Physics 1501

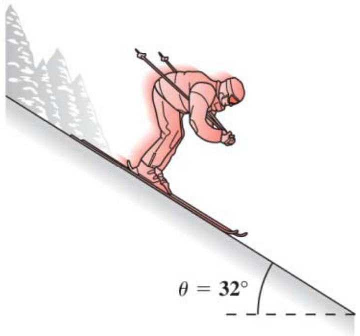
Fall 2008

Mechanics, Thermodynamics, Waves, Fluids

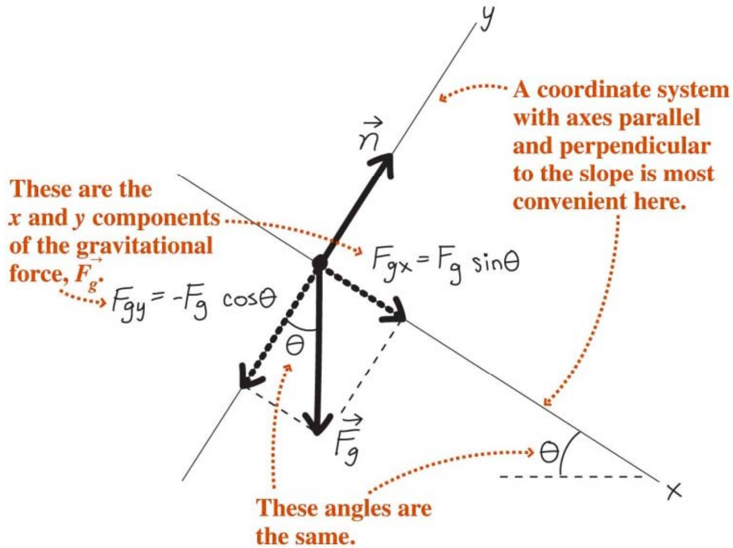
Lecture 10: using Newton's laws II

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

- Physical diagram:



- Free-body diagram:



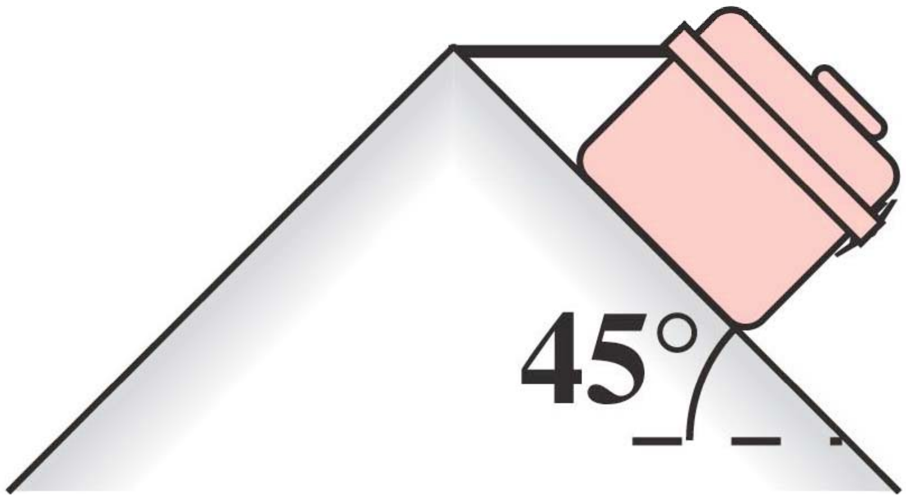
- **Newton's law:**

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

- **In components:**
- **x component: $mg \sin\theta = ma$**
- **y component: $n - mg \cos\theta = 0$**

- **Solve to get the answers:**
- **$a = g \sin\theta (9.8\ \text{m/s}^2)(\sin 32°) = 5.2\ \text{m/s}^2$**
- **$n = mg \cos\theta = 540\ \text{N}$**

