ME 141

Engineering Mechanics

Lecture 7: Friction

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Courtesy: Vector Mechanics for Engineers, Beer and Johnston

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).

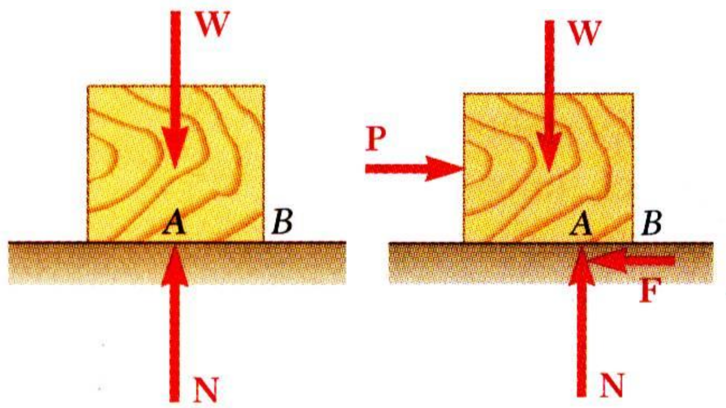
- Actually, no perfectly frictionless surface exists. For two surfaces in contact, tangential forces, called *friction forces*, will develop if one attempts to move one relative to the other.

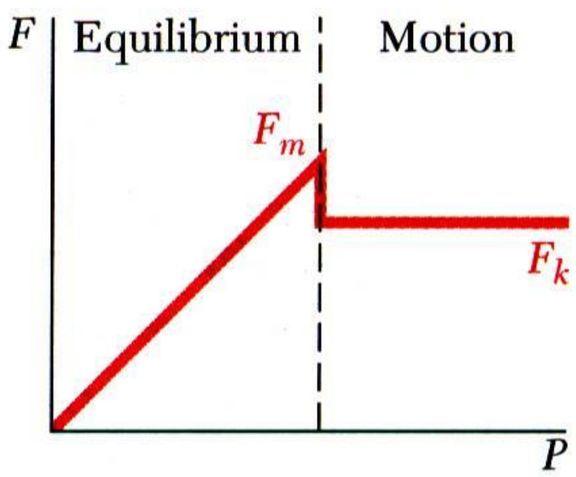
- However, the friction forces are limited in magnitude and will not prevent motion if sufficiently large forces are applied.

- The distinction between frictionless and rough is, therefore, a matter of degree.

- There are two types of friction: *dry* or *Coulomb friction* and *fluid friction*. Fluid friction applies to lubricated mechanisms. The present discussion is limited to dry friction between nonlubricated surfaces.

The Laws of Dry Friction. Coefficients of Friction





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

- Small horizontal force *P* applied to block. For 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.

$$F_m = \mu_s N$$

- Further increase in P causes the block to begin to move as *F* drops to a smaller *kinetic-friction force* F_k.

$$F_k = \mu_k N$$

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:

