# physics

## FOR SCIENTISTS AND ENGINEERS

## a strategic approach

THIRD EDITION

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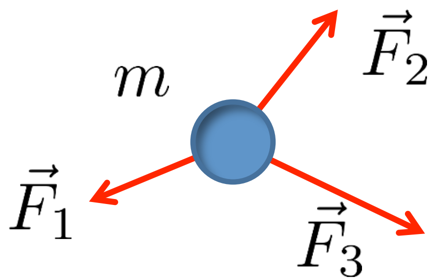
# Ch 6.1 – 6.2: Equilibrium and Newton's Second Law

# Dynamics

In the beginning:

- Kinematics
- Dynamics

**Newton's Second Law:**




$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

The acceleration of the body is:

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

Once we know the acceleration, kinematics tells us how the object moves.

We will simplify this equation for 1D problems: $F_x = ma_x$

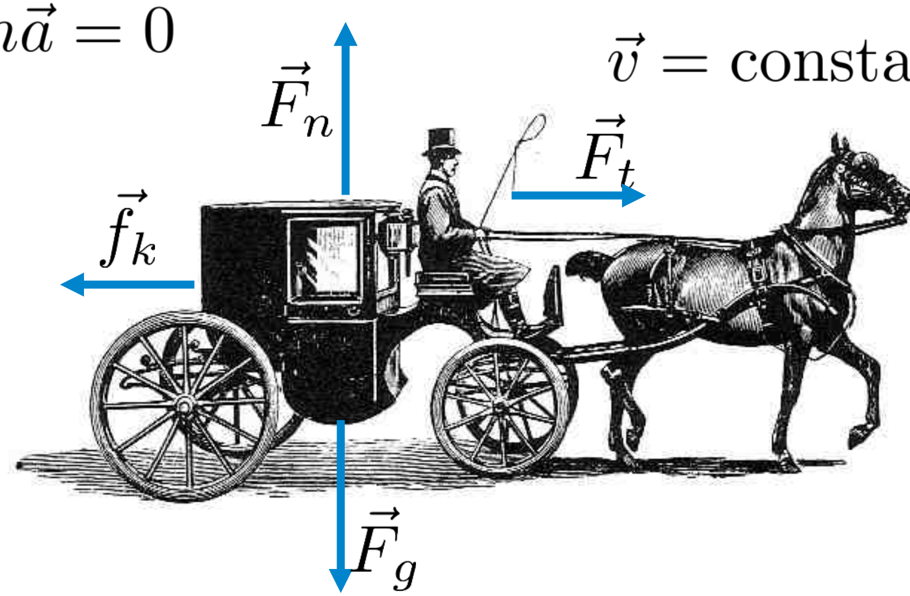
And the 1D kinematics equations: $v_x = \frac{dx}{dt}$ and $a_x = \frac{dv_x}{dt}$

# Equilibrium (Sec 6.1)

Defined as an object on which the net force is zero.

$$\vec{F}_{net} = m\vec{a} = 0$$

$$\vec{v} = \text{constant}$$

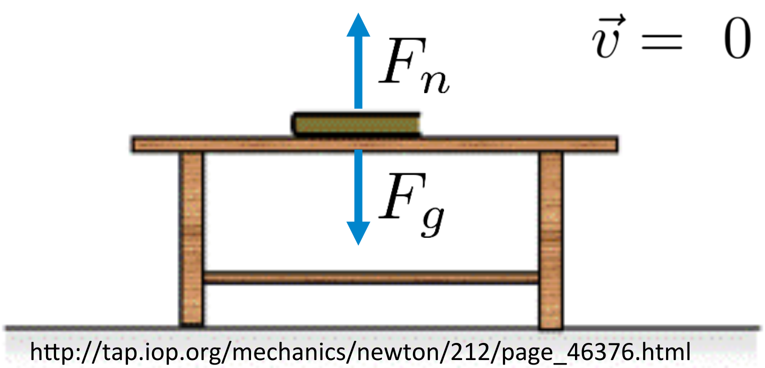



Two conditions:

Dynamic – moving

$$\vec{v} = \text{ constant and } \vec{a} = 0$$

Static - stationary




$$\vec{v} = \ 0 \text{ and } \vec{a} = 0$$

In 2D to verify if the net force = 0:

Sum x-components $\Sigma F_x = 0$

Sum y-components $\Sigma F_y = 0$

PROBLEM-SOLVING STRATEGY 6.1

# Equilibrium problems

**MODEL** Make simplifying assumptions. When appropriate, represent the object as a particle.

(will always be the case until we get to chapter 12)

**VISUALIZE**

- Establish a coordinate system, define symbols, and identify what the problem is asking you to find. This is the process of translating words into symbols.
- Identify *all* forces acting on the object and show them on a free-body diagram.
- These elements form the **pictorial representation** of the problem.

