Chapter 5

Applying Newton's Laws

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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Goals for Chapter 5

- To use Newton's first law for bodies in equilibrium
- To use Newton's second law for accelerating bodies
- To study the types of friction and fluid resistance
- To solve problems involving circular motion

Introduction

- We’ll start with equilibrium, in which a body is at rest or moving with constant velocity.
- Next, we’ll study objects that are not in equilibrium and deal with the relationship between forces and motion.
- We’ll analyze the friction force that acts when a body slides over a surface.
- We’ll analyze the forces on a body in circular motion at constant speed.

Particles in Equilibrium

If the acceleration of an object that can be modeled as a particle is zero, the object is said to be in **equilibrium**

- The model is the *particle in equilibrium model*

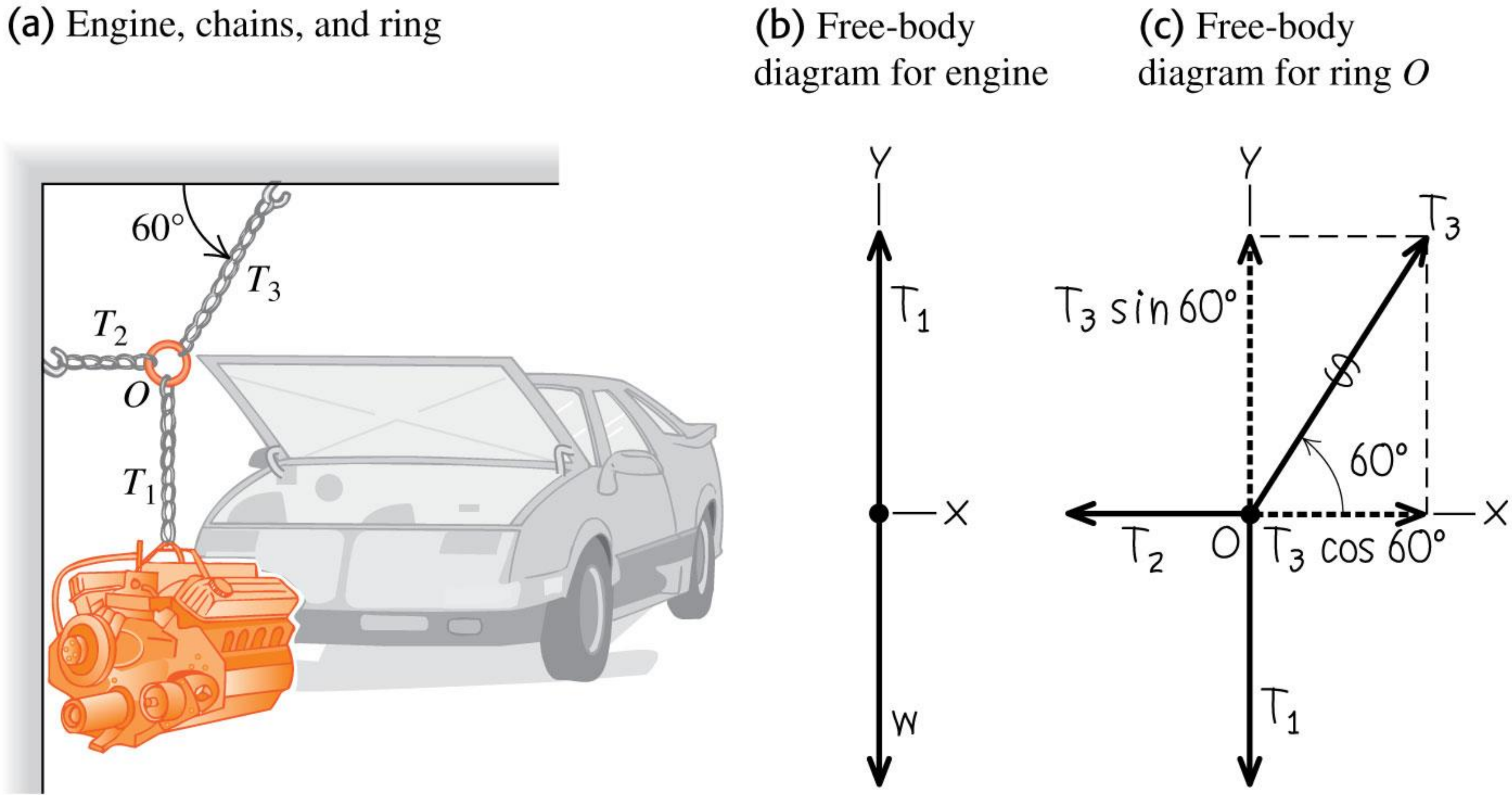
Mathematically, the net force acting on the object is zero

$$\sum \vec{\mathbf{F}} = 0$$

$$\sum F_x = 0 \text{ and } \sum F_y = 0$$

Two-dimensional equilibrium : Example

- A car engine hangs from several chains.
- Find the expression for the tension in each of three chains in terms of w



Two dimensional equilibrium: Example

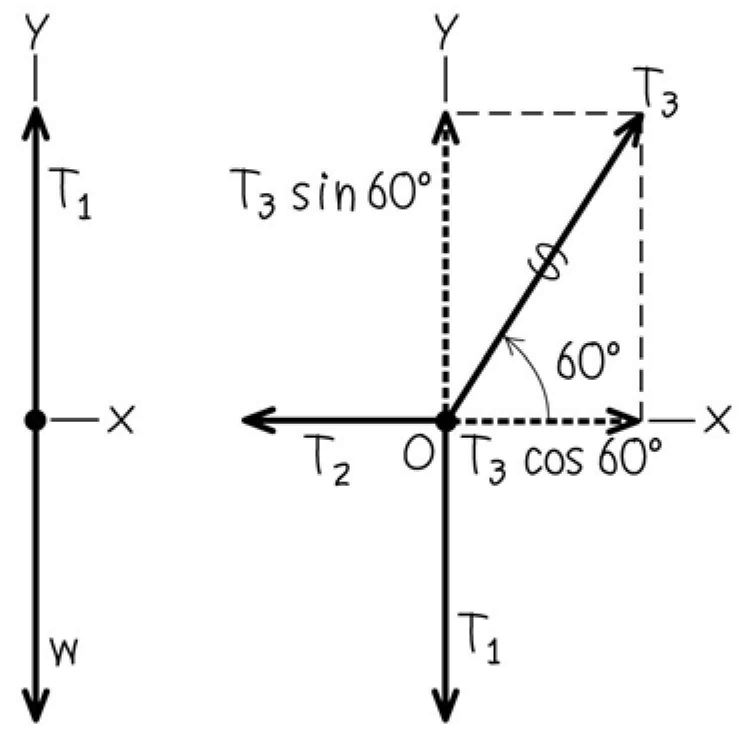
Solution: $T_1 = w$

$$\sum F_x = T_3 \cos 60° + (-T_2) = 0$$
$$\sum F_y = T_3 \sin 60° + (-T_1) = 0$$

$T_3 \cos 60^0 = T_2$ $\quad$ $T_3 \sin 60^0 = T_1$

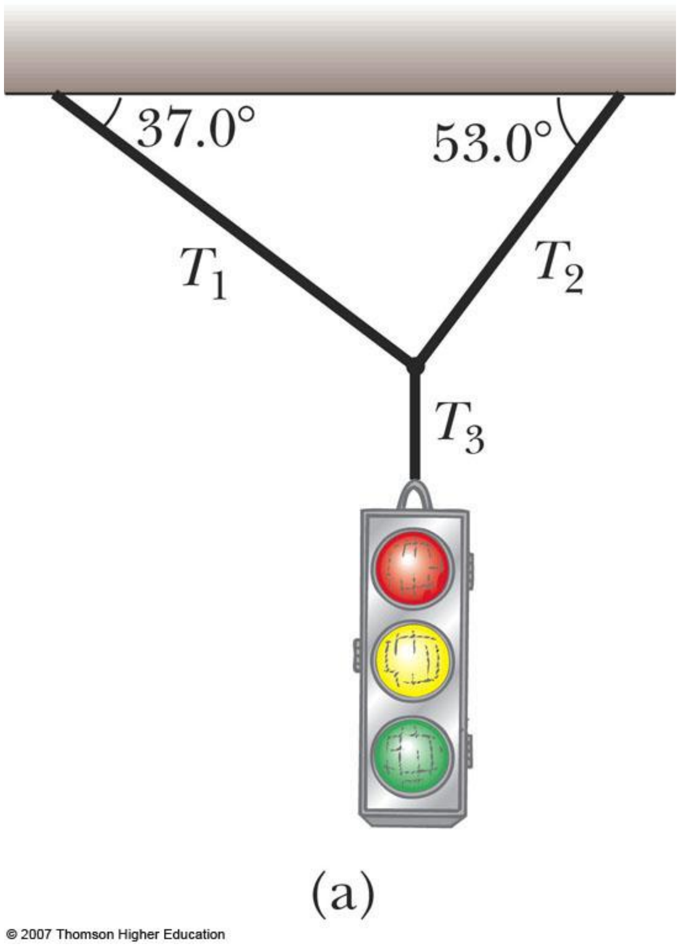
$$T_3 = \frac{T_1}{\sin 60°} = \frac{w}{\sin 60°} = 1.2w$$