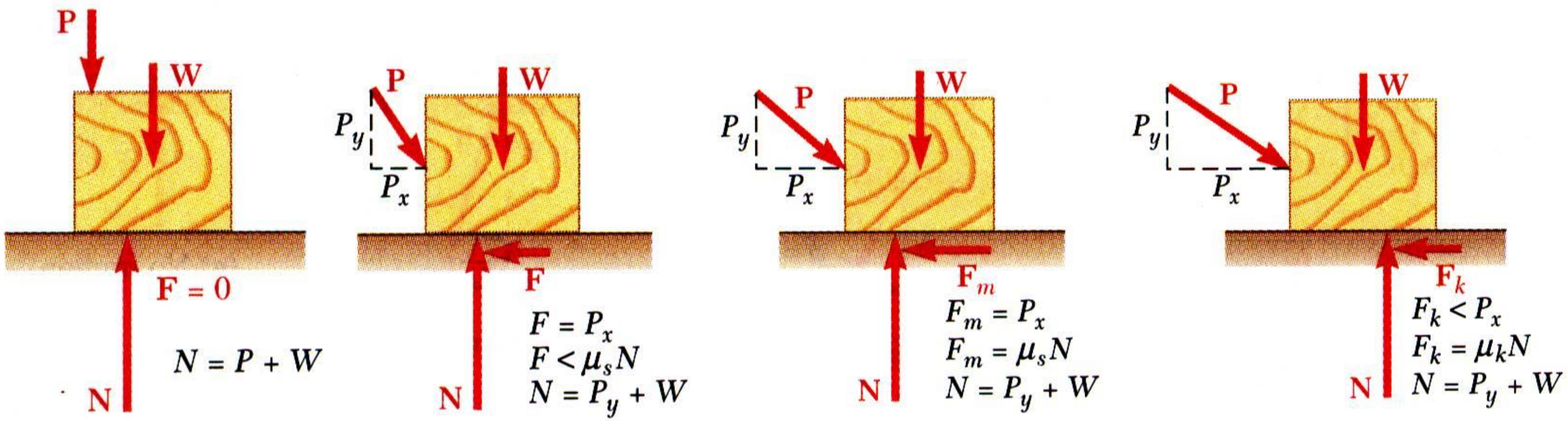
$$F_k = \mu_k N$$

$$\mu_k \cong 0.75 \mu_s$$

- 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

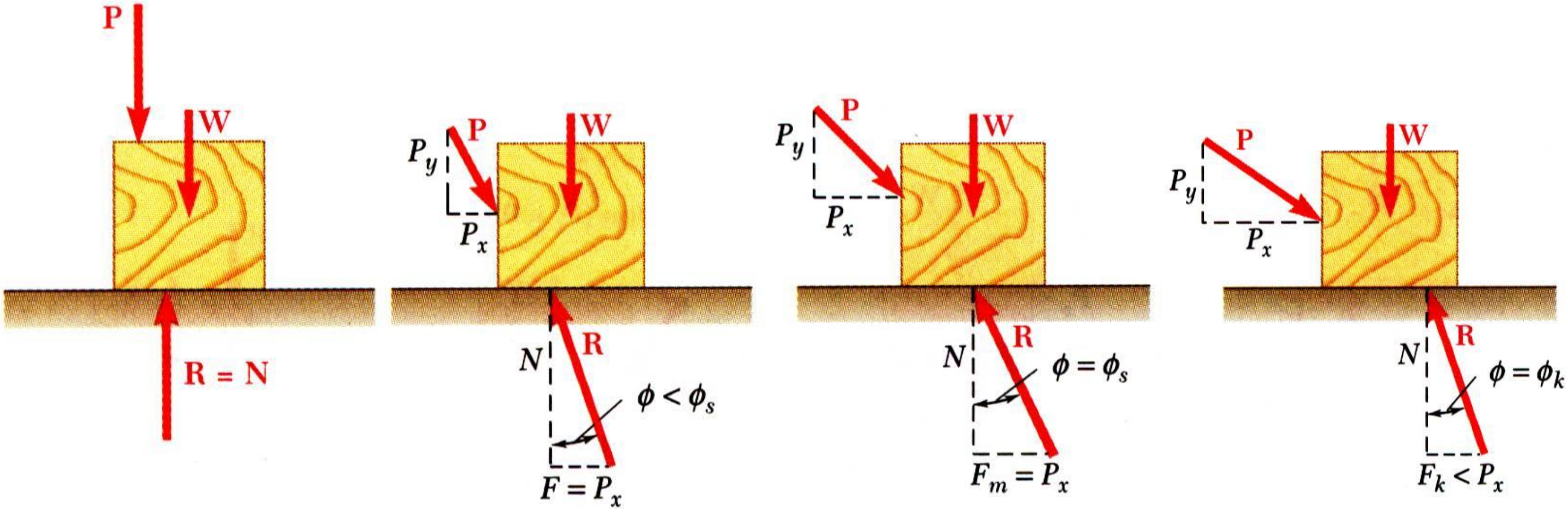
- Four situations can occur when a rigid body is in contact with a horizontal surface:



- No friction, ($P_x = 0$)
- No motion, ($P_x < F_m$)
- 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

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

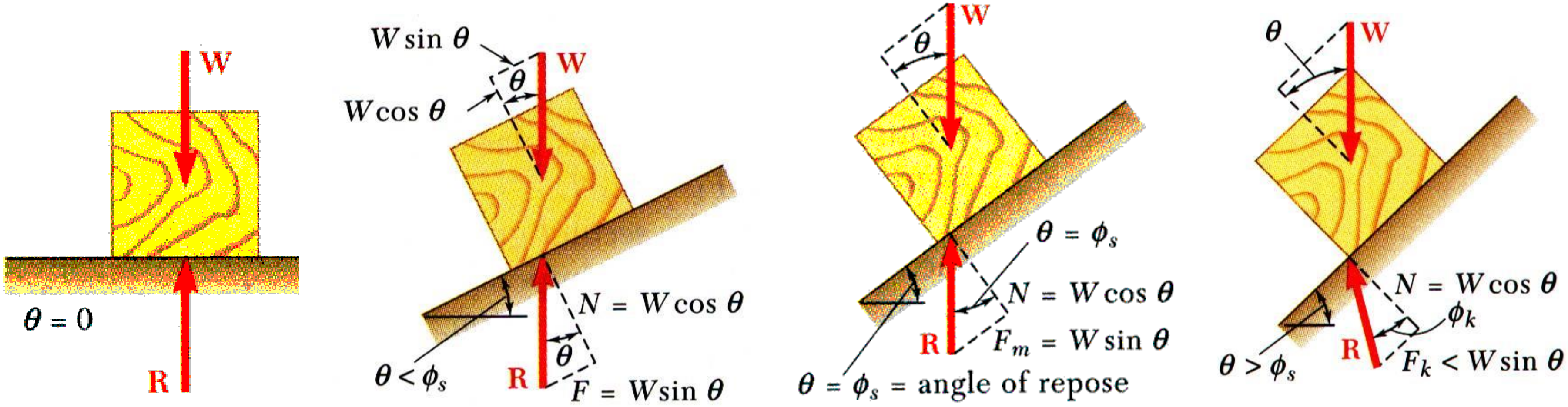
$$\tan \phi_s = \mu_s$$

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

$$\tan \phi_k = \mu_k$$

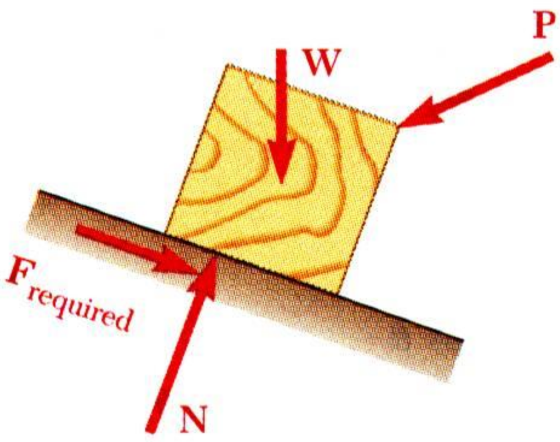
Angles of Friction

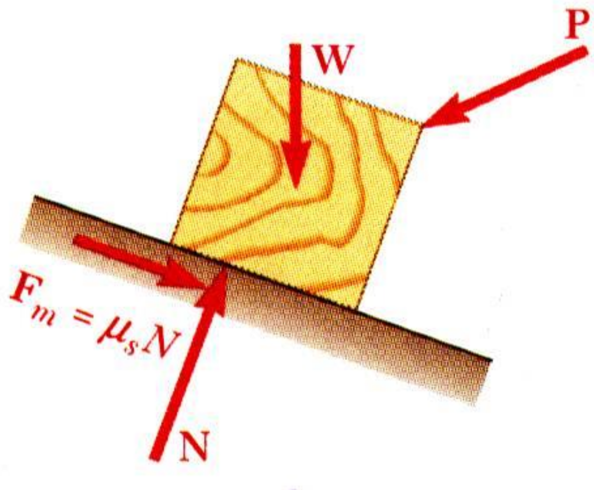
- Consider block of weight *W* resting on board with variable inclination angle θ.

