Physics 111: Mechanics
Lecture 5

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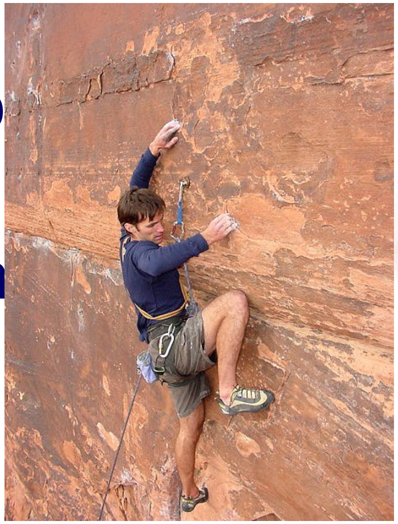
Forces of Friction: f

- When an object is in motion
  viscous medium, there will b
  motion. This resistance is ca



- This is due to the interaction
  its environment
- Force of static friction: f_s
- Force of kinetic friction: f_k
- Direction: parallel along the surface, opposite the direction of the intended motion
  - in direction opposite velocity if moving
  - in direction vector sum of other forces if stationary

You are walking on a level floor. You are getting good traction, so the soles of your shoes don’t slip on the floor.

Which of the following forces *should* be included in a free-body diagram for your body?

A. the force of kinetic friction that the floor exerts on your shoes

B. the force of static friction that the floor exerts on your shoes

C. the force of kinetic friction that your shoes exert on the floor

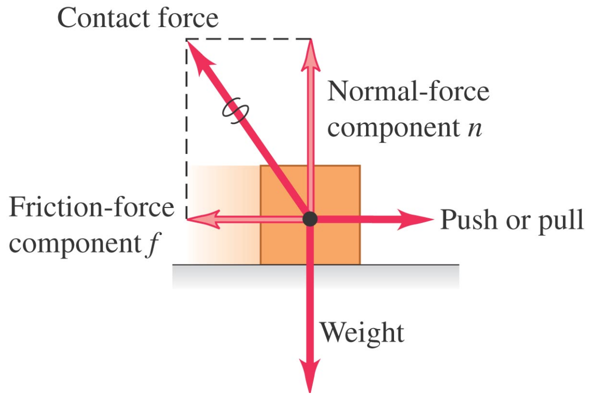
D. the force of static friction that your shoes exert on the floor

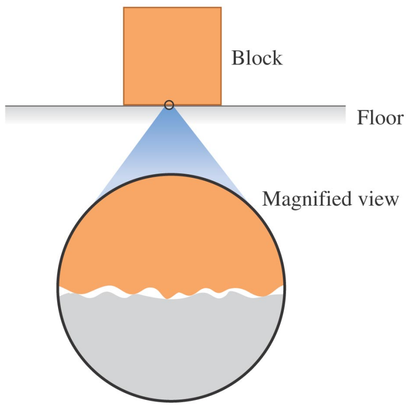
E. more than one of these

Frictional forces

- When a body rests or slides on a surface, the *friction force* is parallel to the surface.
- Friction between two surfaces arises from interactions between molecules on the surfaces.

The friction and normal forces are really components of a single contact force.





On a microscopic level, even smooth surfaces are rough; they tend to catch and cling.

Forces of Friction: *Magnitude*

- Magnitude: Friction is proportional to the normal force
  - Static friction: $F_f = F \leq \mu_s N$
  - Kinetic friction: $F_f = \mu_k N$
  - μ is the **coefficient of friction**
- The coefficients of friction are nearly independent of the area of contact