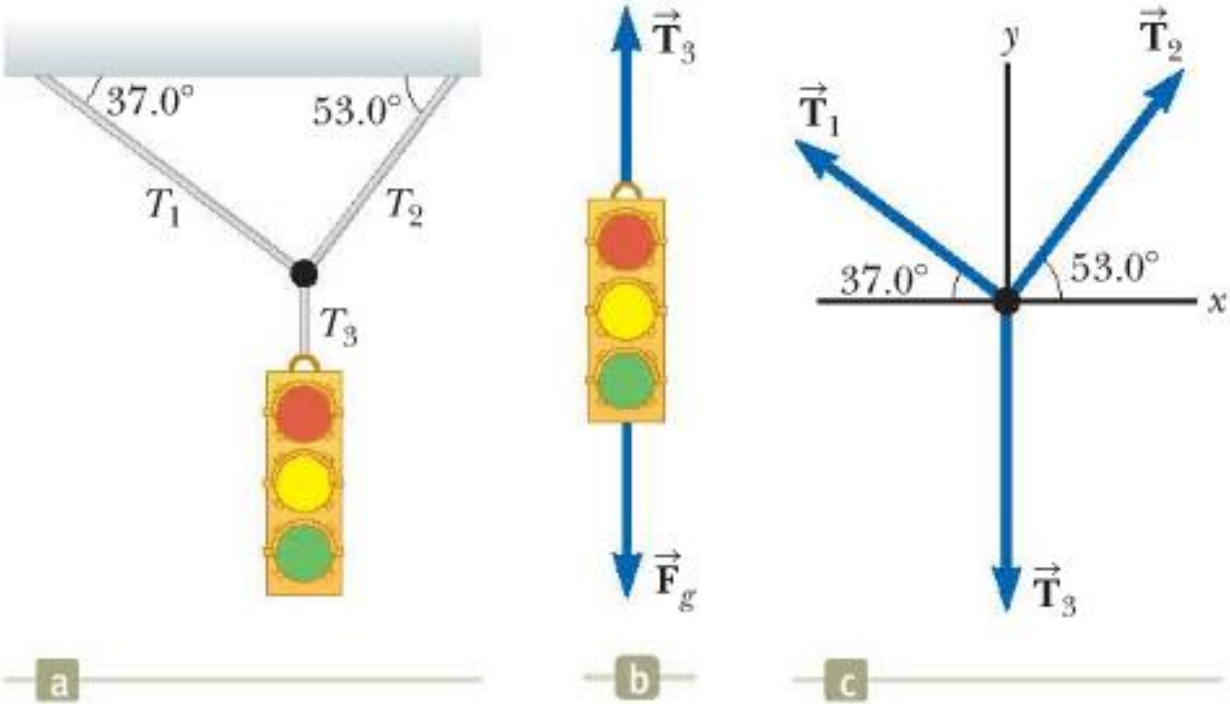
$$T_2 = T_3 \cos 60° = w\frac{\cos 60°}{\sin 60°} = 0.58w$$



Equilibrium, Example 2

Find tension in each cable if the weight of street lamp is 122 N





Force	*x* Component	*y* Component
$\vec{T}_1$	$-T_1 \cos 37.0°$	$T_1 \sin 37.0°$
$\vec{T}_2$	$T_2 \cos 53.0°$	$T_2 \sin 53.0°$
$\vec{T}_3$	0	-122 N

$$(1)\ \sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0$$

$$(2)\ \sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-122\ \text{N}) = 0$$

Force	x Component	y Component
$\vec{\mathbf{T}}_1$	$-T_1 \cos 37.0°$	$T_1 \sin 37.0°$
$\vec{\mathbf{T}}_2$	$T_2 \cos 53.0°$	$T_2 \sin 53.0°$
$\vec{\mathbf{T}}_3$	0	-122 N

$$(1) \quad \sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0$$

$$(2) \quad \sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-122 \text{ N}) = 0$$

$$T_2 = T_1\left(\frac{\cos 37.0°}{\cos 53.0°}\right) = 1.33\,T_1$$

$$T_1 \sin 37.0° + (1.33T_1)(\sin 53.0°) - 122 \text{ N} = 0$$

$$T_1 = 73.4 \text{ N}$$

$$T_2 = 1.33T_1 = 97.4 \text{ N}$$

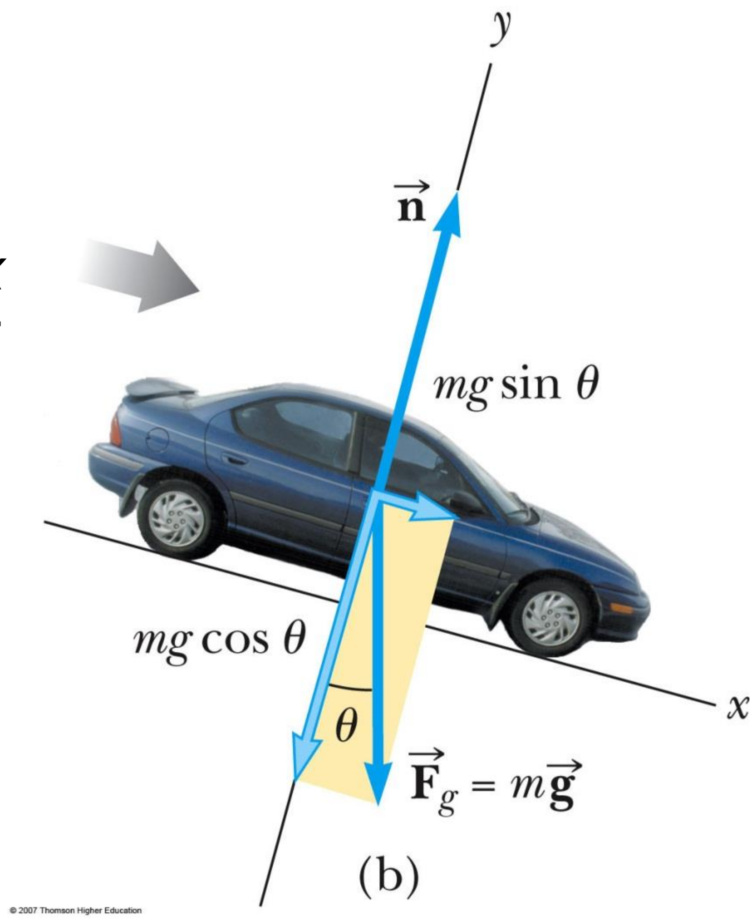
Inclined Planes

Forces acting on the object:

- The normal force acts perpendicular to the plane
- The gravitational force acts straight down

Choose the coordinate system with *x* along the incline and *y* perpendicular to the incline