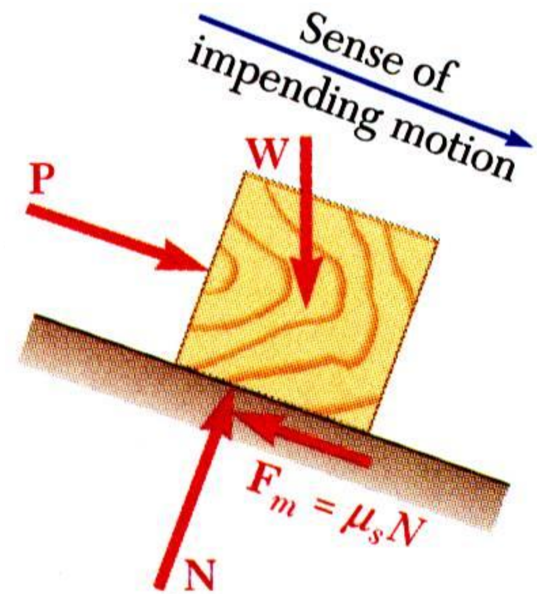


- No friction
- No motion
- Motion impending
- Motion

Problems Involving Dry Friction





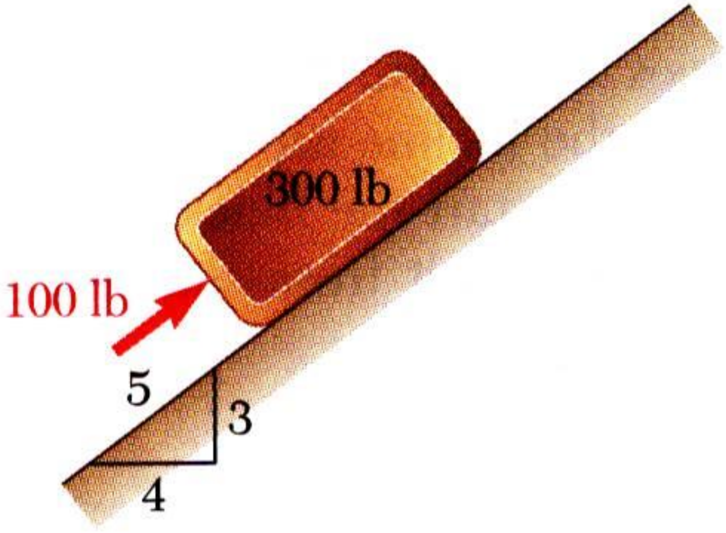


- All applied forces known
- Coefficient of static friction is known
- Determine whether body will remain at rest or slide

- 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

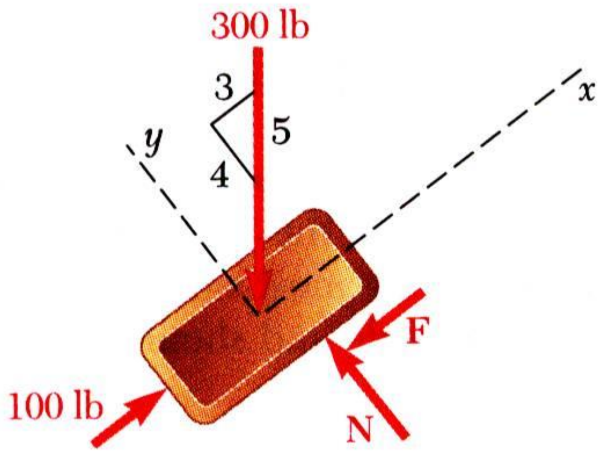


A 100 lb force acts as shown on a 300 lb block placed on an inclined plane. The coefficients of friction between the block and plane are $\mu_s = 0.25$ and $\mu_k = 0.20$. Determine whether the block is in equilibrium and find the value of the friction force.