**SOLVE** The mathematical representation is based on Newton's first law:

$$\vec{F}_{net} = \sum_i \vec{F}_i = \vec{0}$$

Use in component form:

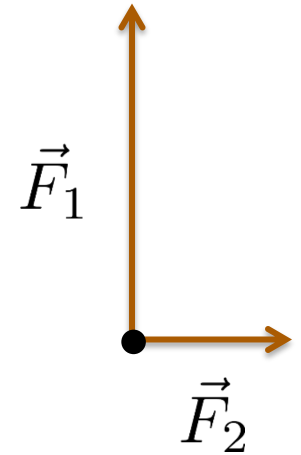
$$\begin{cases} \sum F_x = 0 \\ \sum F_y = 0 \end{cases}$$

The vector sum of the forces is found directly from the free-body diagram.

**ASSESS** Check that your result has the correct units, is reasonable, and answers the question.

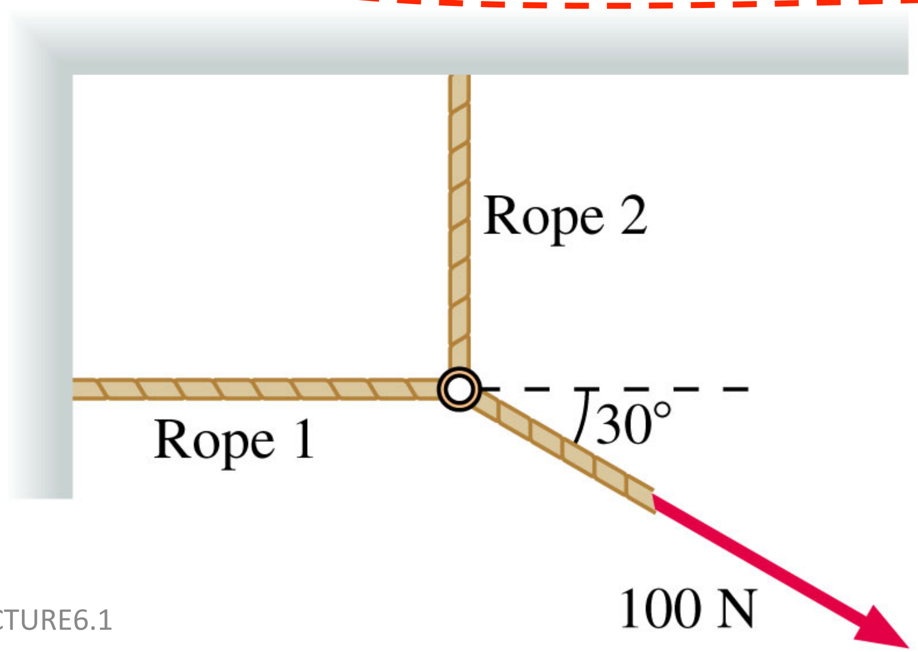
# Whiteboard Problem 6.1

The object below is in equilibrium. Draw the 3[rd] force acting on the object.




Three ropes are tied to a small, light ring (here we mean the mass is negligible). Two of the ropes are anchored to the wall at right angles, and the third rope pulls as shown.