Replace the force of gravity with its components

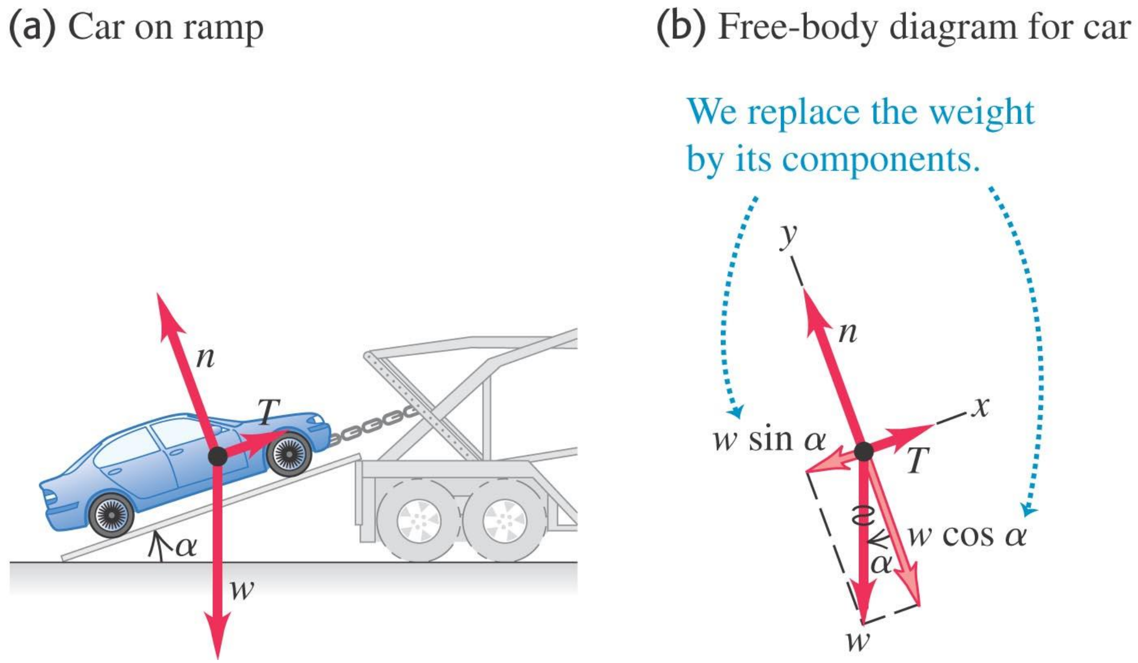


A car on an inclined plane

An car of weight *w* rests on a slanted ramp attached to a trailer. Only a cable running from the trailer prevents the car form rolling off the ramp. Find the tension in the cable and the force that the ramp exerts on the car's tires. $W = mg$

$$T - mg\sin\alpha = 0 \quad T = mg\sin\alpha$$

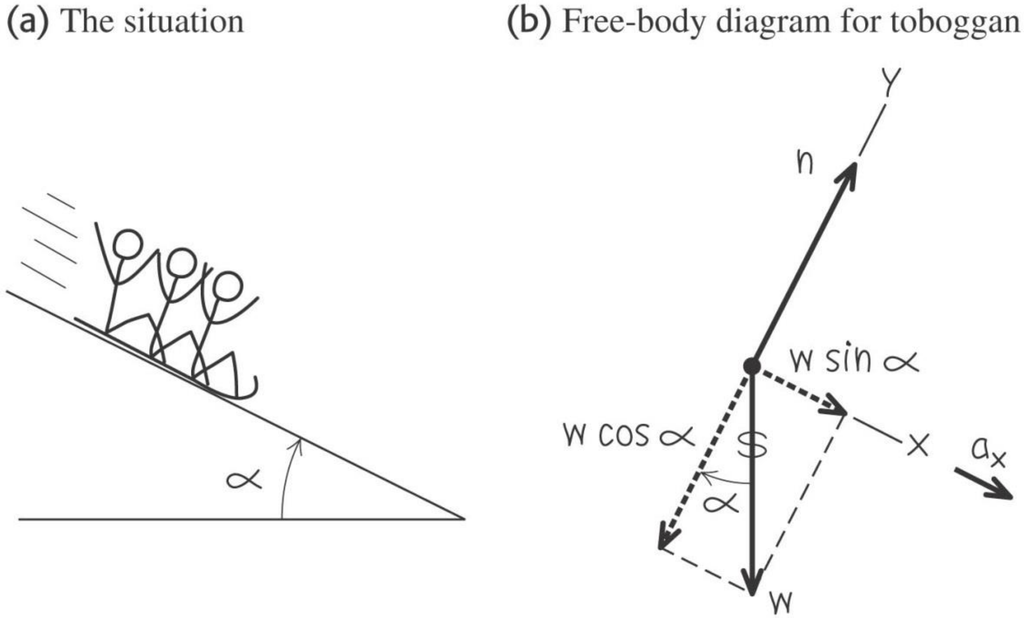
$$n - mg\cos\alpha = 0 \quad n = mg\cos\alpha$$



Incline plane. Object not in equilibrium: $\Sigma F = ma$

- What is the acceleration of a toboggan loaded with students of total mass of 500 kg sliding down a friction-free slope? Assume $\alpha = 15^0$.

$$mg\sin\alpha = ma \qquad a = g\sin\alpha = 9.8 m/s^2 \sin 15^0 = 2.53 m/s^2$$



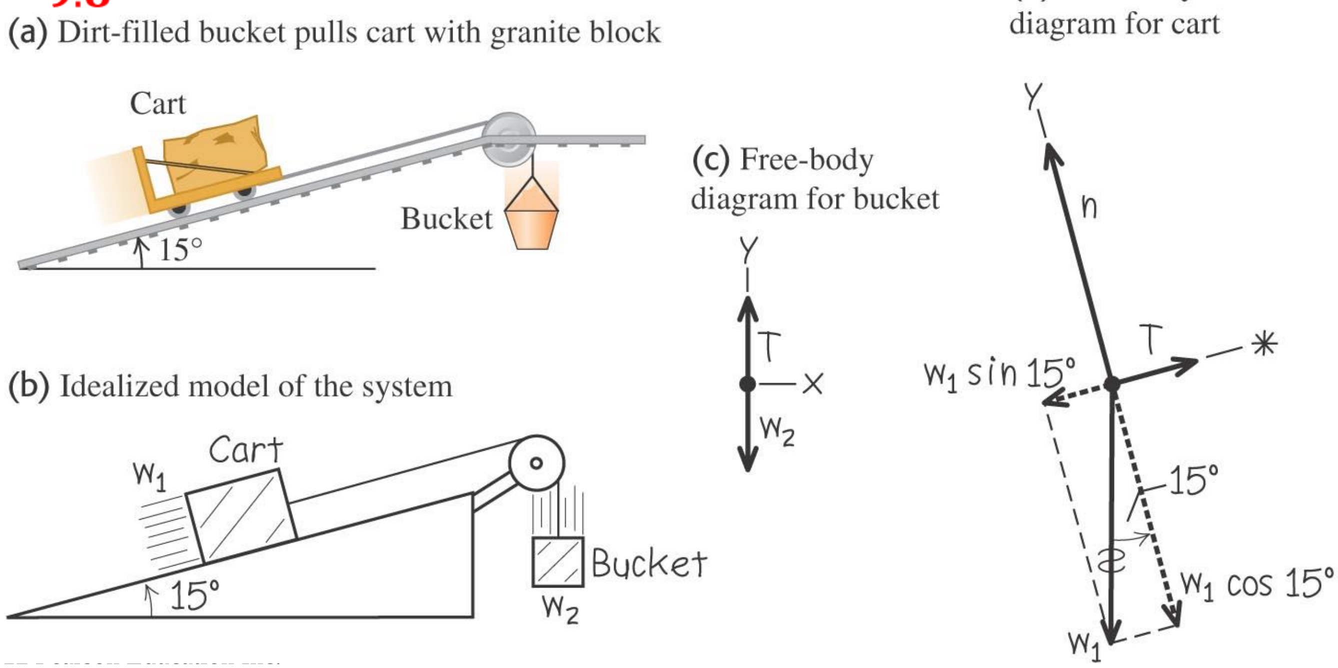
Multiple Objects. Bodies connected by a cable and pulley

A 500-N cart is connected to a bucket by a cable passing over a pulley. What mass of the bucket is needed for the system to move up the 15^0 incline with constant speed?

- Draw separate free-body diagrams for the bucket and the cart.
- Apply Newton's second law $\Sigma F_x = ma_x \, \Sigma F_y = ma_y$ for each element of the system.

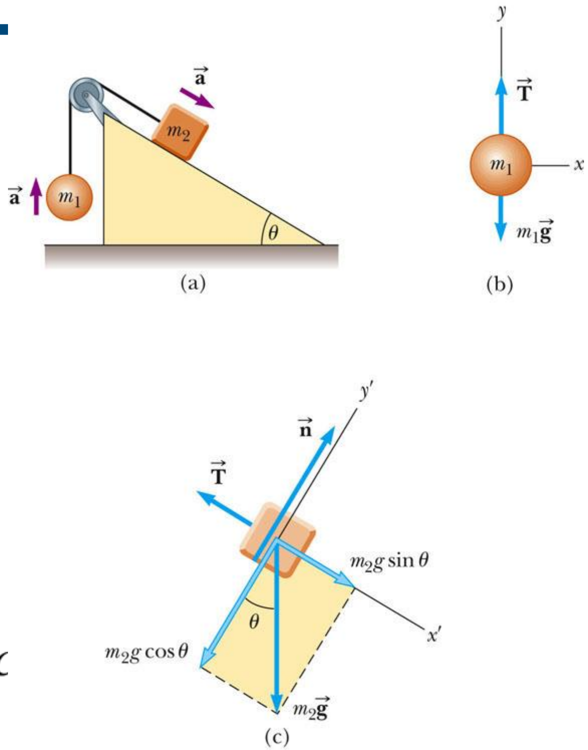
a=0 For bucket: $T - m_2 g = 0$ For cart: $T - 500\text{N}\sin 15^0 = 0$ $T = 129.4\text{N}$

$$m_2 = \frac{129.4\ N}{9.8} = 13.2\ \text{kg}$$



Multiple Objects, Example

Find the magnitude of the acceleration of the system if m_1=2kg m_2 =5.5 kg, incline angle θ= 32^0 .