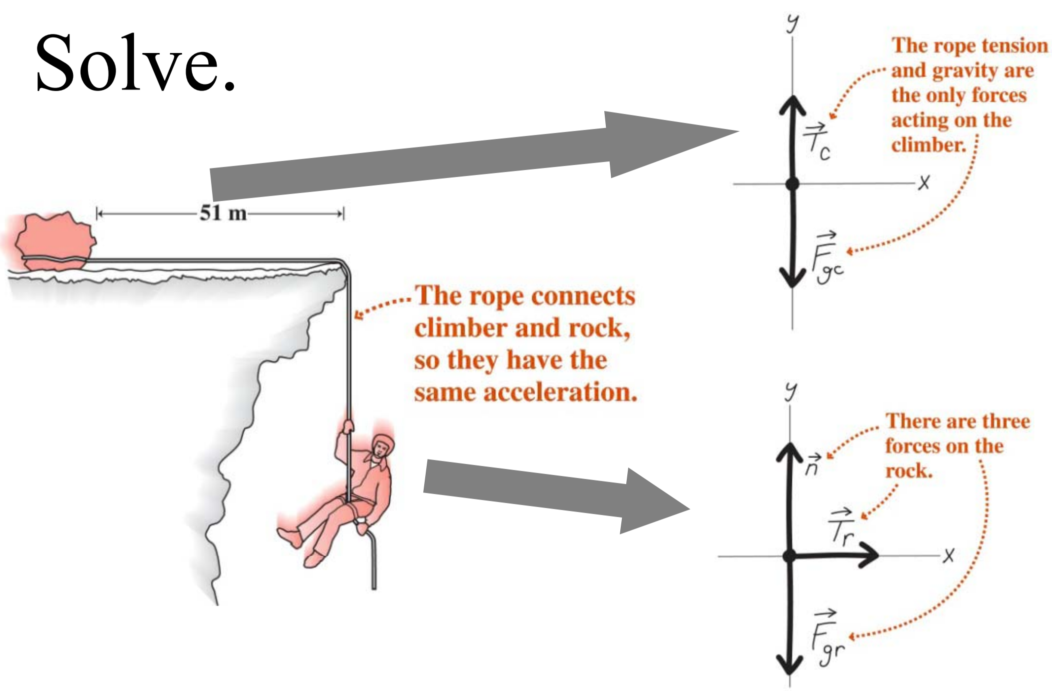
question



- 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.



Newton's law:

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

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

In components:

climber, y: $T - m_c g = -m_c a$

rock, x: $T = m_r a$

rock, y: $n - m_r g = 0$

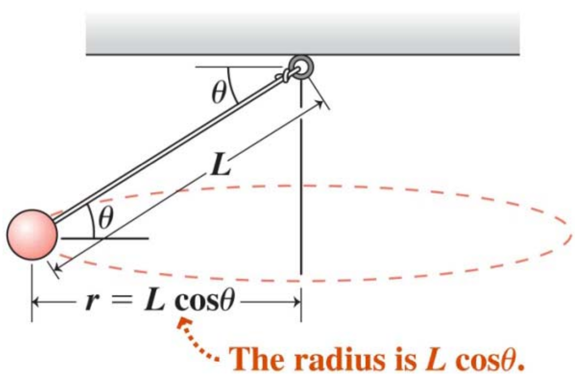
Solution:

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

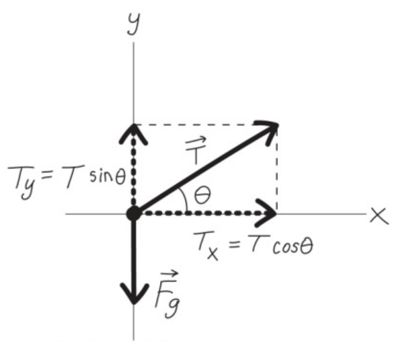
Circular Motion

- 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.

A ball whirling on a string:



Freebody diagram:



Newton's law:

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

In components:

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

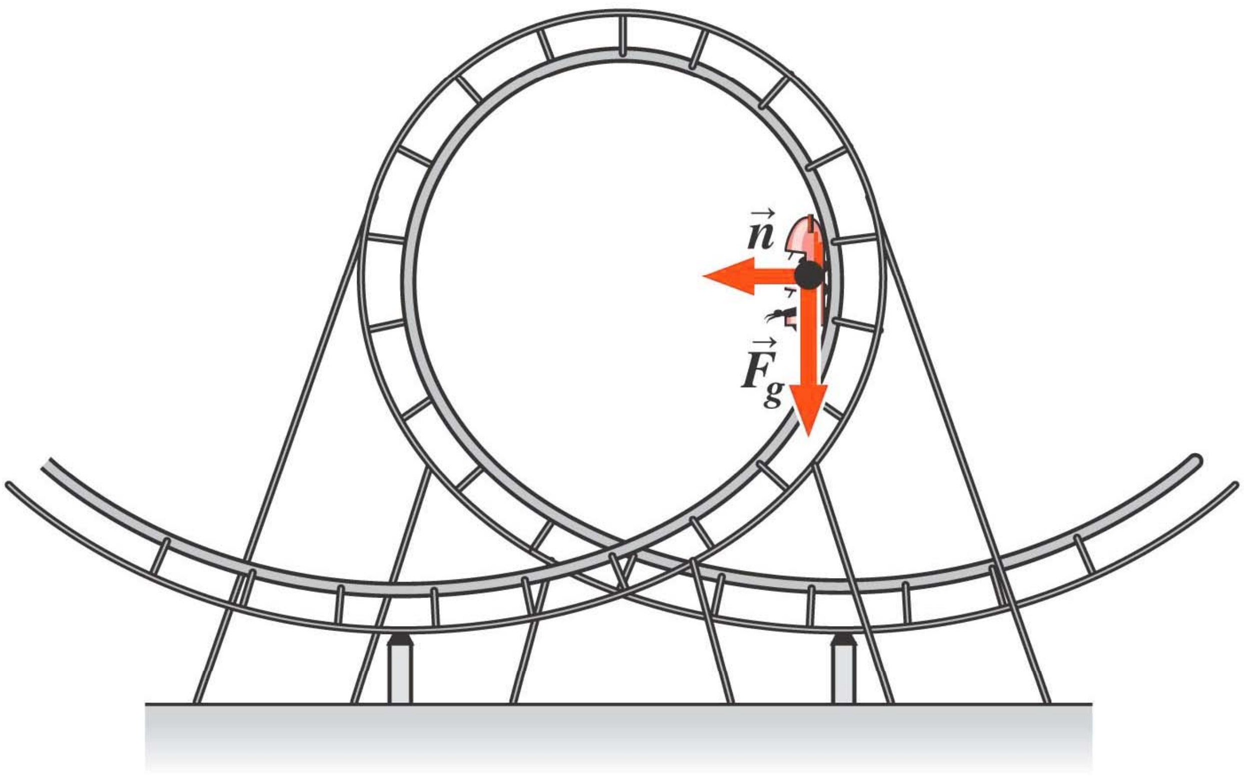
$$y: \quad T\sin\theta - mg = 0$$

Solve for the ball's speed:

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

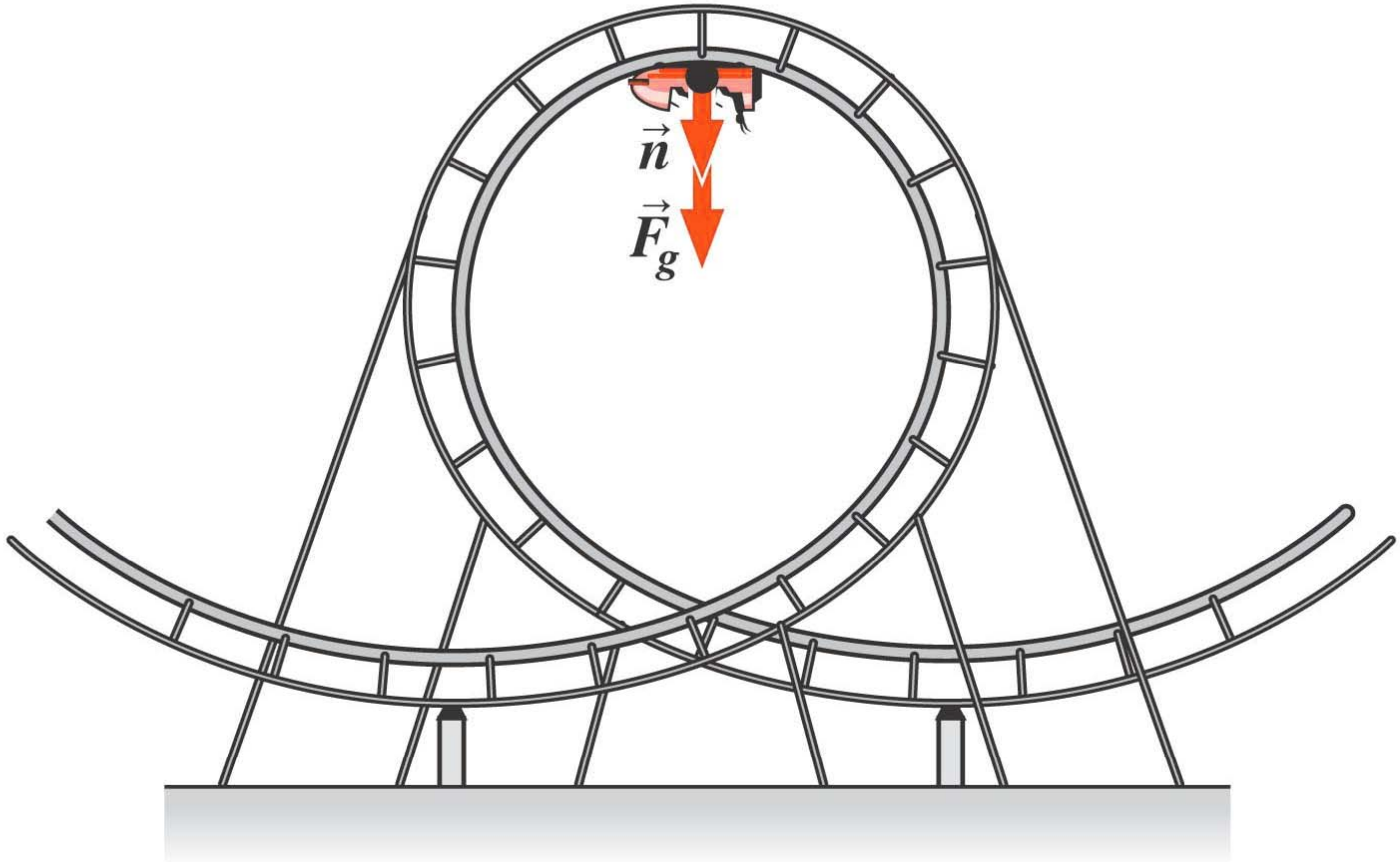
Loop-the-Loop!

- 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.