TABLE 5.1

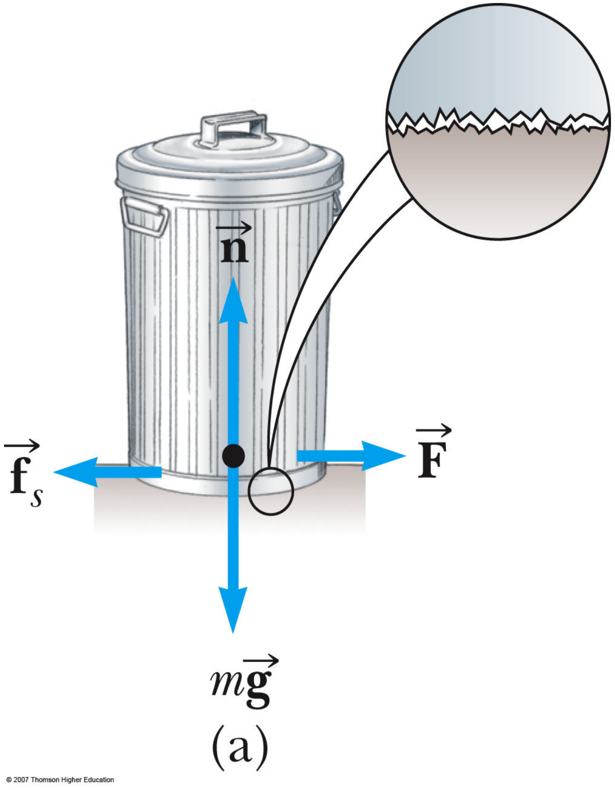
Coefficients of Friction

	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

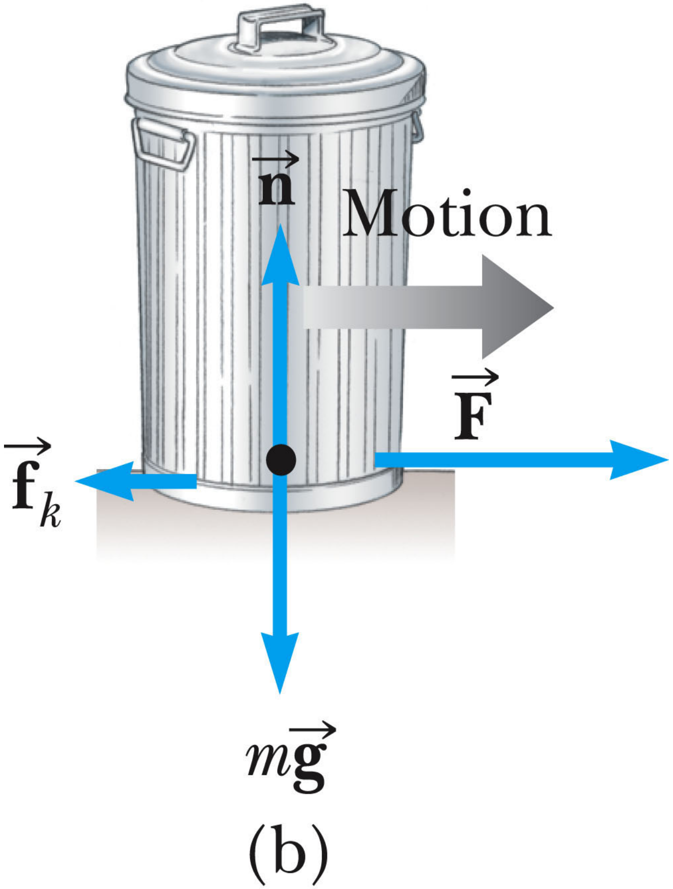
Static Friction

- Static friction acts to keep the object from moving
- If $\vec{\mathbf{F}}$ increases, so does $\vec{f}_s$
- If $\vec{\mathbf{F}}$ decreases, so does $\vec{f}_s$
- $f_s \le \mu_s N$
  - Remember, the equality holds only when the surfaces are on the verge of slipping

