# Essential University Physics

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# 5 Using Newton's Laws

PowerPoint® Lecture prepared by Richard Wolfson

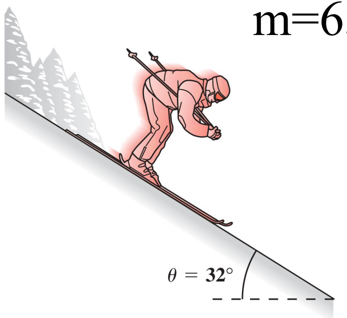
# In this lecture you'll learn

- To use Newton's second law to solve problems involving
  - Objects moving in two dimensions
  - Multiple objects
  - Circular motion
  - Frictional forces
    - And the nature of friction

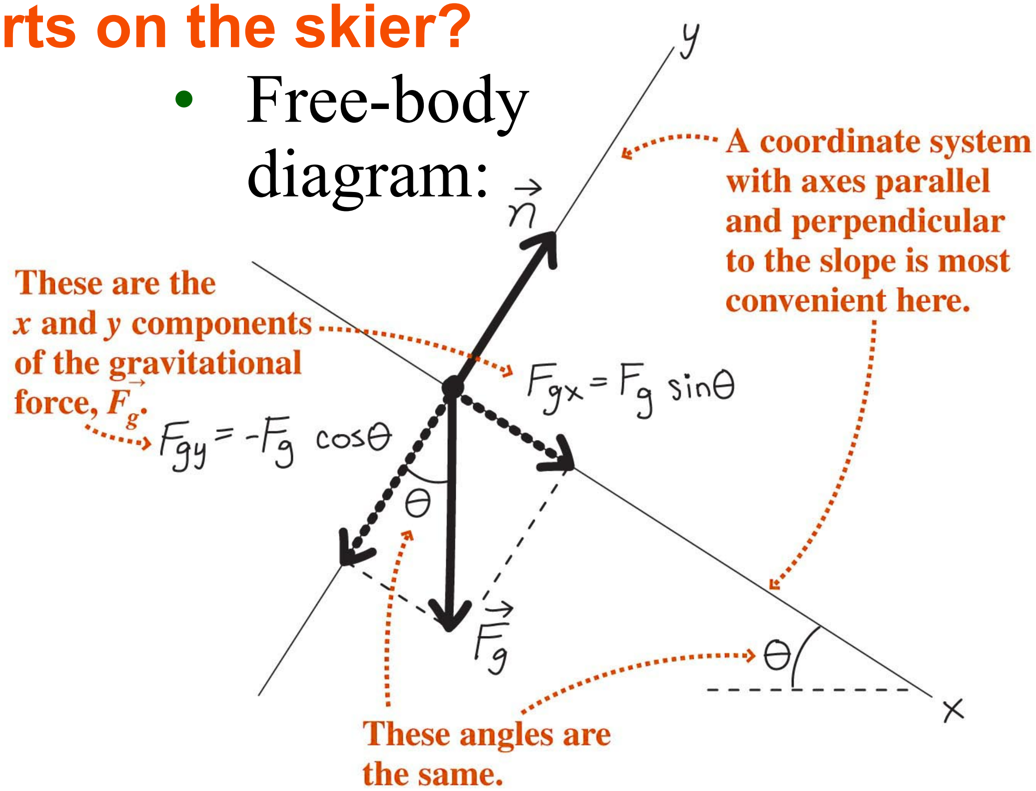
# A Typical Problem: What's the skier's acceleration?
## What's the force the snow exerts on the skier?

- Physical diagram:

m=65kg




- Free-body diagram:




- Newton's law:

$$\vec{F}_{net} = \vec{n} + \vec{F}_g = m\vec{a}$$

- In components:
- $x$ component:

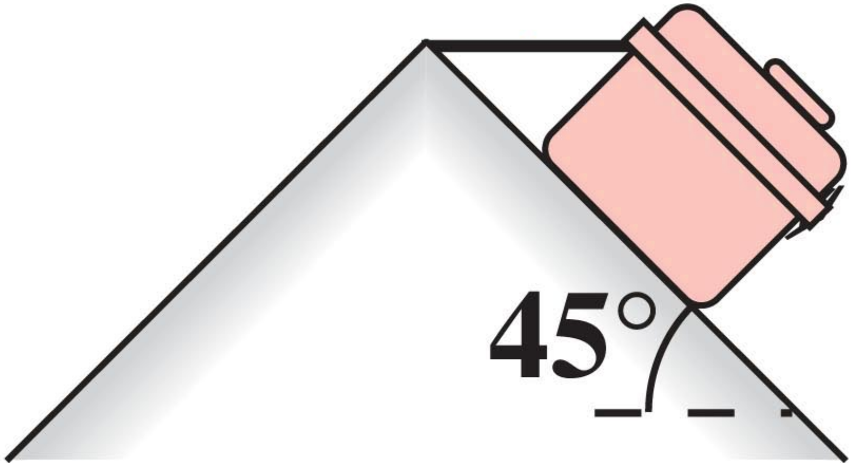
$$mg\sin\theta = ma \quad \Longrightarrow \quad a = g\sin\theta = (9.8\text{m/s}^2)(\sin 32^0) = 5.2\text{ m/s}^2$$

- $y$ component:

$$n - mg\cos\theta = 0 \quad \Longrightarrow \quad n = mg\cos\theta = 540\text{N}$$

- Solve to get the answers:

# Clicker question

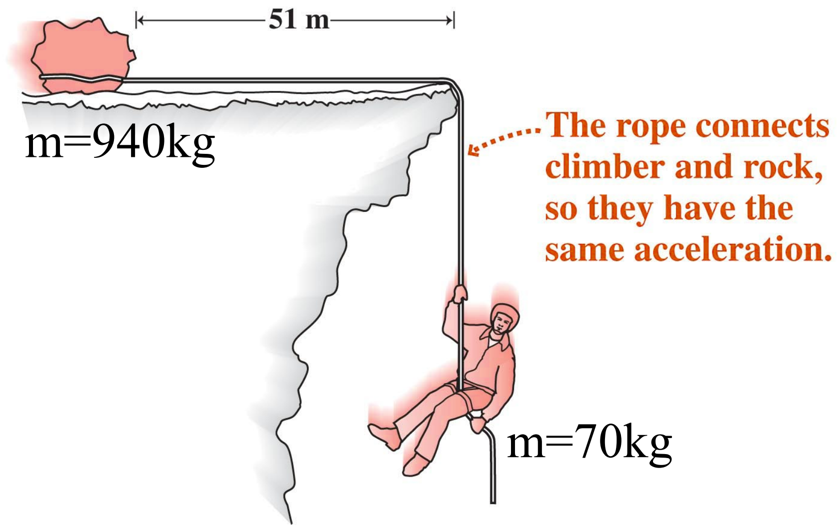



- A roofer's toolbox rests on an essentially frictionless metal roof with a 45° slope, secured by a horizontal rope as shown. Is the rope tension (A) greater than, (B) equal to, or (C) less than the box's weight?