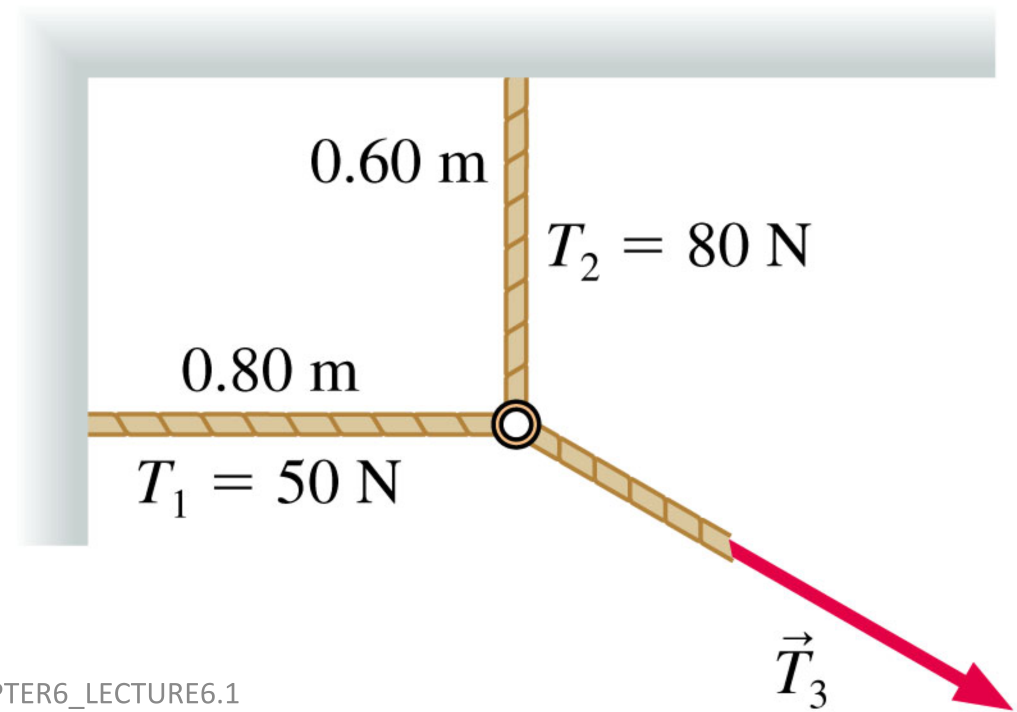
What are $T_1$ and $T_2$, the magnitudes of the tension forces in the first two ropes?



# Whiteboard Problem 6.2

The three ropes in the figure below are tied to a small, very light ring. Two ropes are anchored to the wall at right angles.

What are the magnitude and direction of the tension $\vec{T}_3$ in the third rope, if the ring is in equilibrium?



PROBLEM-SOLVING STRATEGY 6.2

# Dynamics problems where $\vec{a} \neq 0$

**Sec 6.2)**

MODEL Make simplifying assumptions.

VISUALIZE Draw a **pictorial representation.**

- Show important points in the motion with a sketch, establish a coordinate system, define symbols, and identify what the problem is trying to find.
- Use a motion diagram to determine the object's acceleration vector $\vec{a}$.
- Identify all forces acting on the object *at this instant* and show them on a free-body diagram.
- It's OK to go back and forth between these steps as you visualize the situation.

SOLVE The mathematical representation is based on Newton's second law:

Use in component form:

$$\vec{F}_{\text{net}} = \sum_i \vec{F}_i = m\vec{a} \quad \begin{cases} \sum F_x = ma_x \\ \sum F_y = ma_y \end{cases}$$

The vector sum of the forces is found directly from the free-body diagram. Depending on the problem, either