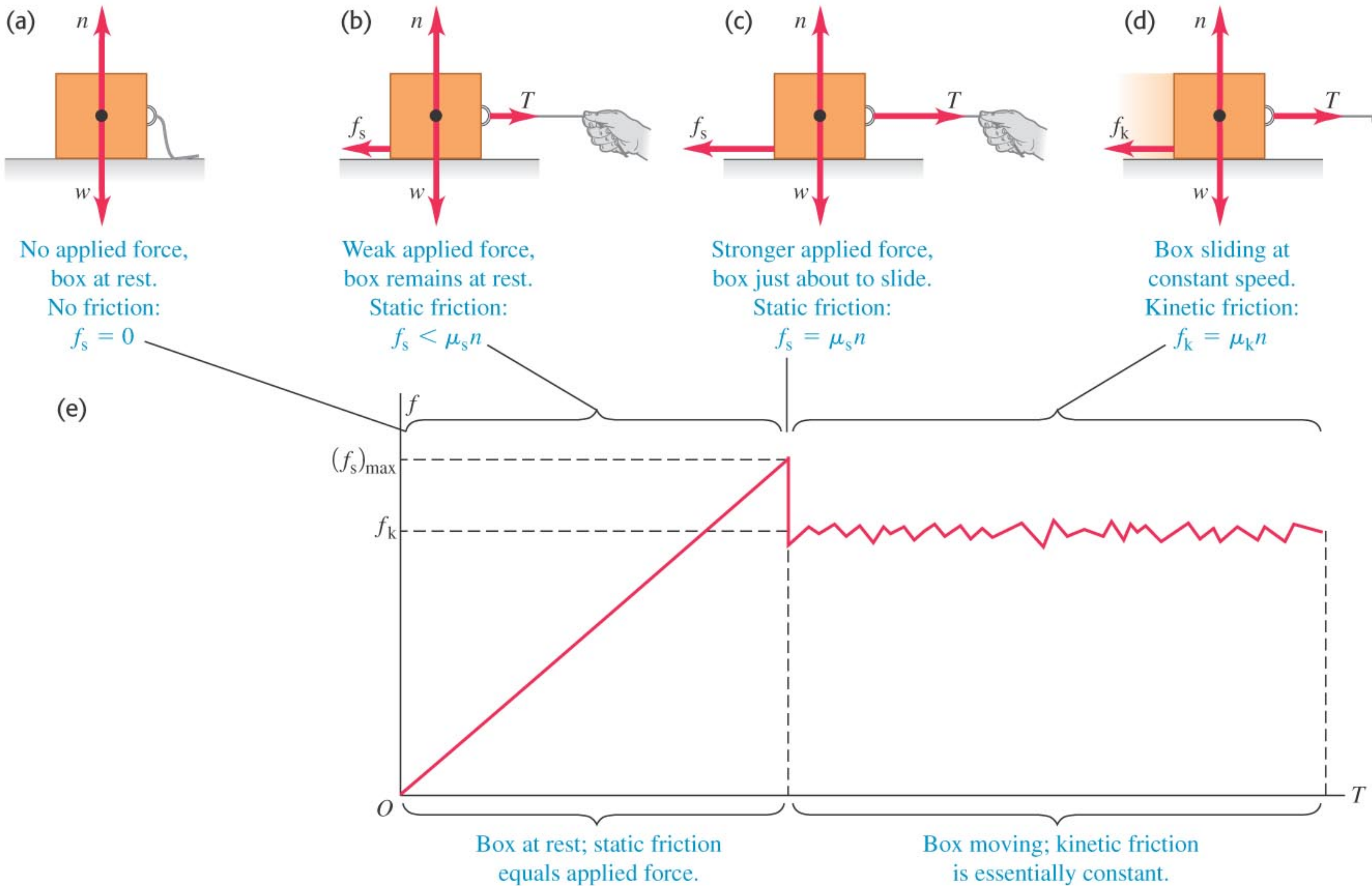


Kinetic Friction

- The force of kinetic friction acts when the object is in motion
- Although μ_k can vary with speed, we neglect any such variations in this class
- $f_k = \mu_k N$

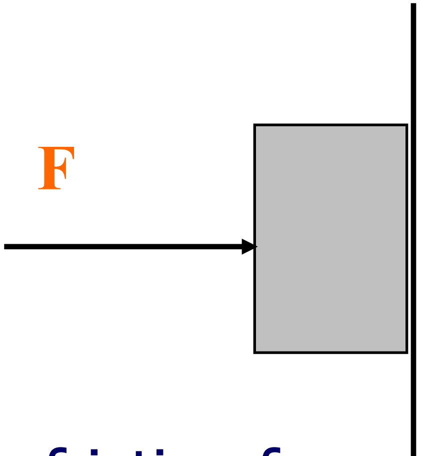


Explore Forces of Friction



Free Body Diagram

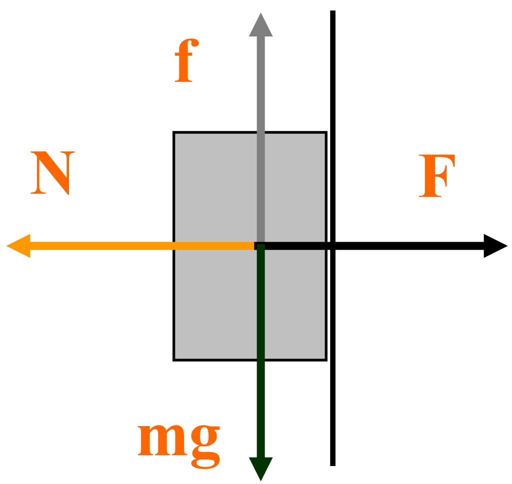
- A force F is applied on a block such that the block will not slide down the wall. How many forces are on the block?

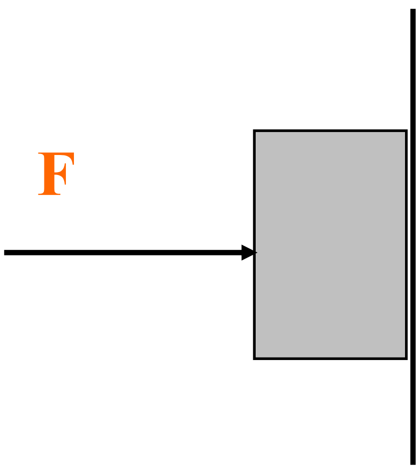


A) Only external force F
B) Gravity and F
C) Gravity, F, and normal force
D) Gravity, F, normal force and static friction force
E) Gravity, F, normal force and kinetic friction force