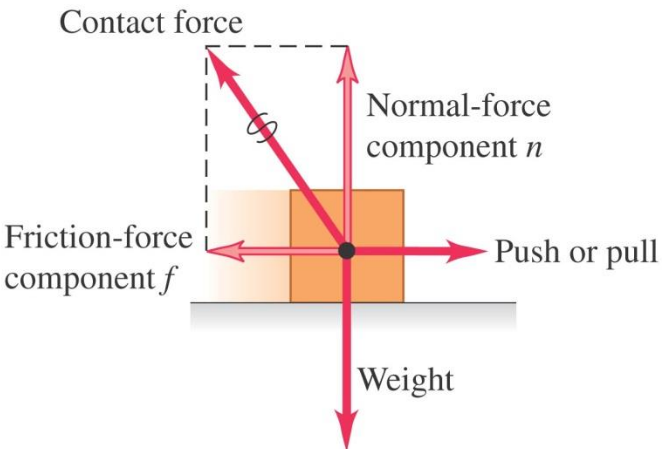
Draw the free-body diagram for each object

- *One cord, so tension is the same for both objects*
- *Connected, so acceleration is the same for both objec*
- $T - m_1 g = m_1 a$
- $m_2 g\sin\theta - T = m_2 a$
- $T - m_1 g + m_2 g\sin\theta - T = m_1 a + m_2 a$
- $a = \frac{m_2 \sin\theta - m_1}{m_1 + m_2} g = \frac{5.5\ kg\sin 32^0 - 2kg}{5.5\ kg + 2\ kg} 9.8 m/s^2 = 1.2\ m/s^2$

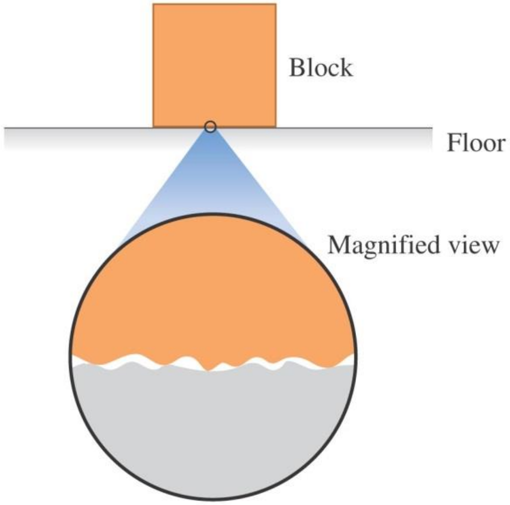
Frictional forces

- When a body rests or slides on a surface, the *friction force* is parallel to the surface.

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



- Friction between two surfaces arises from interactions between molecules on the surfaces.



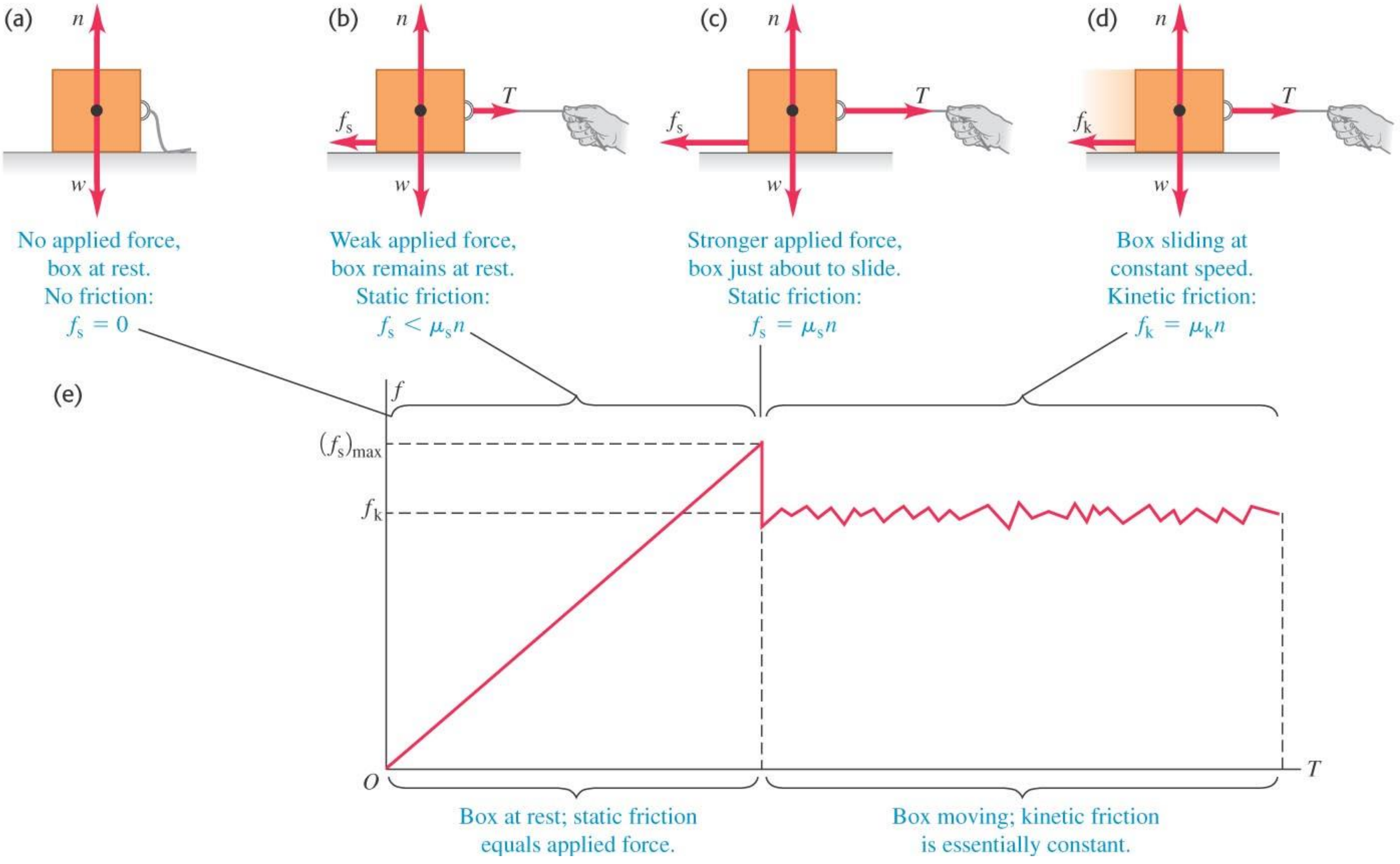
On a microscopic level, even smooth surfaces are rough; they tend to catch and cling.

Kinetic and static friction

- *Kinetic friction* acts when a body slides over a surface.
- The *kinetic friction force* is $f_k = \mu_k n$.
- *Static friction* acts when there is no relative motion between bodies.
- The *static friction force* can vary between zero and its maximum value: $f_s \leq \mu_s n$.

Static friction followed by kinetic friction

- Before the box slides, static friction acts. But once it starts to slide, kinetic friction acts.