SOLUTION:

- Determine values of friction force and normal reaction force from plane required to maintain equilibrium.
- Calculate maximum friction force and compare with friction force required for equilibrium. If it is greater, block will not slide.
- If maximum friction force is less than friction force required for equilibrium, block will slide. Calculate kinetic-friction force.

Sample Problem 8.1



SOLUTION:

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

$$\sum F_x = 0: \qquad 100\,\text{lb} - \tfrac{3}{5}(300\,\text{lb}) - F = 0$$

$$F = -80\,\text{lb}$$

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

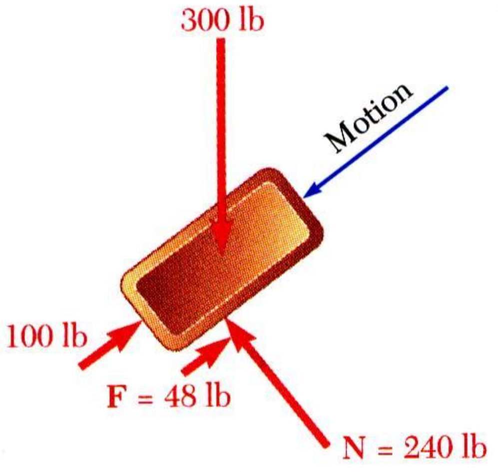
$$N = 240\,\text{lb}$$

- Calculate maximum friction force and compare with friction force required for equilibrium. If it is greater, block will not slide.

$$F_m = \mu_s N \qquad F_m = 0.25(240\,\text{lb}) = 48\,\text{lb}$$

The block will slide down the plane.

Sample Problem 8.1



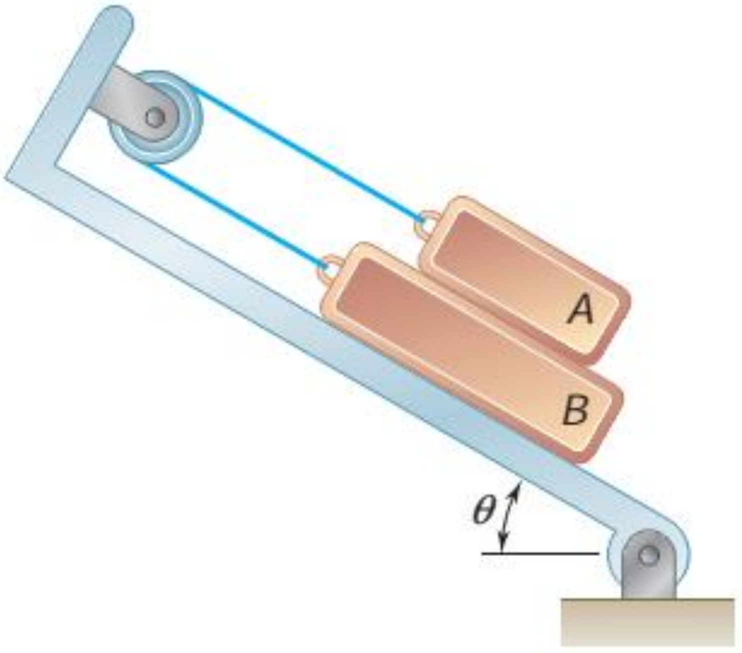
- If maximum friction force is less than friction force required for equilibrium, block will slide. Calculate kinetic-friction force.