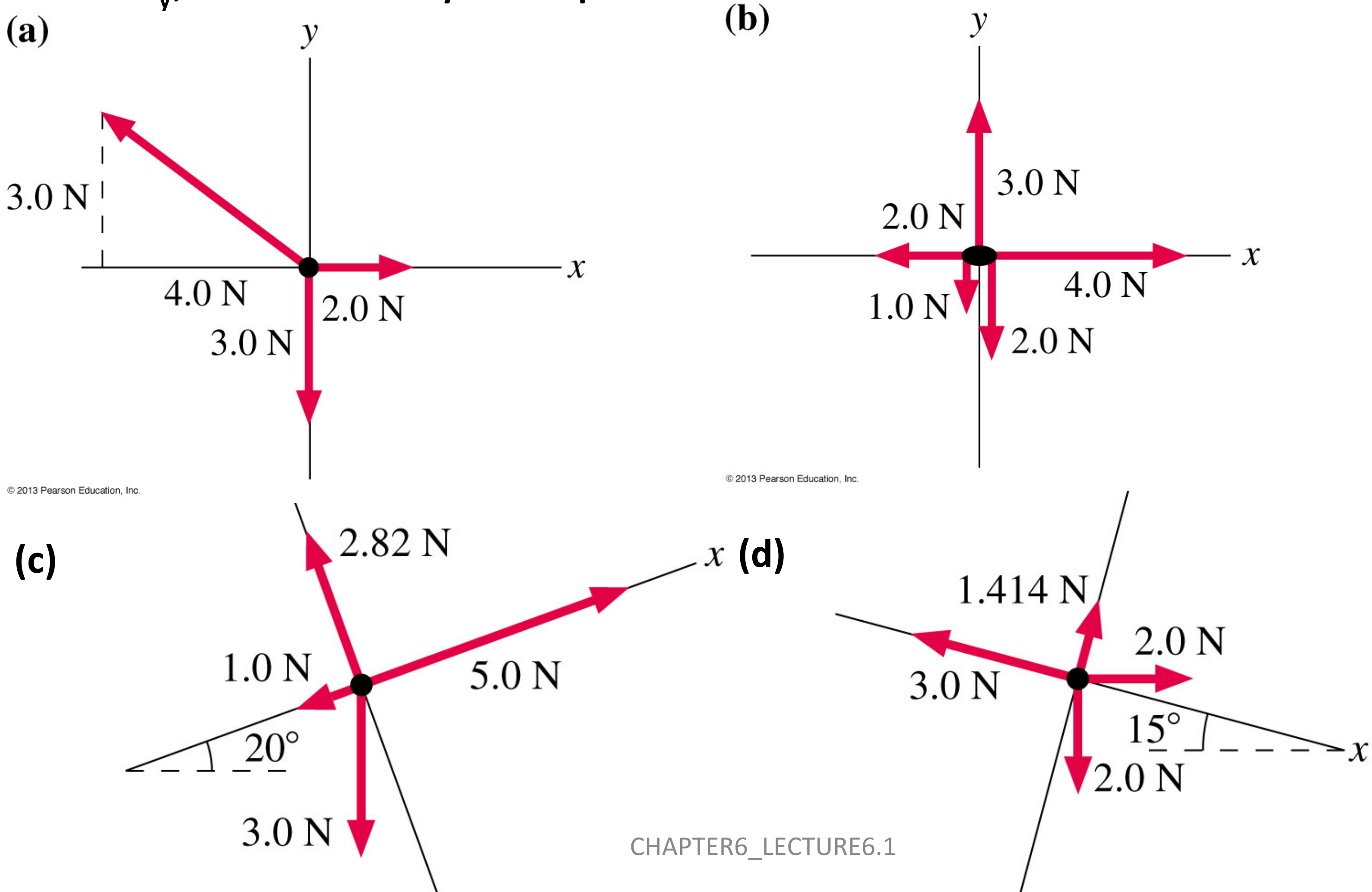
- Solve for the acceleration, then use kinematics to find velocities and positions; or
- Use kinematics to determine the acceleration, then solve for unknown forces.

ASSESS Check that your result has the correct units, is reasonable, and answers the question.

Exercise 22

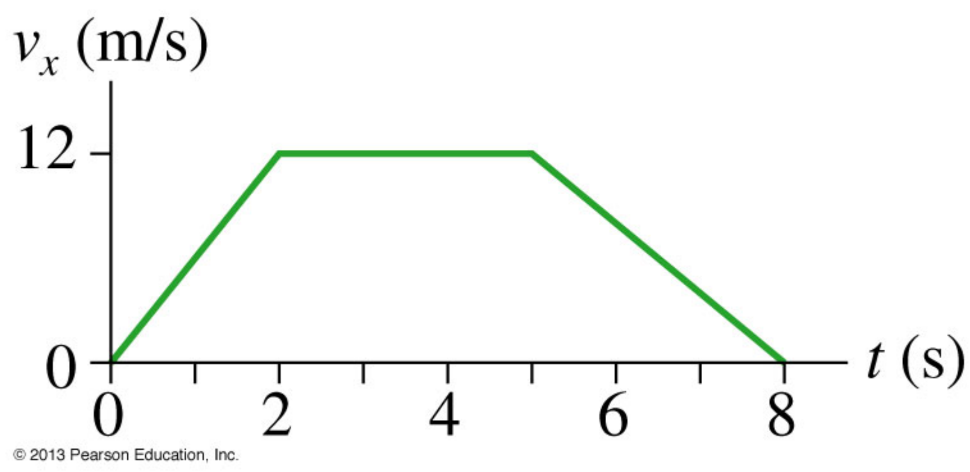
# Whiteboard Problem 6.3 (Sec 6.2)

In each of the two free-body diagrams below, the forces are acting on a 2.0 kg object. For each diagram, find the values of $a_x$ and $a_y$, the x- and y-components of the acceleration.