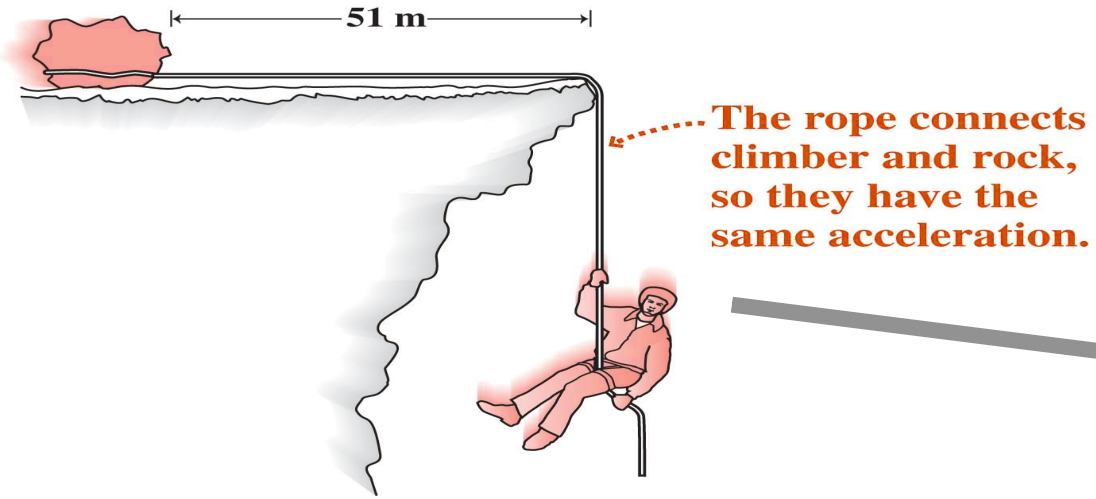
# Multiple Objects

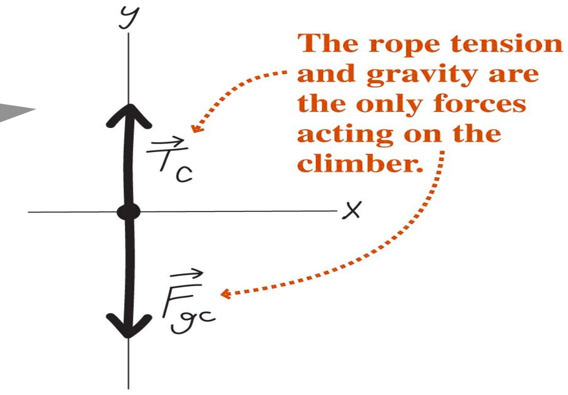
- Solve problems involving multiple objects by first identifying each object and all the forces on it.
- Draw a freebody diagram for each.
- Write Newton's law for each.
- Identify connections between the objects, which give common terms in the Newton's law equations.
- Solve.

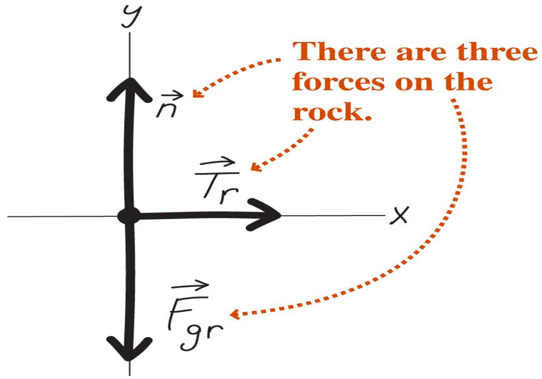
**Example:**



# Rescuing a Climber:




**Newton's law:**

$$\text{climber}: \vec{T}_c + \vec{F}_{gc} = m_c \vec{a}_c$$

$$\text{rock}: \vec{T}_r + \vec{F}_{gr} + \vec{n} = m_r \vec{a}_r$$

**In components:**

$$\text{climber, y}: T - m_c g = -m_c a$$

**In components:**

$$\text{rock,x}: T = m_r a$$

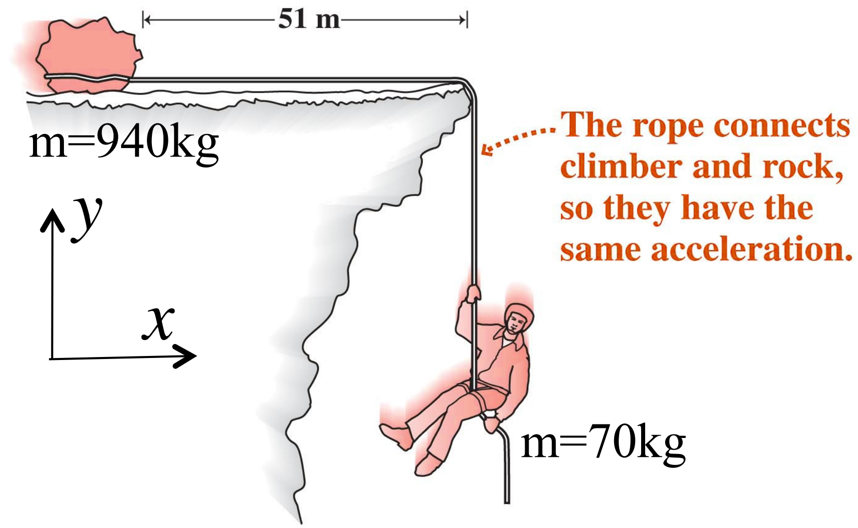
$$\text{rock,y}: n - m_r g = 0$$

**Solution:**

$$a = \frac{m_c g}{m_c + m_r}$$

# Rescuing a Climber:

$(x_0, y_0)$




**Solution:**

$$a = \frac{m_c g}{m_c + m_r}$$

$$a = \frac{(70\text{kg})(9.8\text{m/s}^2)}{(70\text{kg} + 940\text{kg})} = 0.679\text{m/s}^2$$

How much time?

