frac{F_k}{N} = \frac{\mu_k N}{N}$$

$$\tan\phi_k = \mu_k$$

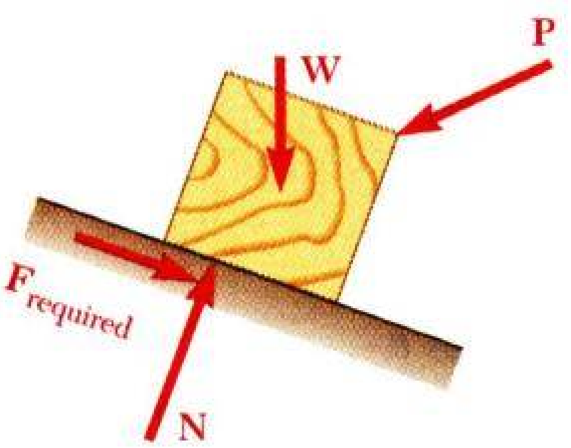
Angles of Friction

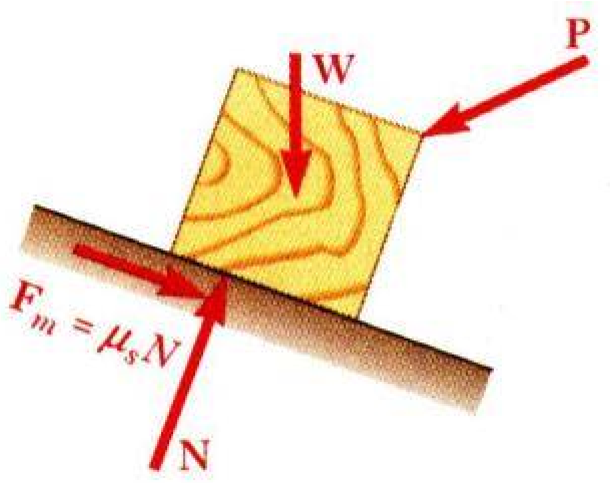
- Consider block of weight **W** resting on board with variable inclination angle θ.

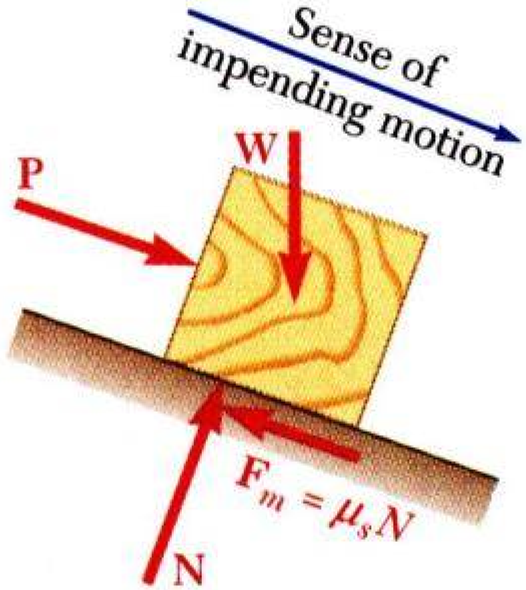


- No friction
- No motion
- Motion impending
- Motion

Problems involving Dry Friction





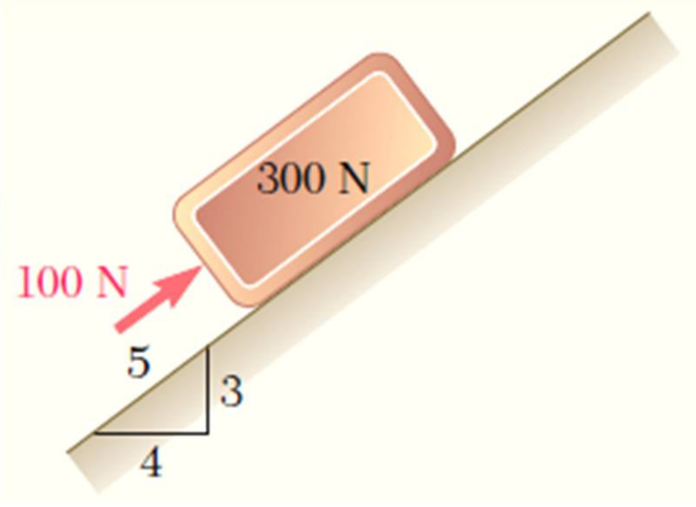


- All applied forces known
- Coefficient of static friction is known
- Determine whether body will remain at rest or slide

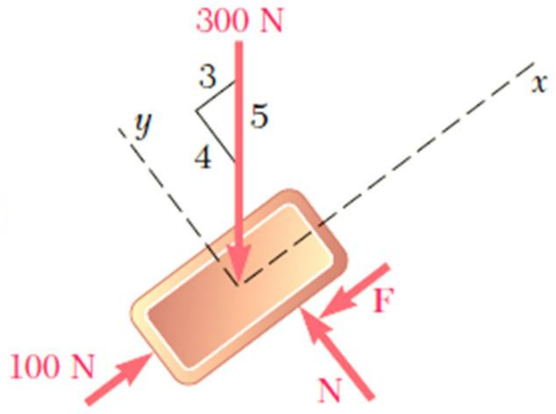
- All applied forces known
- Motion is impending
- Determine value of coefficient of static friction.