Equilibrium, Example 1

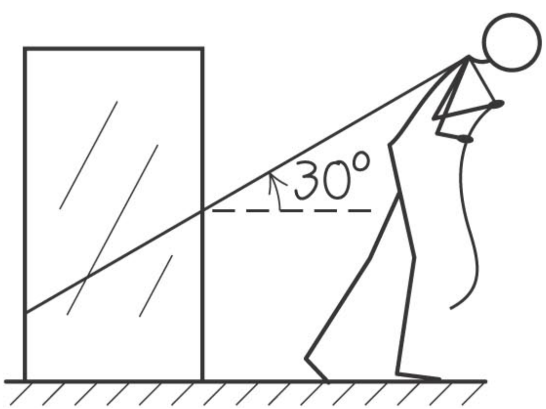
- What is the smallest value of the force F such that the 2.0-kg block will not slide down the wall? The coefficient of static friction between the block and the wall is 0.2.

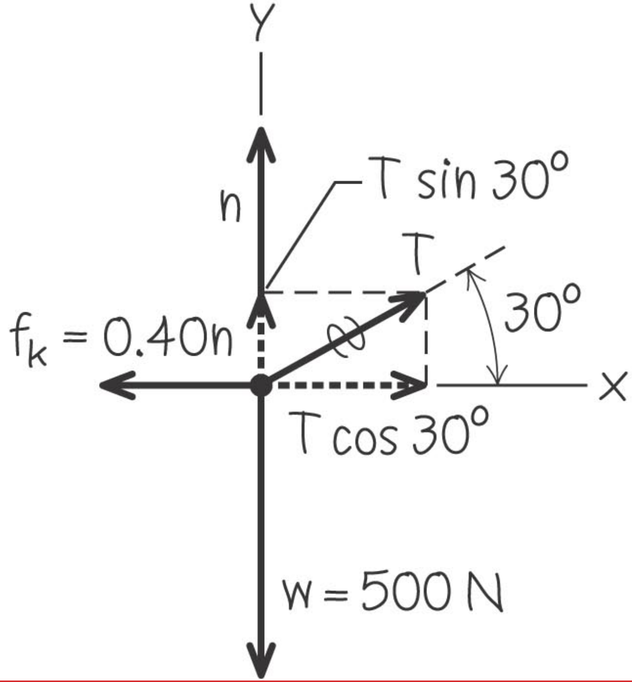




Pulling a crate at an angle

- How hard should you pull to make it move at a constant speed?
- The angle of the pull affects the normal force, which in turn affects the friction force.





Pulling a crate at an angle

From equilibrium conditions:

$$\sum F_x = T\cos 30° + (-f_k) = 0 \quad \text{so} \quad T\cos 30° = \mu_k n$$
$$\sum F_y = T\sin 30° + n + (-w) = 0 \quad \text{so} \quad n = w - T\sin 30°$$

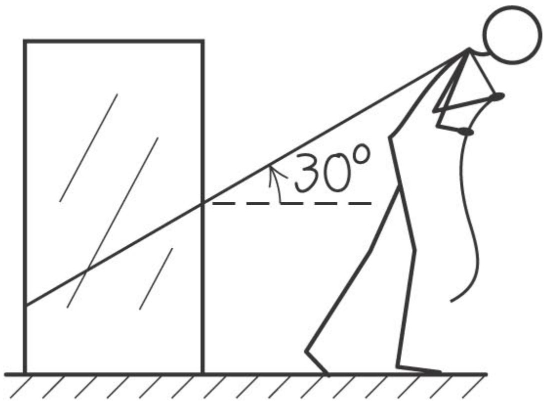
Substitute n in Eq. 1 with Eq. 2,

and solve for T

$$T\cos 30° = \mu_k(w - T\sin 30°)$$

$$T = \frac{\mu_k w}{\cos 30° + \mu_k \sin 30°} = 188\ \text{N}$$

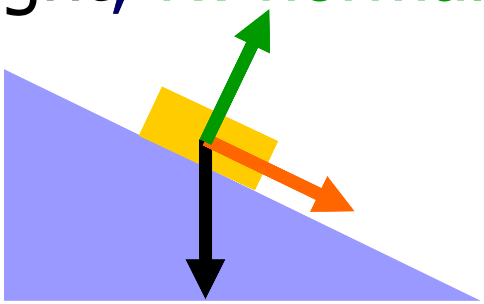
(a) Pulling a crate at an angle



Free Body Diagram

- Which diagram can represent the drawing free-body diagram for the block on a ramp? (mg: weight; N: normal force; f: friction force)

A)