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$x_0 = 0, \quad v_0 = 0$$

$$51\text{m} = \frac{1}{2}(0.679\text{m/s}^2) \cdot t^2$$

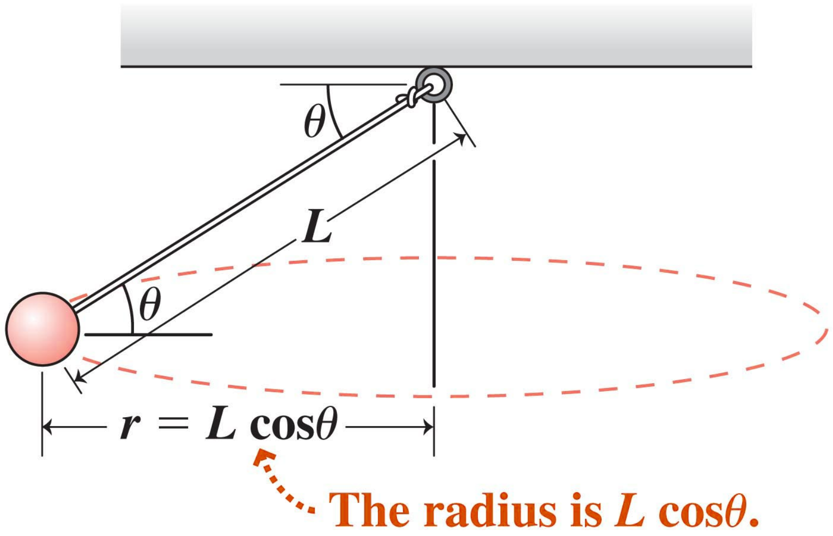
$$t = 12\text{s}$$

# Circular Motion

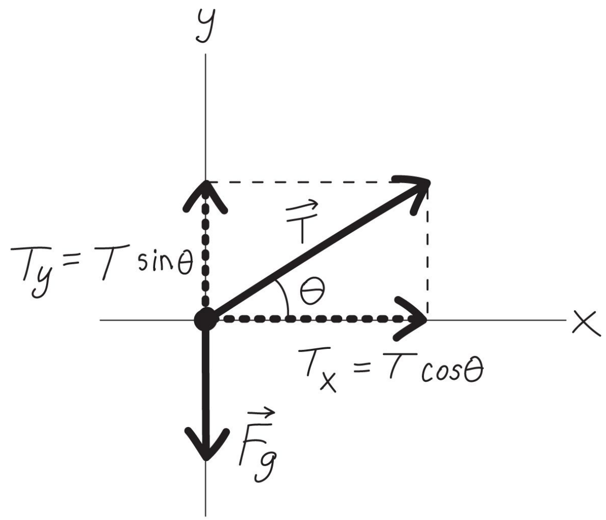
- Problems involving circular motion are no different from other Newton's law problems.
- Identify the forces, draw a freebody diagram, write Newton's law.
- Here the acceleration has magnitude $v^2/r$ and points toward the center of the circle.