$$F_{actual} = F_k = \mu_k N$$
$$= 0.20(240\text{ lb})$$

$$\boxed{F_{actual} = 48\text{ lb}}$$

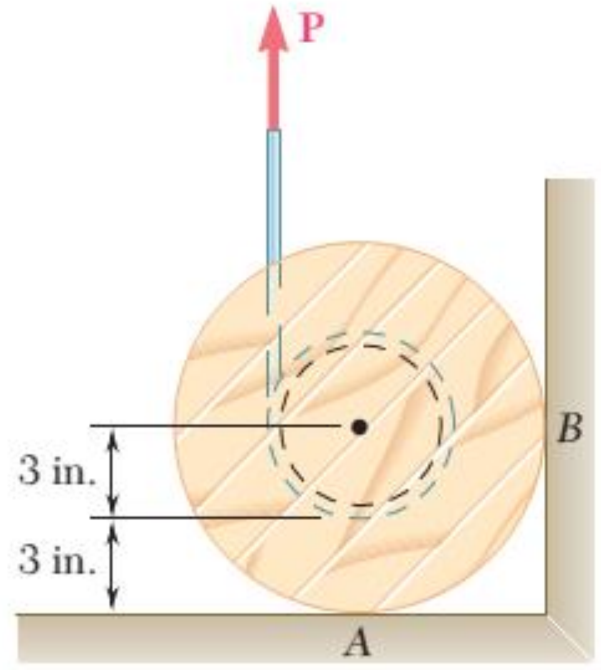
Prob # 8.12

The 20-lb block A and the 30-lb block B are supported by an incline that is held in the position shown. Knowing that the coefficient of static friction is 0.15 between all surfaces of contact, determine the value of θ for which motion is impending.

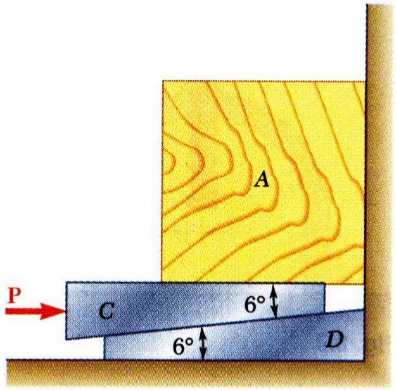


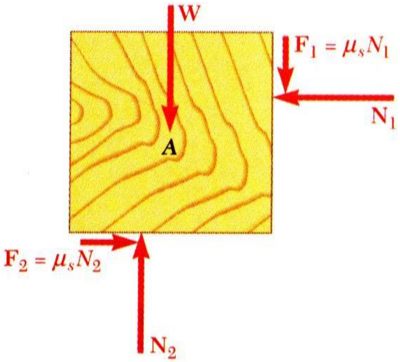
Prob # 8.19

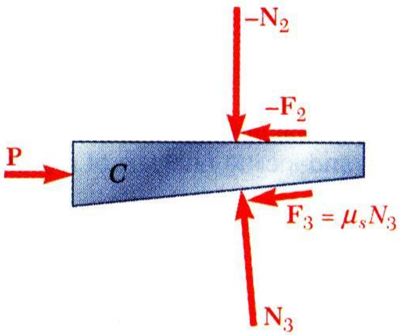
Wire is being drawn at a constant rate from a spool by applying a vertical force P to the wire as shown. The spool and the wire wrapped on the spool have a combined weight of 20 lb. Knowing that the coefficients of friction at both A and B are $\mu_s = 0.40$ and $\mu_k = 0.30$, determine the required magnitude of the force P.