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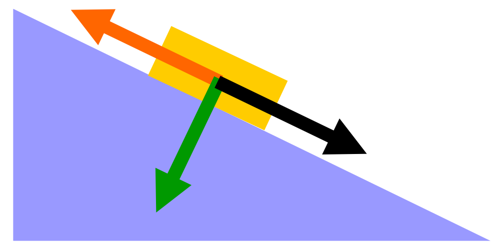
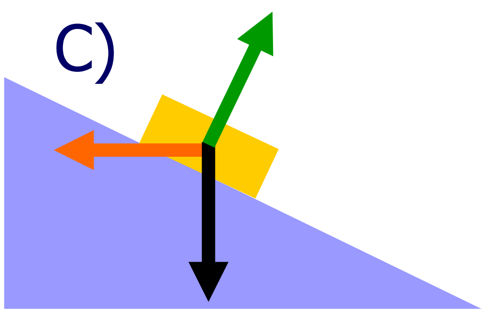
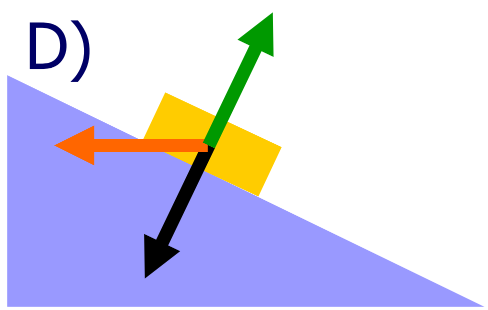


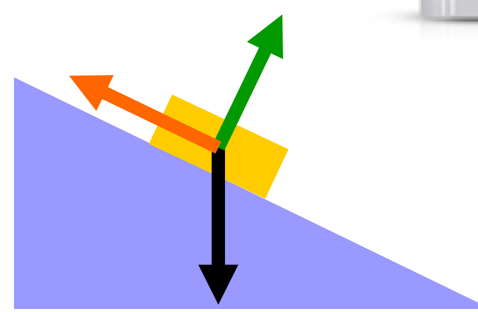
C)



D)

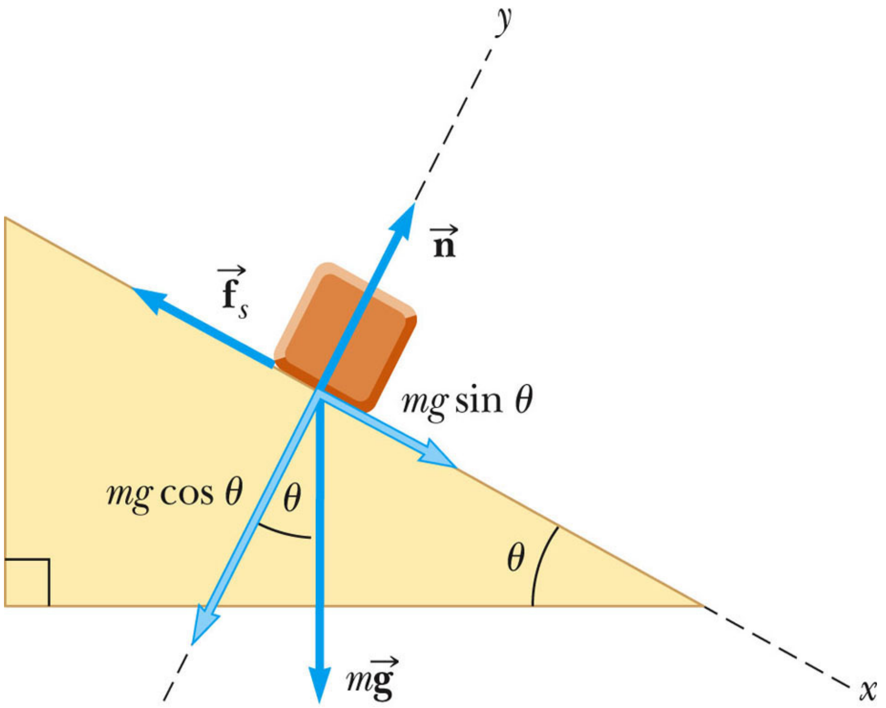


E)



Inclined Plane

- Suppose a block with a mass of 2.50 kg is resting on a ramp. If the coefficient of static friction between the block and ramp is 0.350, what maximum angle can the ramp make with the horizontal before the block starts to slip down?