# Circular Motion: Find the ball's speed

**A ball whirling on a string:**




**Freebody diagram:**




$$\vec{T} + \vec{F}_g = m\vec{a}$$

**In components:**

$$x : T\cos\theta = \frac{mv^2}{L\cos\theta}$$

$$y : T\sin\theta - mg = 0$$

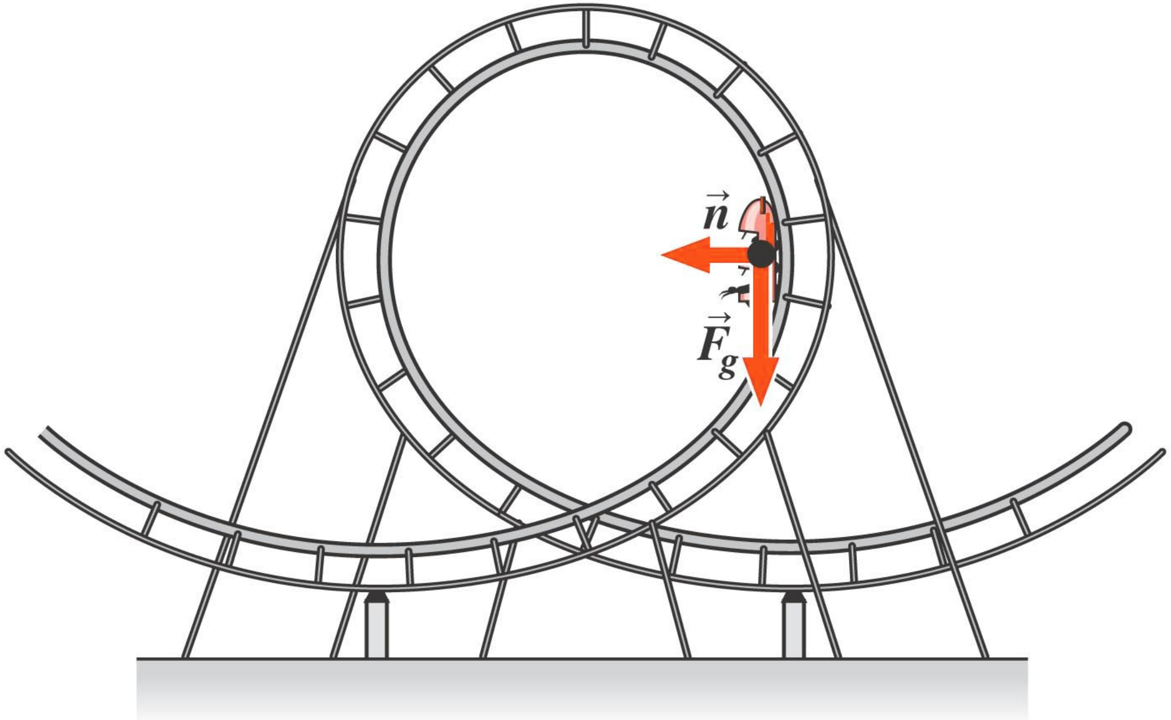
**Solve for the ball's speed:**

$$v = \sqrt{\frac{TL\cos^2\theta}{m}} = \sqrt{\frac{(mg/\sin\theta)L\cos^2\theta}{m}}$$

$$v = \sqrt{\frac{gL\cos^2\theta}{\sin\theta}}$$

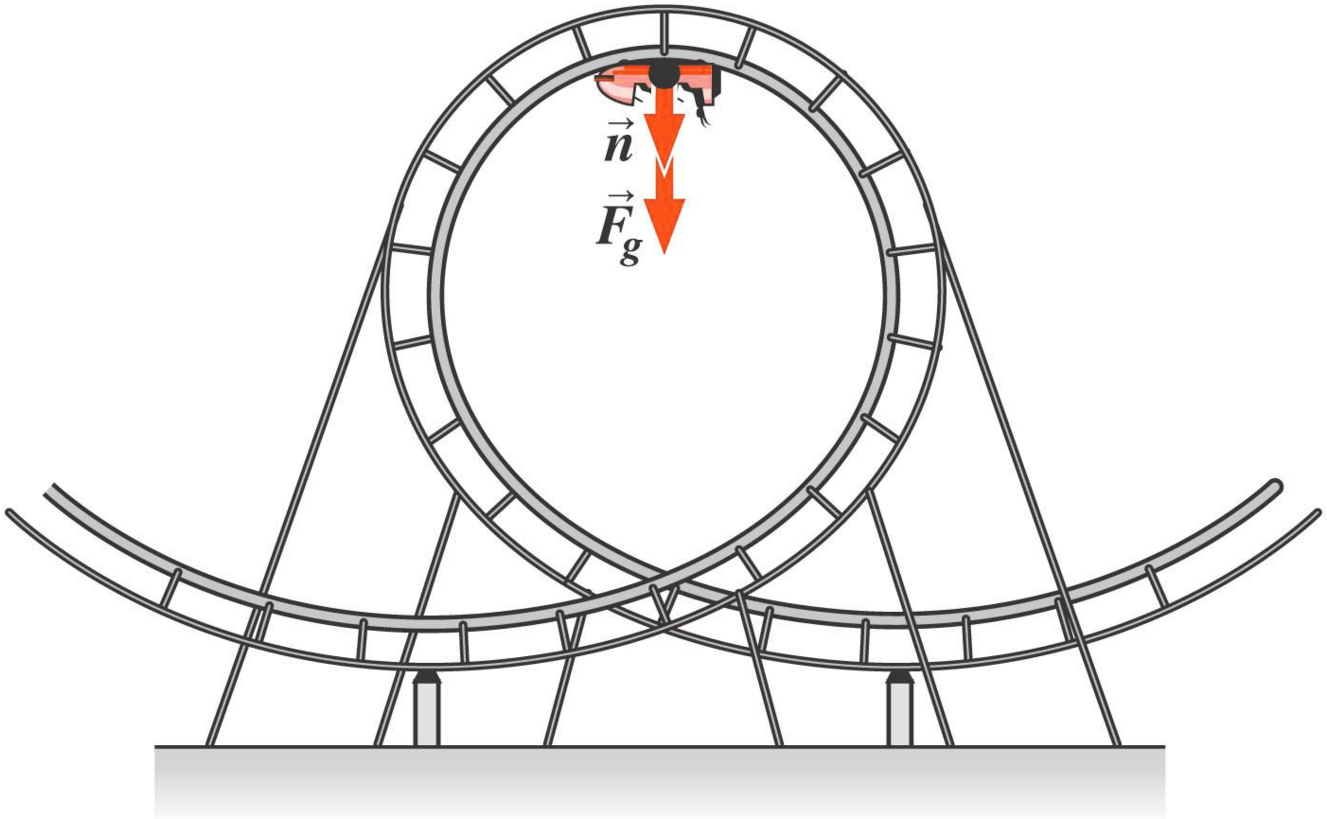
# Loop-the-Loop!