- Coefficient of static friction is known
- Motion is impending
- Determine magnitude or direction of one of the applied forces

Sample Problem 8.1



A 100-N force acts as shown on a 300-N block placed on an inclined plane. The coefficients of friction between the block and plane are $\mu_s = 0.25$ and $\mu_k = 0.20$. Determine whether the block is in equilibrium and find the value of the friction force.



1. Draw the FBD of the system

2. Determine values of friction force and normal reaction force from plane required to maintain equilibrium.

$$\sum F_x = 0: \quad 100\ \text{N} - \tfrac{3}{5}(300\ \text{N}) - F = 0$$

$$F = -80\ \text{N}$$

$$\sum F_y = 0: \quad N - \tfrac{4}{5}(300\ \text{N}) = 0$$

$$N = 240\ \text{N}$$

What does the sign tell you about the assumed direction of impending motion?

Answer: (-ve) sign shows that your first assumption on the force direction is wrong

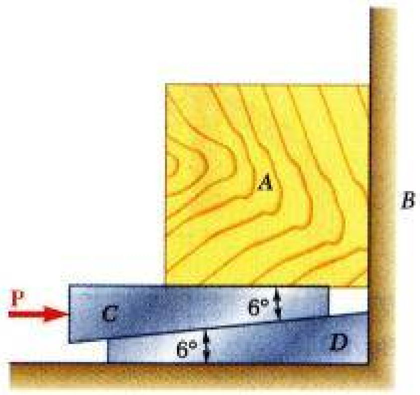
3. Calculate maximum friction force and compare with friction force required for equilibrium.

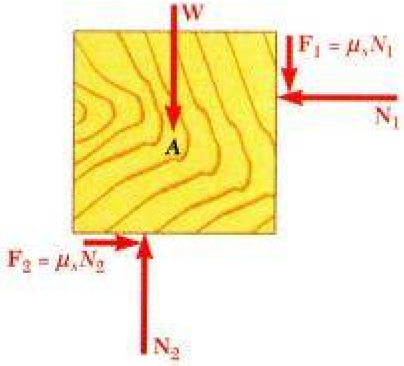
$$F_m = \mu_s N = 0.25(240\ \text{N}) = 60\ \text{N}$$

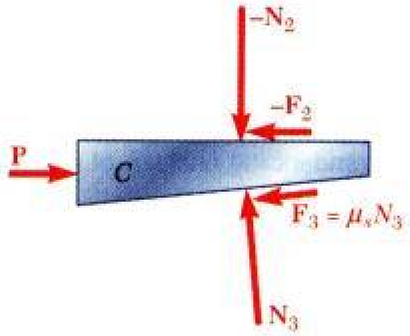
4. What does this solution imply about the block?

The block will slide down the plane as the Fm is smaller than the force required to maintain the block in equiblirium

Wedges







- *Wedges* - simple machines used to raise heavy loads.
- Force required to lift block is significantly less than block weight.
- Friction prevents wedge from sliding out.
- Want to find minimum force **P** to raise block.

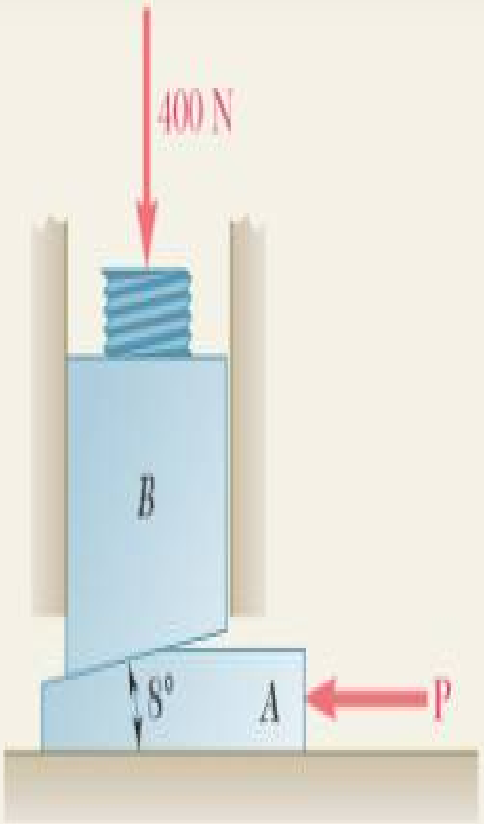
- Block as free body

$$\sum F_x = 0:$$
$$-N_1 + \mu_s N_2 = 0$$
$$\sum F_y = 0:$$
$$-W - \mu_s N_1 + N_2 = 0$$