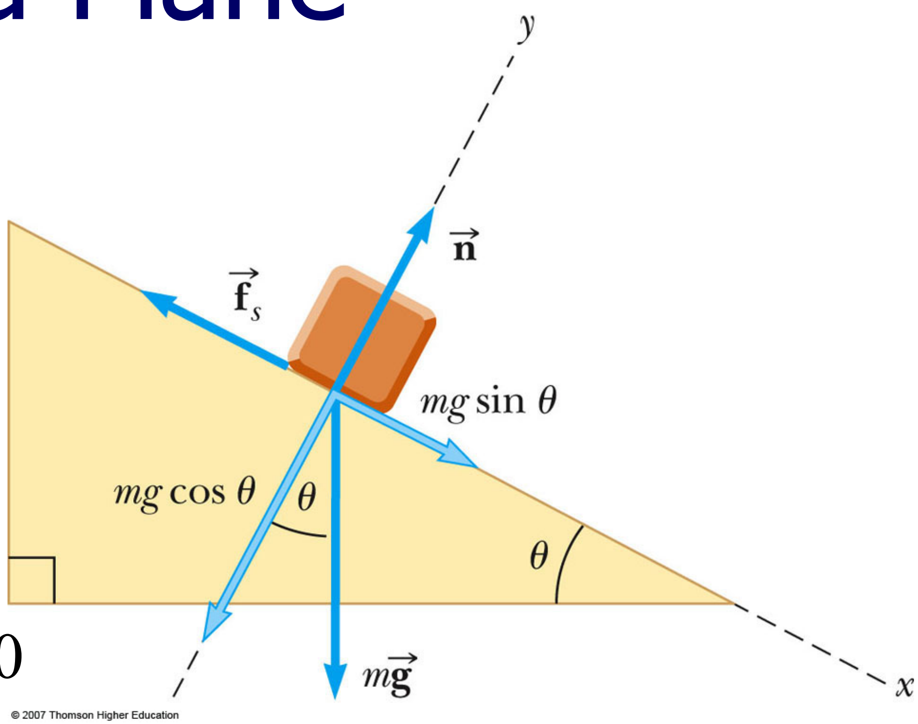


Inclined Plane

- Newton 2nd law:

$$\sum F_x = mg\sin\theta - \mu_s N = 0$$

$$\sum F_y = N - mg\cos\theta = 0$$



- Then

$$N = mg\cos\theta$$

$$\sum F_y = mg\sin\theta - \mu_s mg\cos\theta = 0$$

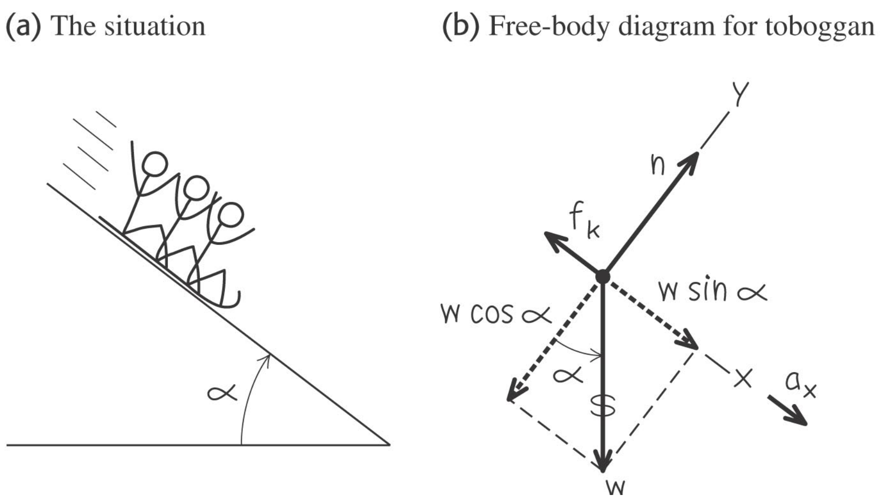
- So

$$\tan\theta = \mu_s = 0.350$$

$$\theta = \tan^{-1}(0.350) = 19.3^\circ$$

Motion on a slope having friction

- Now consider the toboggan in the example of our previous class, now with friction. Derive the acceleration in terms of g, α, μ_k, and m



Motion on a slope having friction

From Newton's 2nd Law:

$$\sum F_x = mg\sin\alpha + (-f_k) = ma_x$$
$$\sum F_y = n + (-mg\cos\alpha) = 0$$