- The two forces acting on the car are gravity and the normal force.
- Gravity is always downward, and the normal force is perpendicular to the track.
- Here the two are at right angles:
  - The normal force acts perpendicular to the car's path, keeping its direction of motion changing.
  - Gravity acts opposite the car's velocity, slowing the car.



# Loop-the-Loop!

- Now both forces are downward:
  - For the car to stay in contact with the track, the normal force must be greater than zero.
  - So the minimum speed is the speed that lets the normal force get arbitrarily close to zero at the top of the loop.
  - Then gravity alone provides the force that keeps the car in circular motion.

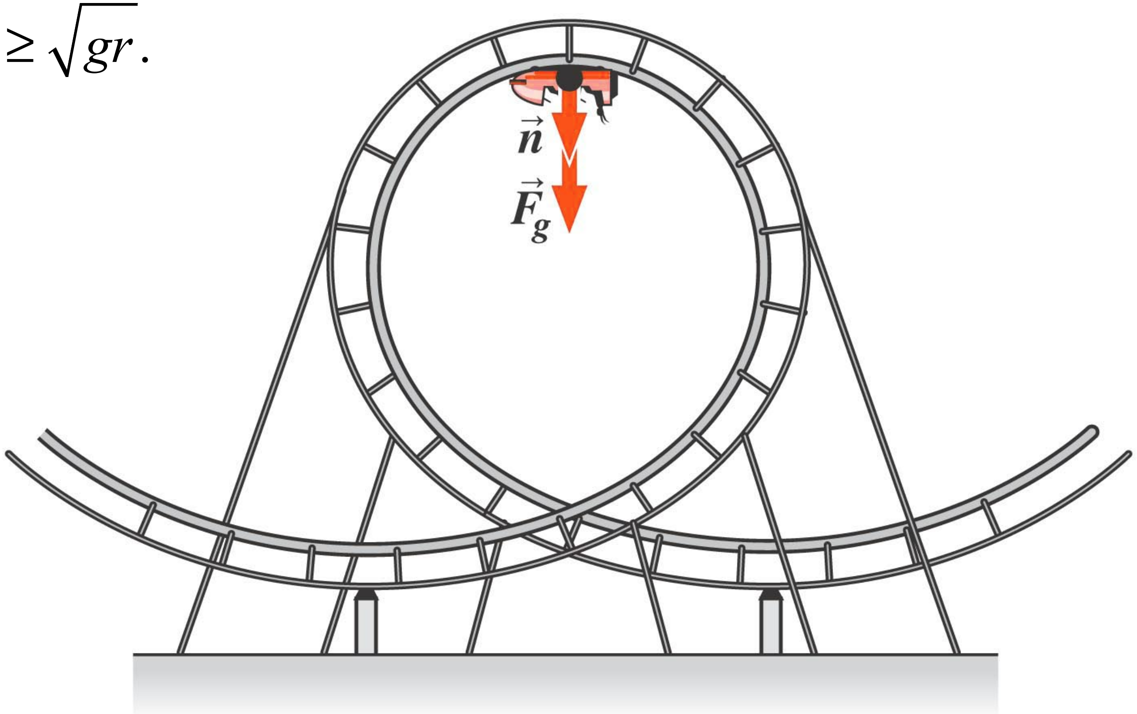


# Loop-the-Loop!

- Therefore Newton's law has a single component, with the gravitational force *mg* providing the acceleration $v^2/r$ that holds the car in its circular path:

$$\vec{F} = m\vec{a} \longrightarrow mg = \frac{mv^2}{r}$$

  - Solving for the minimum speed at the loop top gives $v = \sqrt{gr}$.
  - Slower than this at the top, and the car will leave the track!
  - Since this result is independent of mass, car and passengers will all remain on the track as long as $v \geq \sqrt{gr}$.