- Wedge as free body

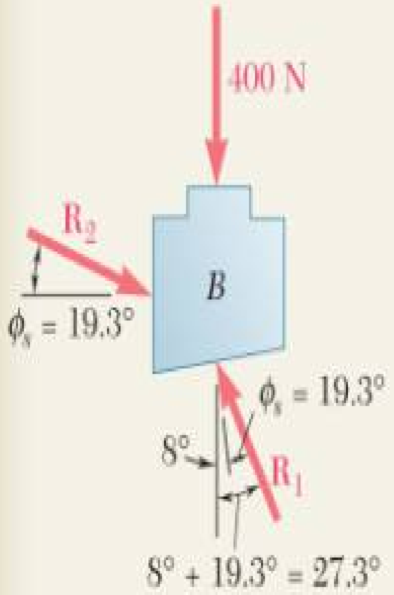
$$\sum F_x = 0:$$
$$-\mu_s N_2 - N_3(\mu_s \cos 6° + \sin 6°)$$
$$+P = 0$$
$$\sum F_y = 0:$$
$$-N_2 + N_3(\cos 6° - \mu_s \sin 6°) = 0$$

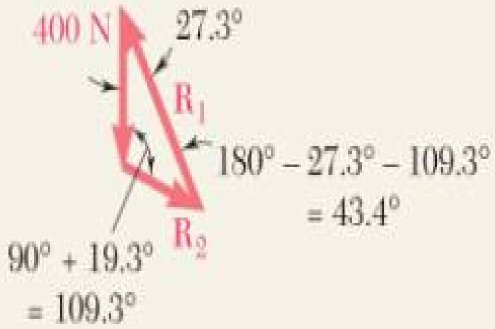
SAMPLE PROBLEM 8.4



The position of the machine block *B* is adjusted by moving the wedge *A*. Knowing that the coefficient of static friction is 0.35 between all surfaces of contact, determine the force **P** required (*a*) to raise block *B*, (*b*) to lower block *B*.

For each part, the free-body diagrams of block B and wedge A are drawn, together with the corresponding force triangles, and the law of sines is used to find the desired forces. We note that since $\mu_s = 0.35$, the angle of friction is





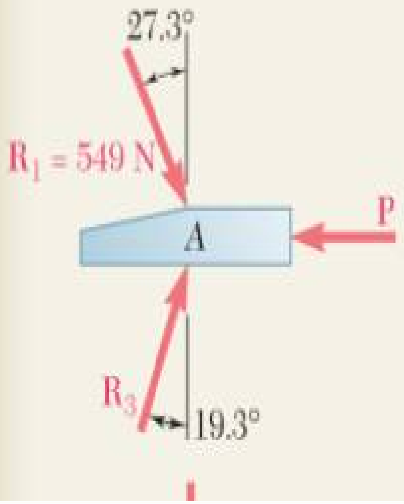
$$\phi_s = \tan^{-1} 0.35 = 19.3°$$

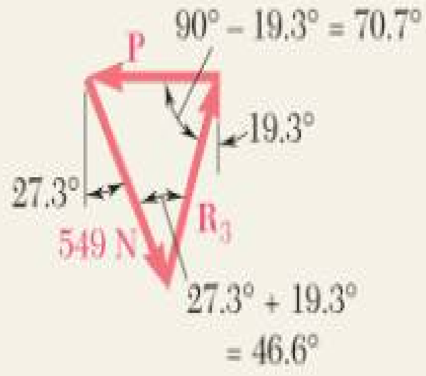
a. Force P to Raise Block

Free Body: Block B

$$\frac{R_1}{\sin 109.3°} = \frac{400\text{ N}}{\sin 43.4°}$$

$$R_1 = 549\text{N}$$





Free Body: Wedge A

$$\frac{P}{\sin 46.6°} = \frac{549\text{ N}}{\sin 70.7°}$$

$P = 423$ N **P** = 423 N ←

References:

1. Beer, Ferdinand P.; Johnston, E. Russell; “Vector Mechanics for Engineers - Statics”, 8th Ed., McGraw-Hill, Singapore, 2007.