Rearrange 2nd equation and

use relation of friction

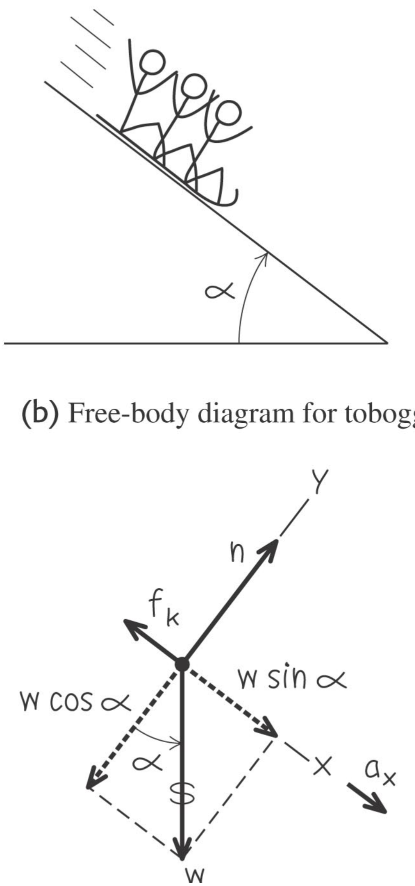
$$n = mg\cos\alpha$$
$$f_k = \mu_k n = \mu_k mg\cos\alpha$$

We substitute this into the x-component equation and solve for a_x:

$$mg\sin\alpha + (-\mu_k mg\cos\alpha) = ma_x$$
$$a_x = g(\sin\alpha - \mu_k\cos\alpha)$$

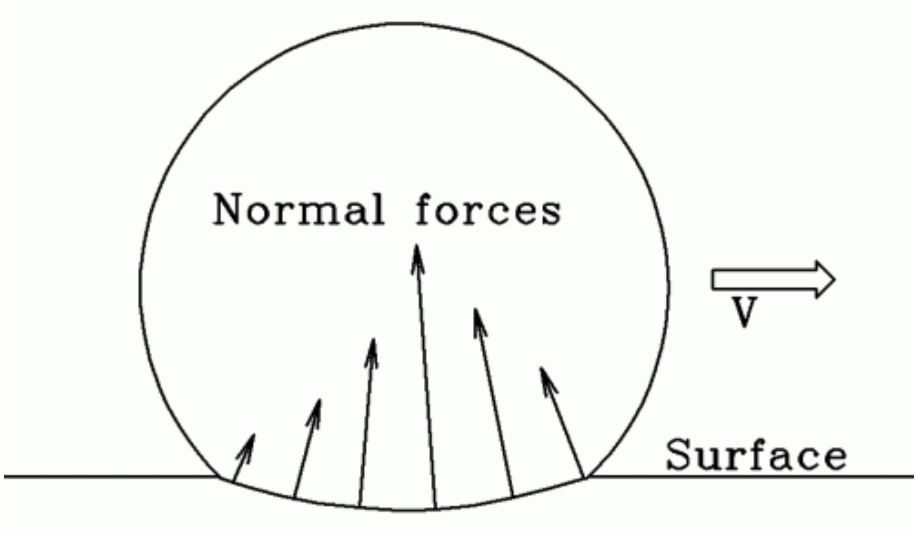
(a) The situation

(b) Free-body diagram for toboggan



Rolling Friction

- μ_r is usually much smaller than sliding coefficient (as you can read from your textbook)
- But why?



Fluid Resistance

- Direction is always opposite to the moving body's direction relative to the fluid
- Magnitude increases with the relative speed

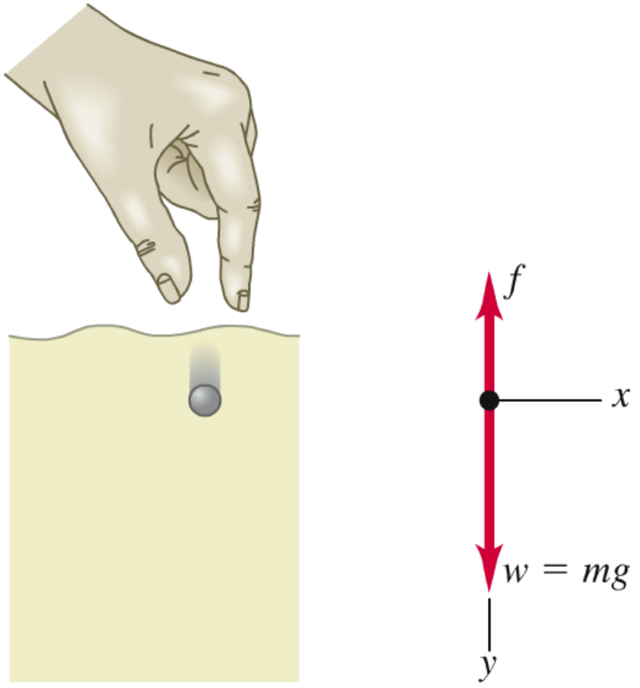
$$f = kv \qquad \text{(fluid resistance at low speed)}$$

$$f = Dv^2 \qquad \text{(fluid resistance at high speed)}$$

5.24 A metal ball falling through a fluid (oil).

(a) Metal ball falling through oil

(b) Free-body diagram for ball in oil



Which falls faster? Bowing Ball or feather?