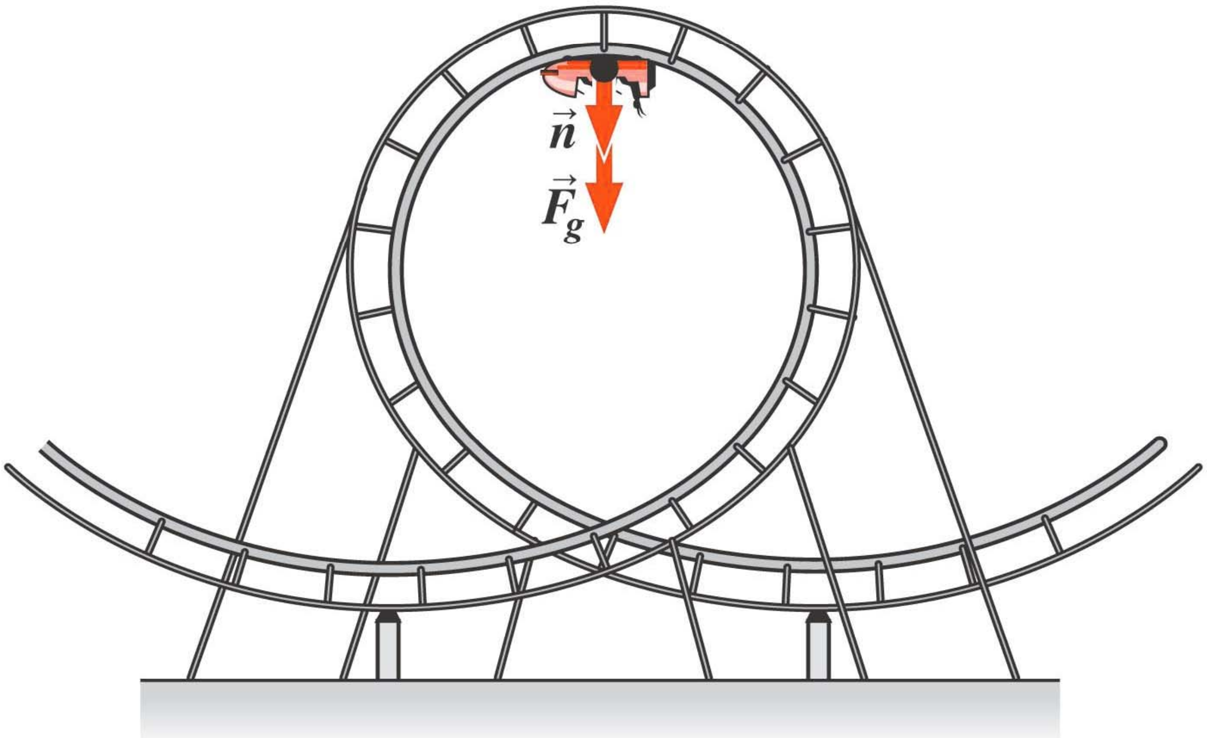


Loop-the-Loop!

- 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:

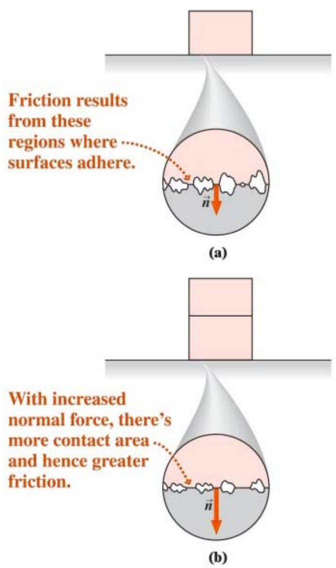
$$\vec{F} = m\vec{a} \quad \rightarrow \quad mg = \frac{mv^2}{r}$$

  - 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 $v \geq \sqrt{gr}$.

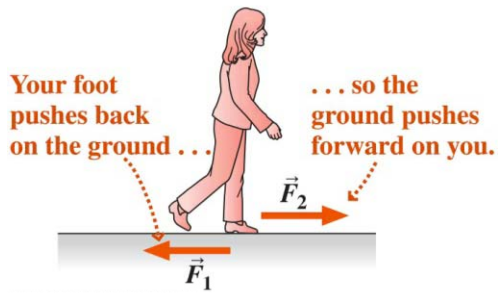


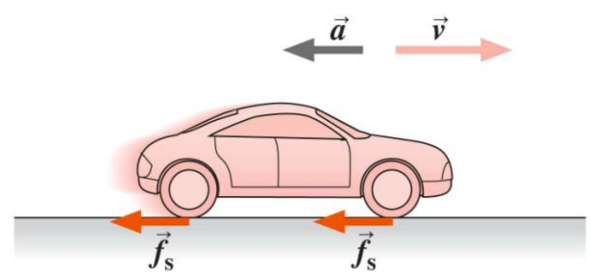
Friction

- **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 $f_s \geq \mu_s n$, where n is the normal force between the surfaces and μ_s is the **coefficient of static friction.**
- **Kinetic friction** occurs between surfaces in motion; its magnitude is $f_k = \mu_k n$.



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

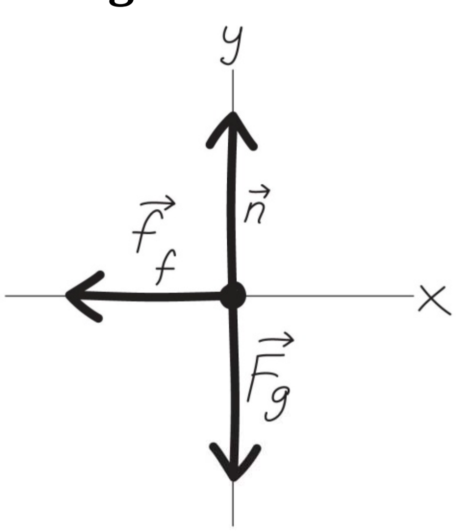




Solving Problems with Friction

- 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.

A braking car: What's the acceleration?



Newton's law:

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

In components:

$$x: \quad -\mu n = ma_x$$

$$y: \quad -mg + n = 0$$

Solve for *a*:

y equation gives $n = mg$,

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