Some approximate coefficients of friction

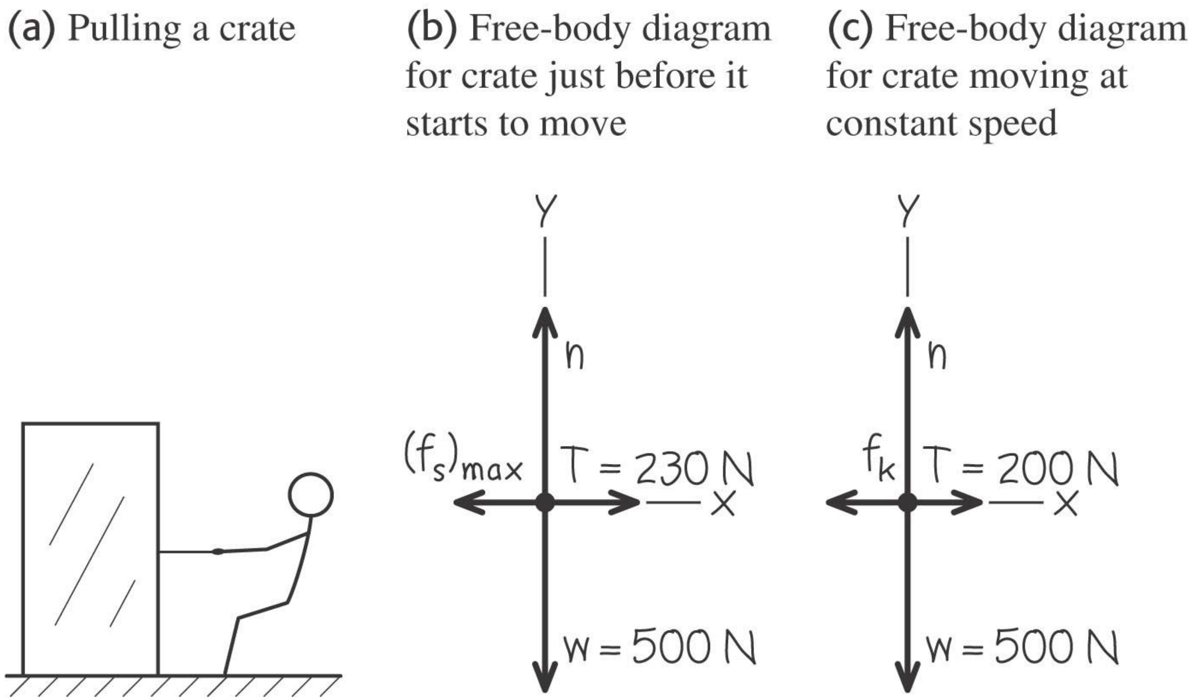
Table 5.1 **Approximate Coefficients of Friction**

Materials	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Brass on steel	0.51	0.44
Zinc on cast iron	0.85	0.21
Copper on cast iron	1.05	0.29
Glass on glass	0.94	0.40
Copper on glass	0.68	0.53
Teflon on Teflon	0.04	0.04
Teflon on steel	0.04	0.04
Rubber on concrete (dry)	1.0	0.8
Rubber on concrete (wet)	0.30	0.25

Friction in horizontal motion

To start a 500-N crate moving across a level floor you have to pull with a 230-N horizontal force. Once the crate starts to move, you can keep it moving at constant speed with only 200N. What are the coefficients of static and kinetic friction?

Before the crate moves, static friction acts on it. After it starts to move, kinetic friction acts.

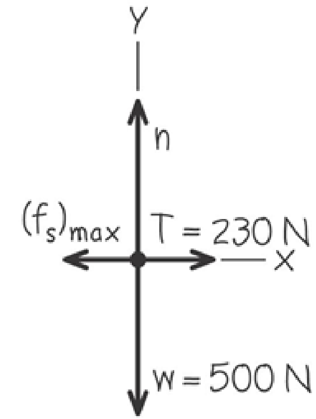


Static friction can be less than the maximum

Static friction only has its maximum value just before the box "breaks loose" and starts to slide.

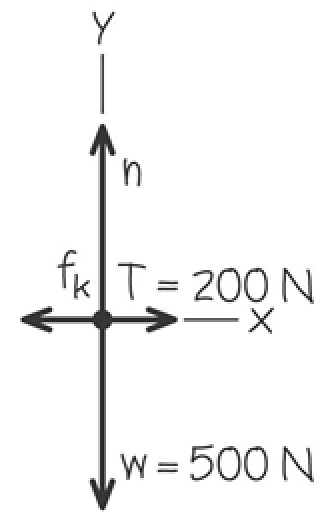
$T - f_{s,max} = 0 \quad f_{s,max} = T \qquad f_{s,max} = \mu_s n$

$n - 500N = 0 \quad n = 500\ N \quad \mu_s = \frac{f_{s,max}}{n} = \frac{230\ N}{500\ N} = 0.46$



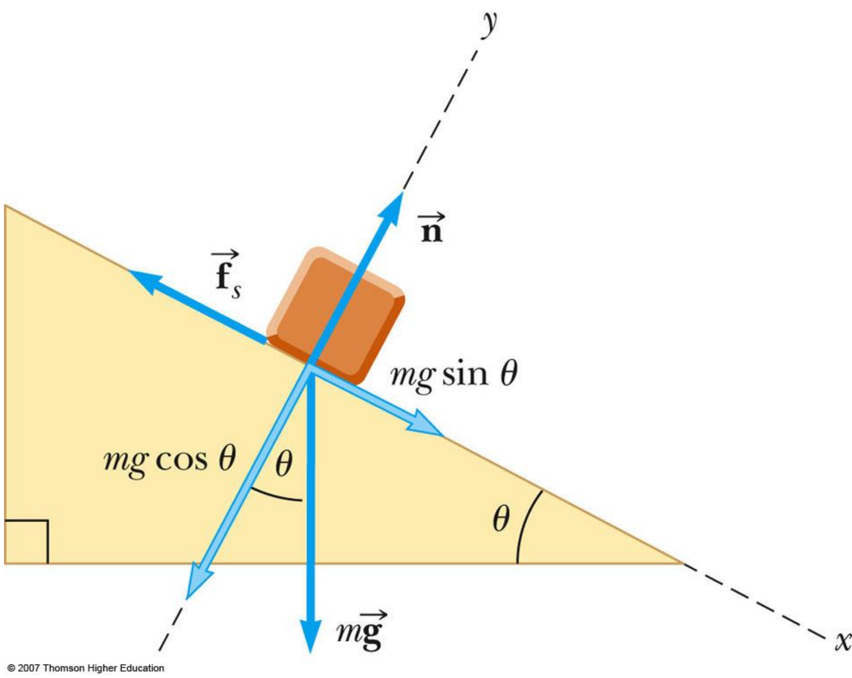
After the crate starts moving: $T - f_k = 0$

$f_k = \mu_k n \quad n = w \quad \mu_k = \frac{f_k}{n} = \frac{200N}{500N} = 0.40$



Friction - Example

Find the coefficient of static friction force if the block starts to slide down at an angle of 12.5^0



Start sliding when $f_s = f_{s,max}$

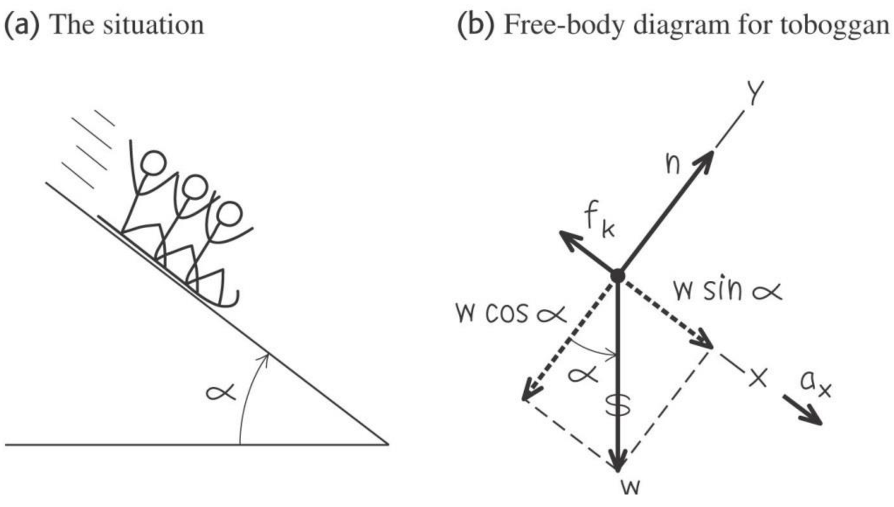
$$f_{s,max} = \mu_s n = \mu_s mg\cos\theta$$

$$mg\sin\theta = \mu_s mg\cos\theta$$

$$\mu_s = \tan\,\theta = \tan 12.5^0 = 0.22$$

Motion on a slope having friction

What is the acceleration of a toboggan loaded with students of total mass of 500 kg sliding down a slope? Assume $\alpha=15^0$ and coefficient of kinetic friction the slope $\mu_k=0.08$.