Terminal Speed

Low Speed

$$f = kv \qquad \text{(fluid resistance at low speed)}$$

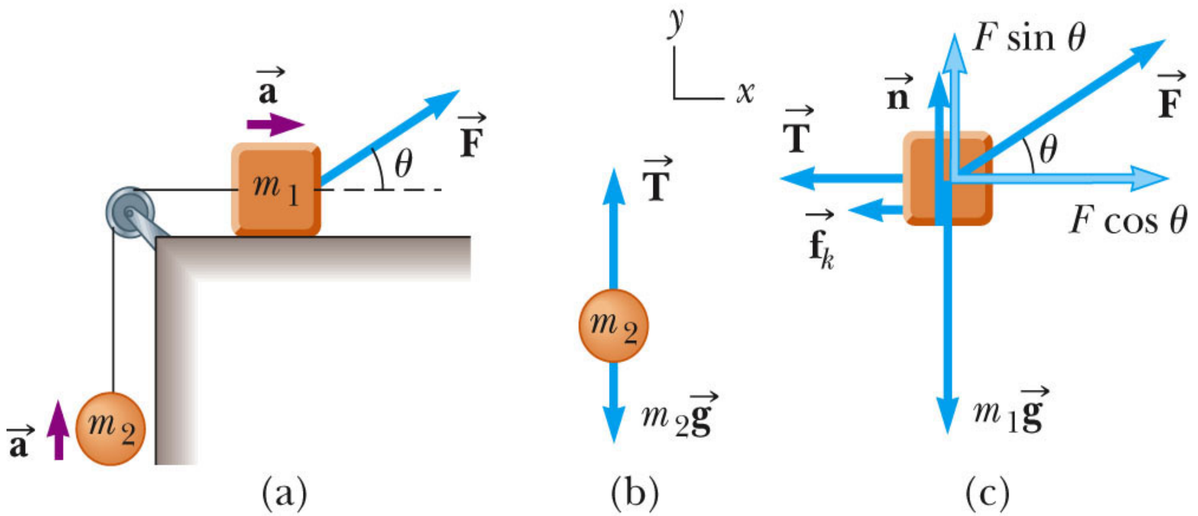
$$v_t = \frac{mg}{k} \qquad \text{(terminal speed, fluid resistance } f = kv\text{)}$$

High Speed

$$f = Dv^2 \qquad \text{(fluid resistance at high speed)}$$

$$v_t = \sqrt{\frac{mg}{D}} \qquad \text{(terminal speed, fluid resistance } f = Dv^2\text{)}$$

Multiple Objects



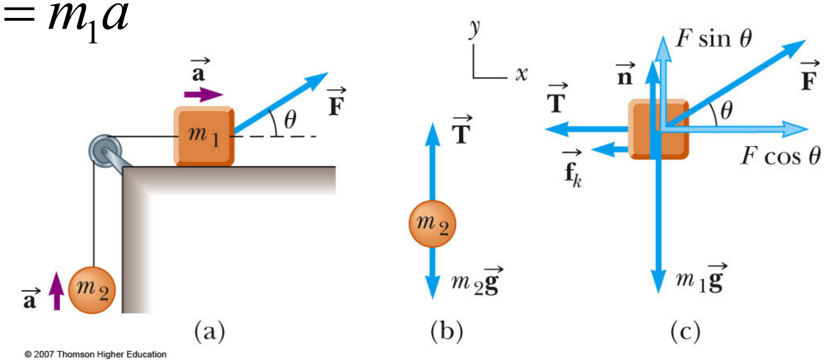
- A block of mass m1 on a rough, horizontal surface is connected to a ball of mass m2 by a lightweight cord over a lightweight, frictionless pulley as shown in figure. A force of magnitude F at an angle θ with the horizontal is applied to the block as shown and the block slides to the right. The coefficient of kinetic friction between the block and surface is μ_k. Find the magnitude of acceleration of the two objects.

Multiple Objects

- m1: $\sum F_x = F\cos\theta - f_k - T = m_1 a_x = m_1 a$

  $\sum F_y = N + F\sin\theta - m_1 g = 0$

- m2: $\sum F_y = T - m_2 g = m_2 a_y = m_2 a$



$$T = m_2(a+g)$$

$$N = m_1 g - F\sin\theta$$

$$f_k = \mu_k N = \mu_k(m_1 g - F\sin\theta)$$

$$F\cos\theta - \mu_k(m_1 g - F\sin\theta) - m_2(a+g) = m_1 a$$

$$a = \frac{F(\cos\theta + \mu_k \sin\theta) - (m_2 + \mu_k m_1)g}{m_1 + m_2}$$