# Friction

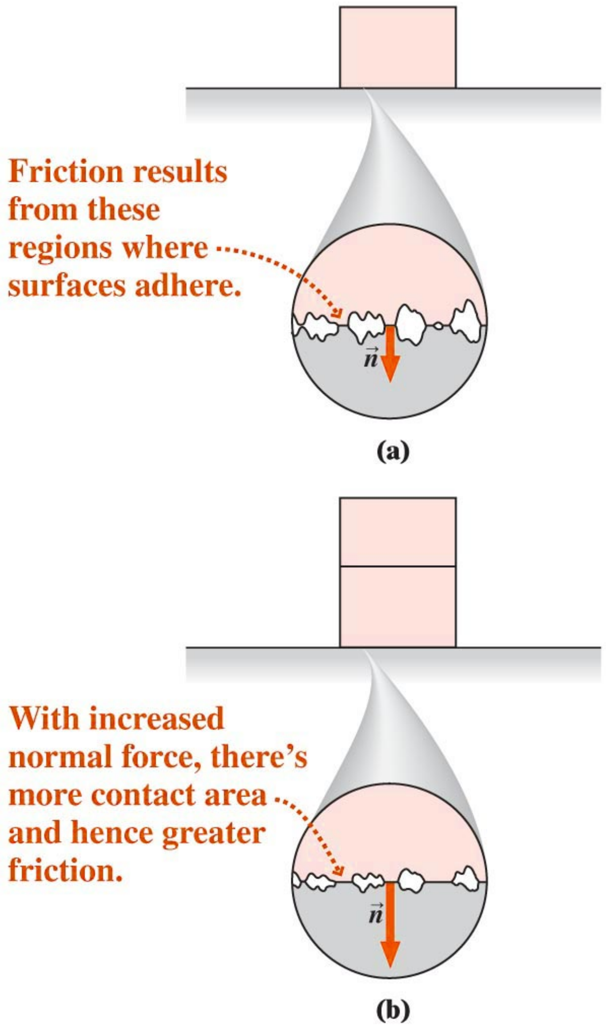
- **Friction** is a force that opposes the relative motion of two contacting surfaces.

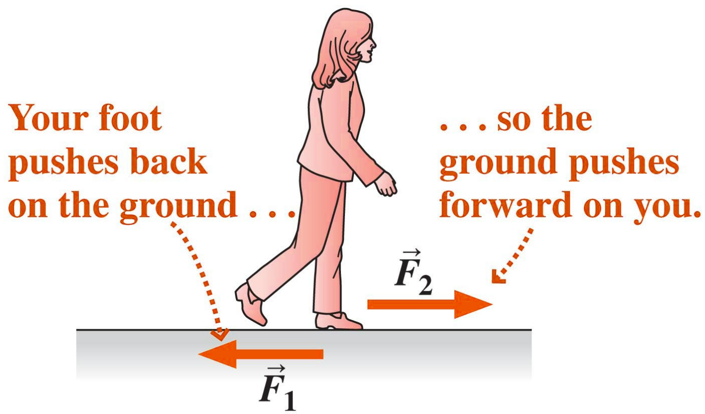
- **Static friction** occurs when the surfaces aren't in motion; its magnitude is $f_s \leq \mu_s n$, where $n$ is the normal force between the surfaces and $\mu_s$ is the **coefficient of static friction.**

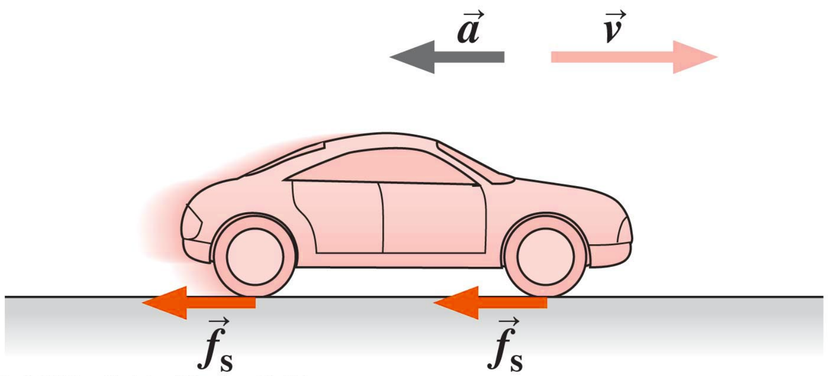
- **Kinetic friction** occurs between surfaces in motion; its magnitude $f_k = \mu_k n$