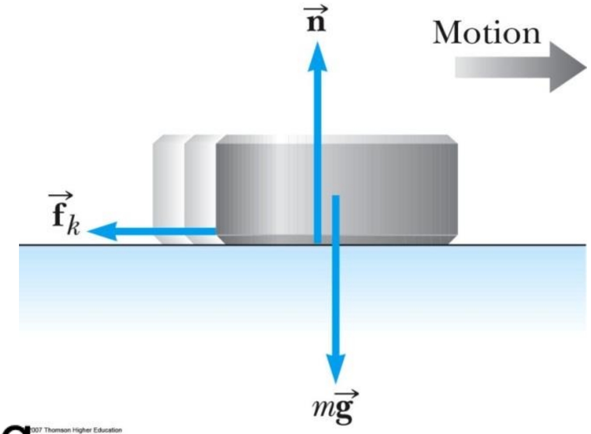
$mg\sin\alpha - f_k = ma \quad f_k = \mu_k n \quad n = mg\cos\alpha$

$f_k = \mu_k mg\cos\alpha \qquad mg\sin\alpha - \mu_k mg\cos\alpha = ma$

$a = g\sin\alpha - \mu_k g\cos\alpha = (\sin 15^0 - 0.08\cos 15^0) 9.8 m/s^2 = 1.78 m/s^2$

Friction, Example

A hockey puck on a frozen pond is given an initial speed of 12 m/s. If the puck slides 60 m before coming to rest, determine the coefficient of kinetic friction between the puck and ice.

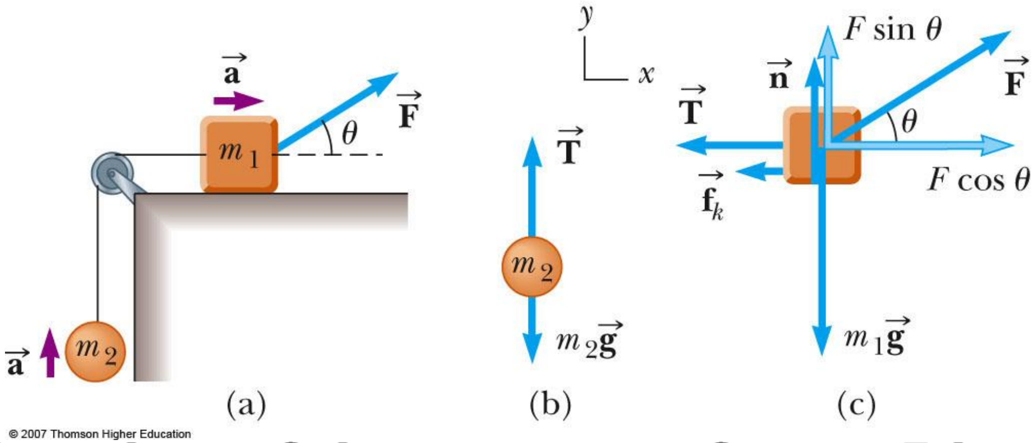


$f_k = ma$ $f_k = \mu_k n$ $n = mg$ $ma = \mu_k n$ $ma = \mu_k mg$

$a = \mu_k g$ $\mu_k = a/g$

$v_i = 12 m/s$ $v_f = 0$ $\Delta x = \frac{0 - v^2}{2a}$ $a = \frac{(12m/s)^2}{2 * 60m} = 1.2\ m/s^2$

Friction, Example



Find the acceleration of the system of m_1 = 5 kg, m_2 = 1.5 kg, F = 25 N, μ_k = 0.12, and $\theta = 28^0$

$T - m_2 g = m_2 a \quad F\cos\theta - F_k - T = m_1 a \quad F\cos\theta - F_k - T + T - m_2 g = m_1 a + m_2 a$

$$a = \frac{F\cos\theta - F_k - m_2 g}{m_1 + m_2} = \frac{25N\cos 28^0 - 4.5N - 1.5kg * 9.8m/s^2}{6.5\ kg} = 0.44 m/s^2$$

$F_k = \mu_k n \quad n + F\sin\theta - m_1 g = 0 \quad n = m_1 g - F\sin\theta$

$F_k = \mu_k (m_1 g - F\sin\theta) = 0.12(5kg * 9.8m/s^2 - 25\ N\sin 28^0) = 4.47N$

Pulling a crate at an angle

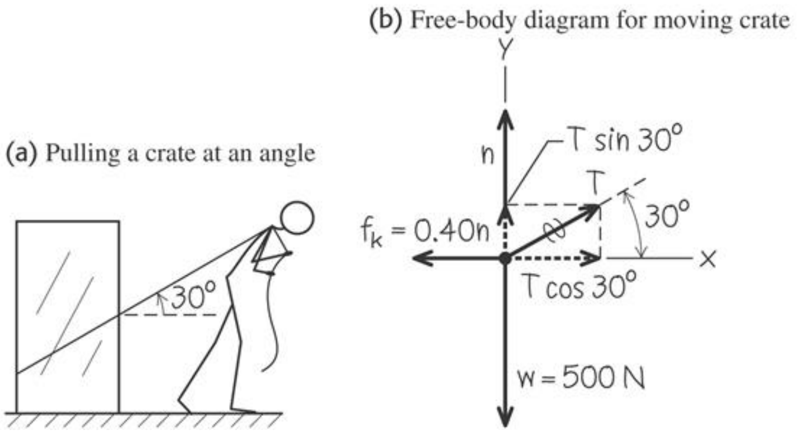
- The angle of the pull affects the normal force, which in turn affects the friction force.
- How hard must you pull the crate to keep it moving with constant velocity? Assume $\mu_k = 0.4$

$F\cos\theta - F_k = 0$ $F_k = \mu_k n$ $n + F\sin\theta - w = 0$ $n = w - F\sin\theta$

$F_k = \mu_k w - \mu_k F\sin\theta$ $F\cos\theta - \mu_k w + \mu_k F\sin\theta = 0$

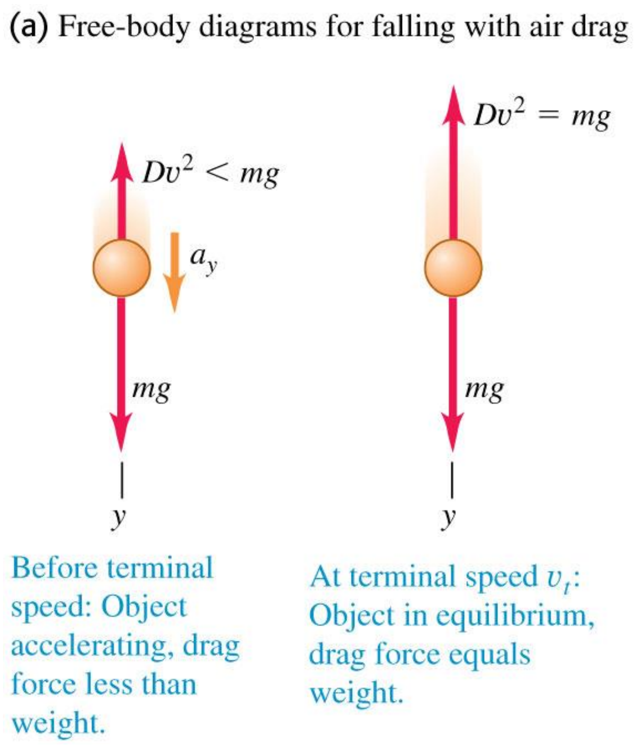
$F(\cos\theta + \mu_k \sin\theta) = \mu_k w$

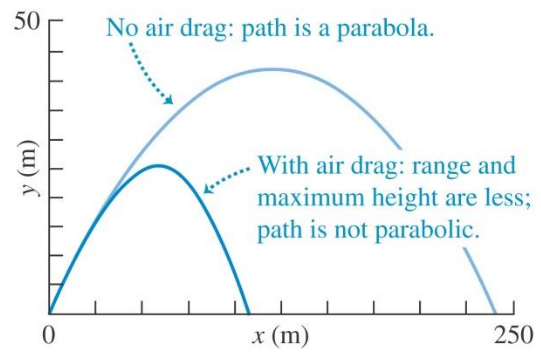
$$F = \frac{0.4 * 500N}{\cos 30^0 + 0.4\sin 30^0} = 188N$$



Fluid resistance and terminal speed

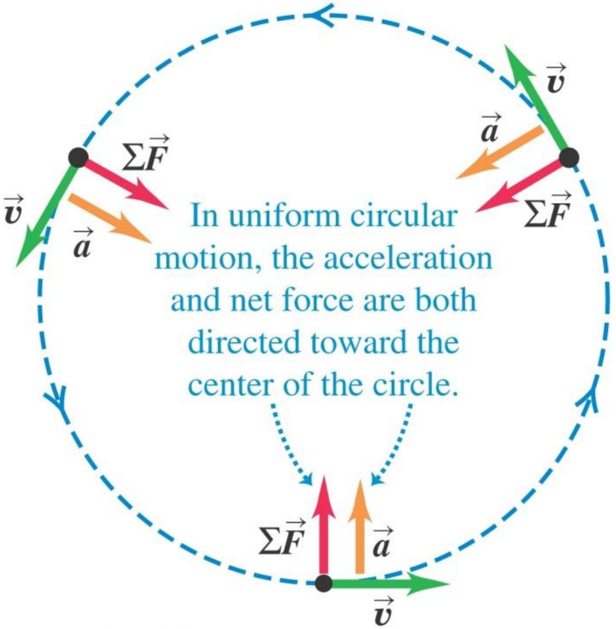
- The *fluid resistance* on a body depends on the speed of the body.
- A falling body reaches its *terminal speed* when the resisting force equals the weight of the body.
- The figures at the right illustrate the effects of air drag.