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

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

or

$$\vec{R}_1 + \vec{R}_2 + \vec{W} = 0$$

- Wedge as free-body

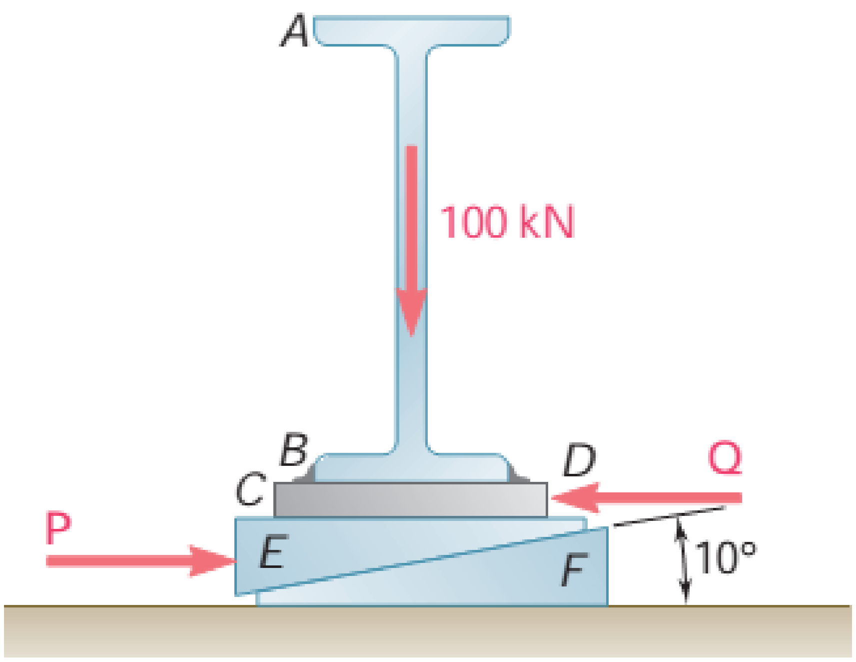
$$\sum F_x = 0:$$
$$-\mu_s N_2 - N_3(\mu_s \cos 6° - \sin 6°) + P = 0$$
$$\sum F_y = 0:$$
$$-N_2 + N_3(\cos 6° - \mu_s \sin 6°) = 0$$

or

$$\vec{P} - \vec{R}_2 + \vec{R}_3 = 0$$

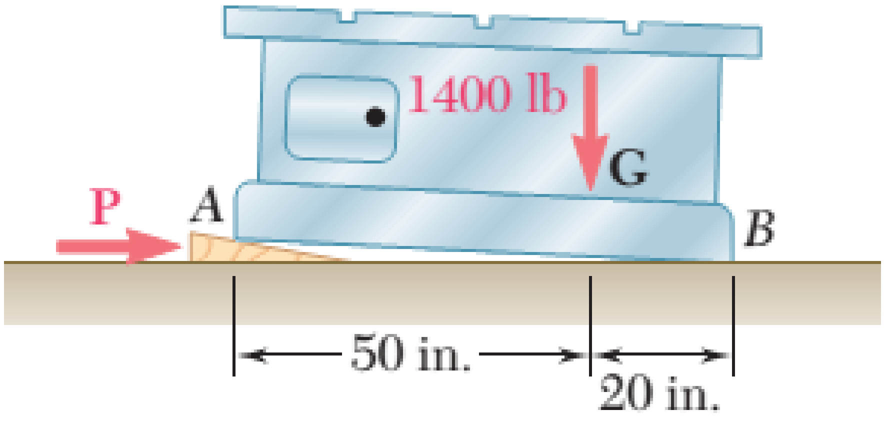
Prob # 8.50

The elevation of the end of the steel beam supported by a concrete floor is adjusted by means of the steel wedges E and F. The base plate CD has been welded to the lower flange of the beam, and the end reaction of the beam is known to be 100 kN. The coefficient of static friction is 0.30 between two steel surfaces and 0.60 between steel and concrete. If the horizontal motion of the beam is prevented by the force Q, determine (a) the force P required to raise the beam, (b) the corresponding force Q



Prob # 8.62

A 5º wedge is to be forced under a 1400-lb machine base at A. Knowing that the coefficient of static friction at all surfaces is 0.20, (a) determine the force P required to move the wedge, (b) indicate whether the machine base will move.



Prob # 8.65

A 15 ^{o} wedge is forced under a 50-kg pipe as shown. Knowing that the coefficient of static friction at both surfaces of the wedge is 0.20, determine the largest coefficient of static friction between the pipe and the vertical wall for which slipping will occur at A