# Friction

Friction is important in walking, driving and a host of other applications:



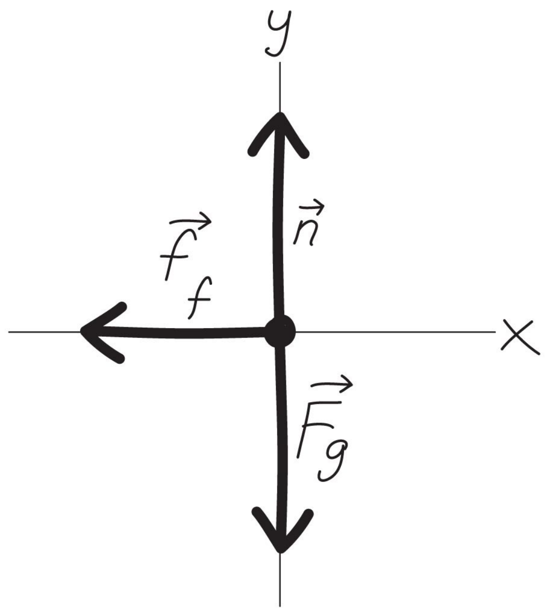



# Solving Problems with Friction

- Problems with friction are like all other Newton's law problems.
- Identify the forces, draw a freebody diagram, write Newton's law.
- You'll need to relate the force components in two perpendicular directions, corresponding to the normal force and the frictional force.

# Solving Problems with Friction

**A braking car: What's the acceleration?**




**Newton's law:**

$$\vec{F}_g + \vec{n} + \vec{f}_f = m\vec{a}$$

**In components:**

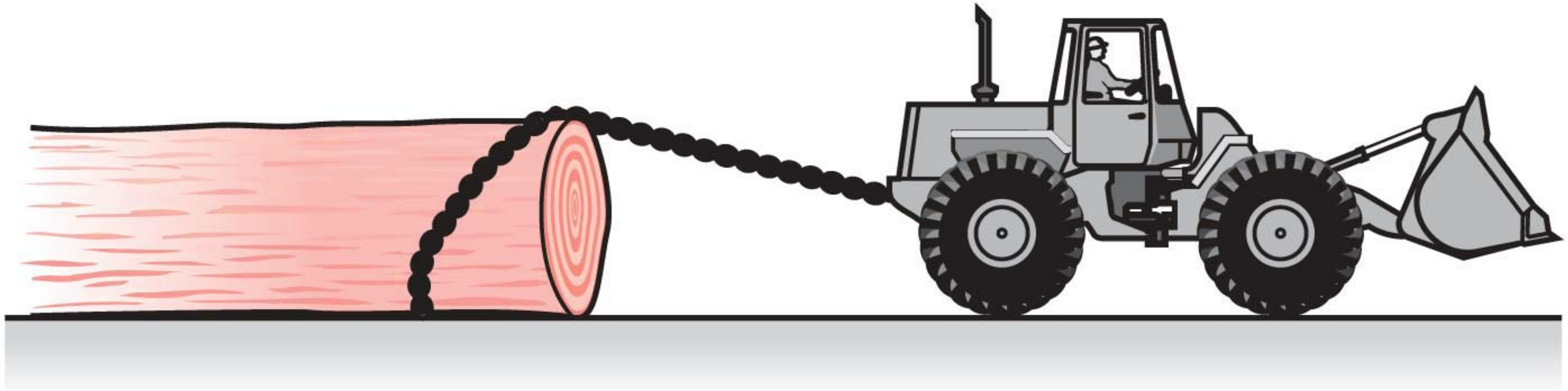
$$x: \quad -\mu \cdot n = m \cdot a_x$$
$$y: \quad -m \cdot g + n = 0$$

**Solve for *a*:**

$y$ equation gives $n = m \cdot g$,

so $x$ equation gives $a_x = -\dfrac{\mu \cdot n}{m} = -\mu \cdot g$

# Clicker question



- The figure shows a logging vehicle pulling a redwood log. Is the frictional force in this case (A) greater than, (B) equal to, or (C) less than the weight multiplied by the coefficient of friction?

# Summary

- All Newton's law problems are the same.
- They're handled by
  - Identifying all the forces acting on the object or objects of interest.
  - Drawing a freebody diagram.
  - Writing Newton's law in vector form:
    - Equating the net force to the mass times the acceleration.
  - Establishing a coordinate system.
  - Writing Newton's law in components.
  - Solving for the quantities of interest.