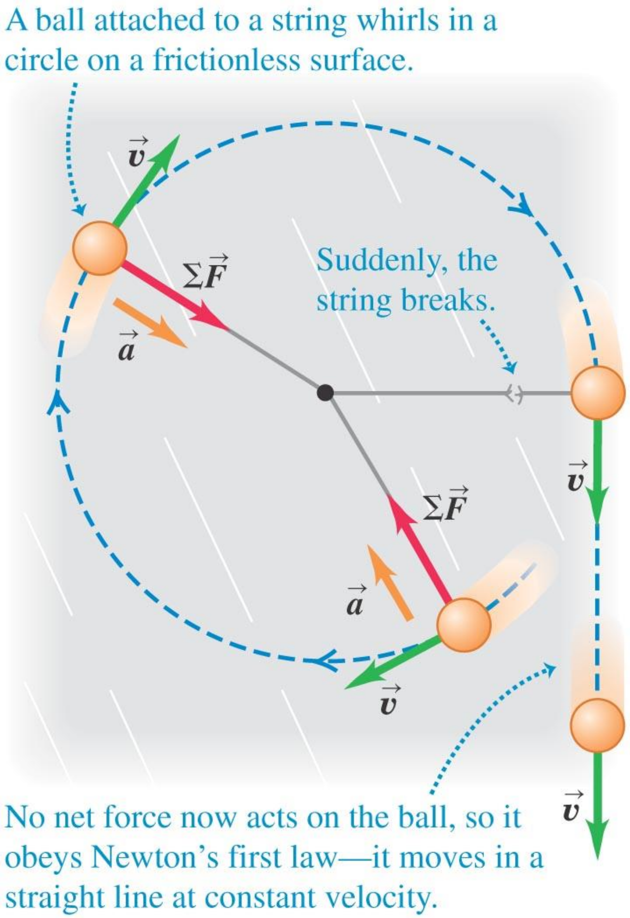
Dynamics of circular motion

- If a particle is in uniform circular motion, both its acceleration and the net force on it are directed toward the center of the circle.
- The net force on the particle is $F_{net} = mv^2/R$.



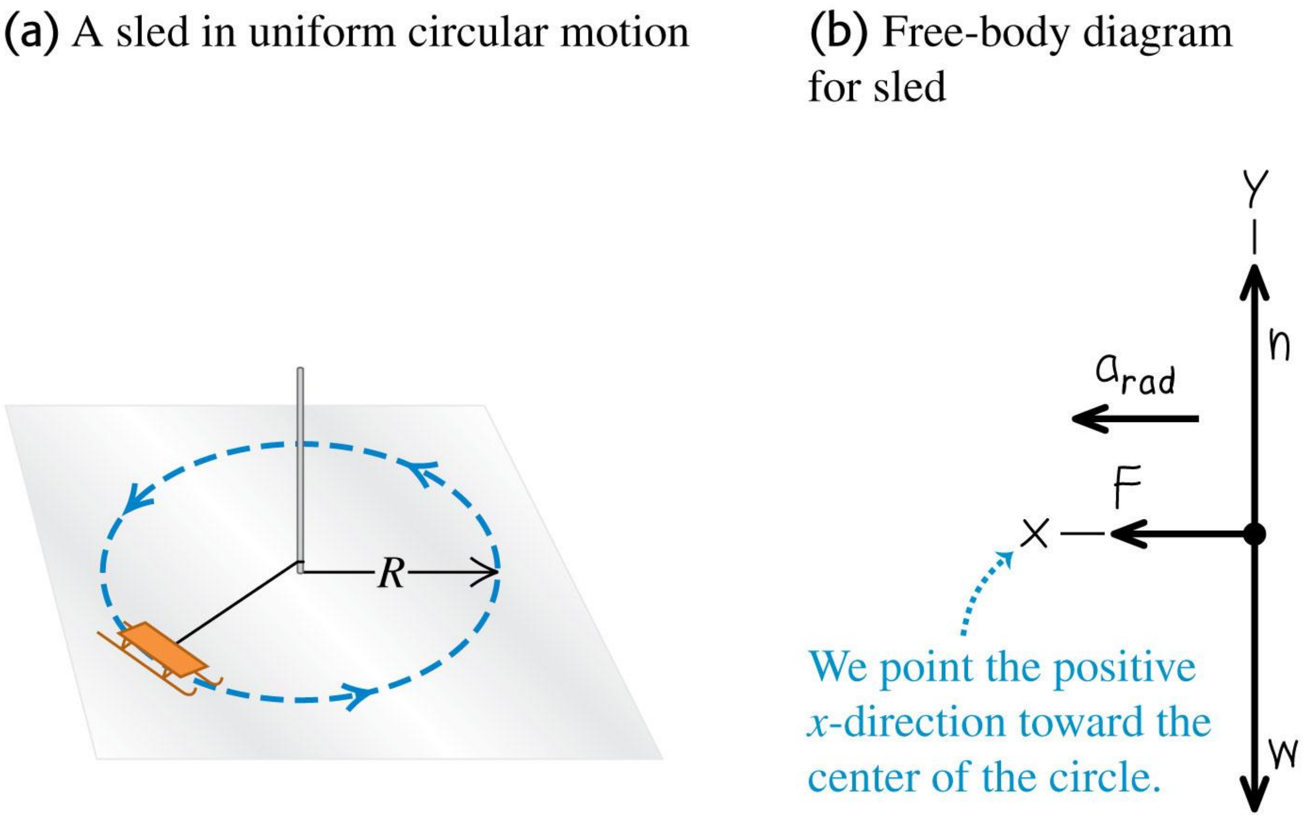
What if the string breaks?

- If the string breaks, no net force acts on the ball, so it obeys Newton's first law and moves in a straight line.



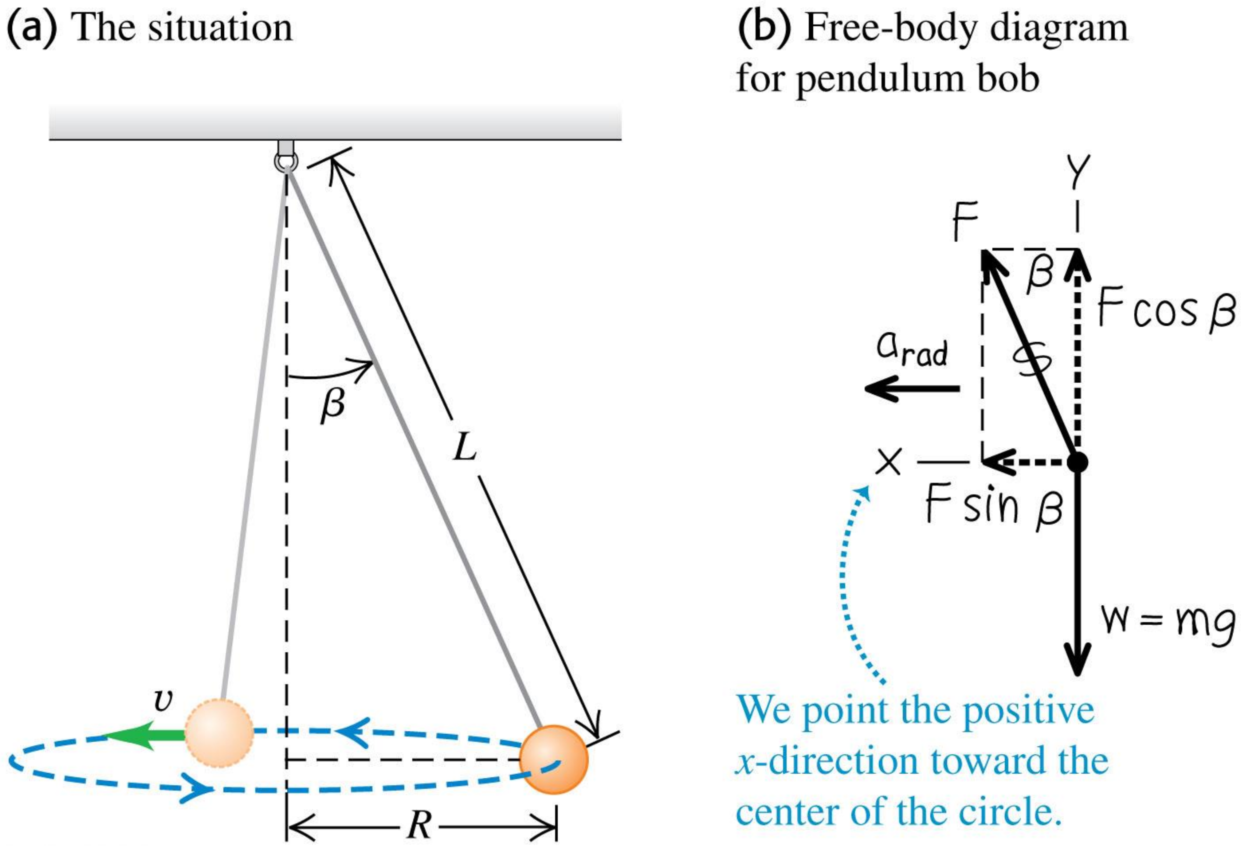
Force in uniform circular motion

- A sled on frictionless ice is kept in uniform circular motion by a rope.
- F =



A conical pendulum

A bob at the end of a wire moves in a horizontal circle with constant speed.

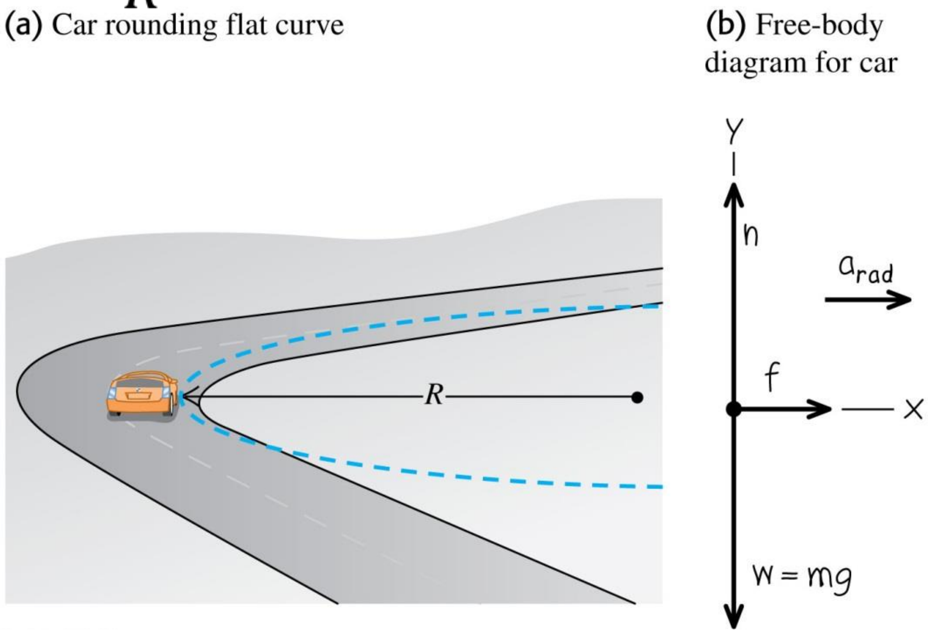


A car rounds a flat curve

- A car rounds a flat unbanked curve of radius R=65 m. What is its maximum speed if the μ_s =0.58 ?

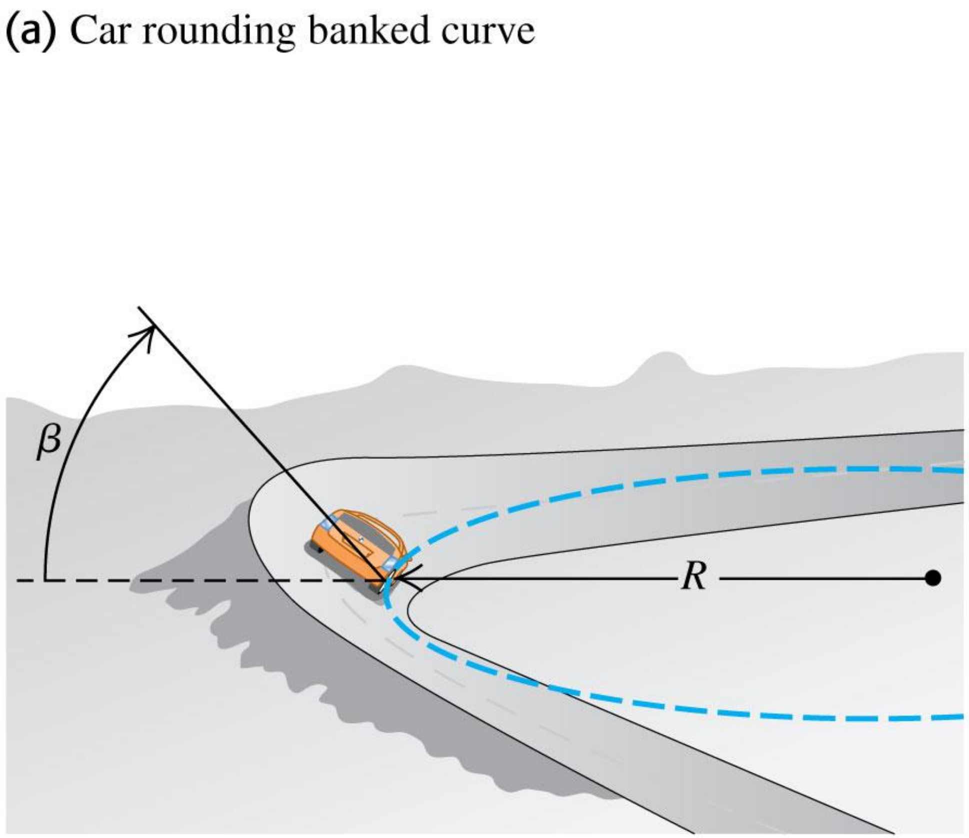
$f_s = m\frac{v^2}{R}$ for max.speed $f_{s,max} = m\frac{v^2}{R}$ $\mu_s n = m\frac{v^2}{R}$

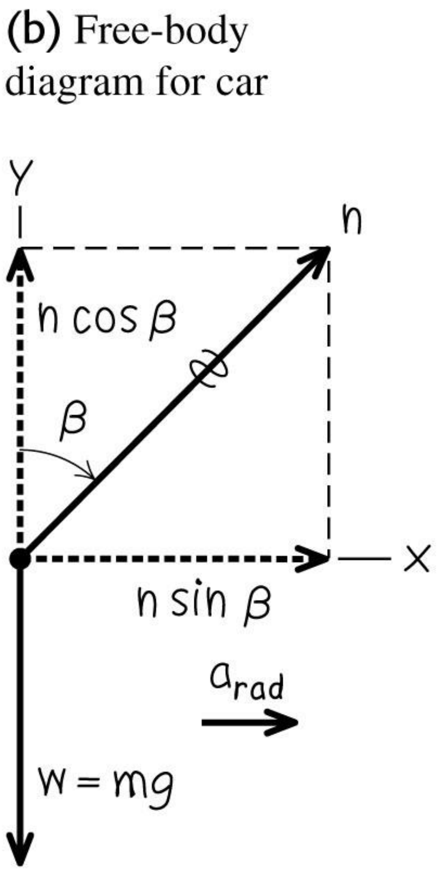
$n = mg$ $\mu_s mg = m\frac{v^2}{R}$ $v_{max} = \sqrt{\mu_s R g} = 19.2$ m/s=43mi/h



A car rounds a banked curve

- At what angle should a curve be banked so a car can make the turn even with no friction?





Uniform motion in a vertical circle

- A person on a Ferris wheel moves in a vertical circle.

Top: $n - w = -ma_c$ $\qquad n = w - ma_c$

Bottom: $n - w = ma_c$ $\qquad n = w + ma_c$