# Whiteboard Problem 6.4 (Sec 6.2)

The figure below shows the velocity graph of a 2.0 kg object as it moves along the x-axis. What is the net force acting on this object at t = 1s? At t = 4s? At t = 7s?



# Whiteboard Problem 6.5 (Sec 6.1 & 6.2)

A 50 kg box hangs from a rope. What is the tension in the rope if:

(A) The box is at rest?

(B) The box moves up at a steady 5.0 m/s?

(C) The box has $v_y$ = 5.0 m/s and is speeding up at 5.0 $m/s^2$?

(D) The box has $v_y$ = 5.0 m/s and is slowing down at 5.0 $m/s^2$?

# Whiteboard Problem 6.6 (Sec 6.2)

Cars are designed with a “crumple-zone” in the front of the car. In the event of an impact, the passenger compartment decelerates over ~1m. An occupant restrained by seat belts and air bags decelerates with the car. In contrast, a passenger not wearing a seat belt or using an air bag decelerates over a distance of 5mm.

(A) A 60kg person is in a head-on collision. The cars speed at impact is 15 m/s. Estimate the net force of the person if the air bag deploys and they are wearing a seat belt.

(B) Same situation as (A), except no air bags or seat belts.

(C) Compare with the person’s ‘weight’ (mg)


http://www.blogcdn.com/www.autoblog.com/media/2009/08/iihs-small-car-crash_0006.jpg

# Whiteboard Problem 6.7 (Sec 6.2)

Calculate the average force a bumper would have to exert if it brought a 1200-kg car (a so-called compact model) to a rest in 15 cm when the car had an initial speed of 2.0 m/s (about 4.5 mph). (Bumpers are built with springs that compress to provide a stopping force without, hopefully, denting the metal.)

# Friction (Sec 6.4)

Every surface is ‘rough’ on some level.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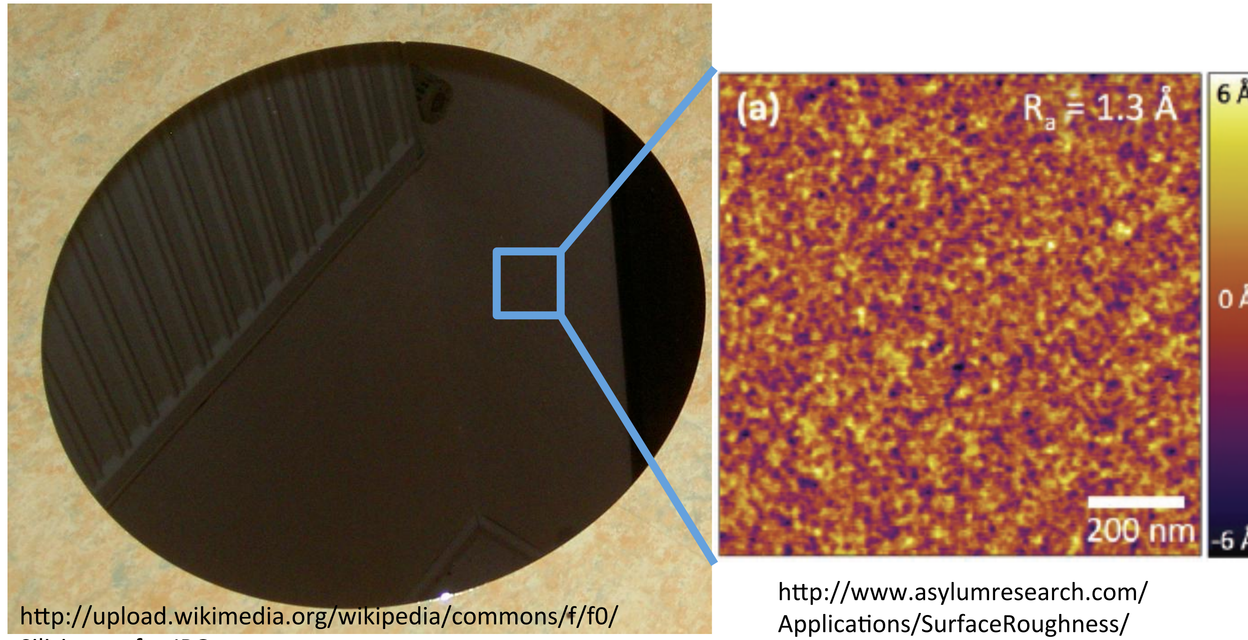
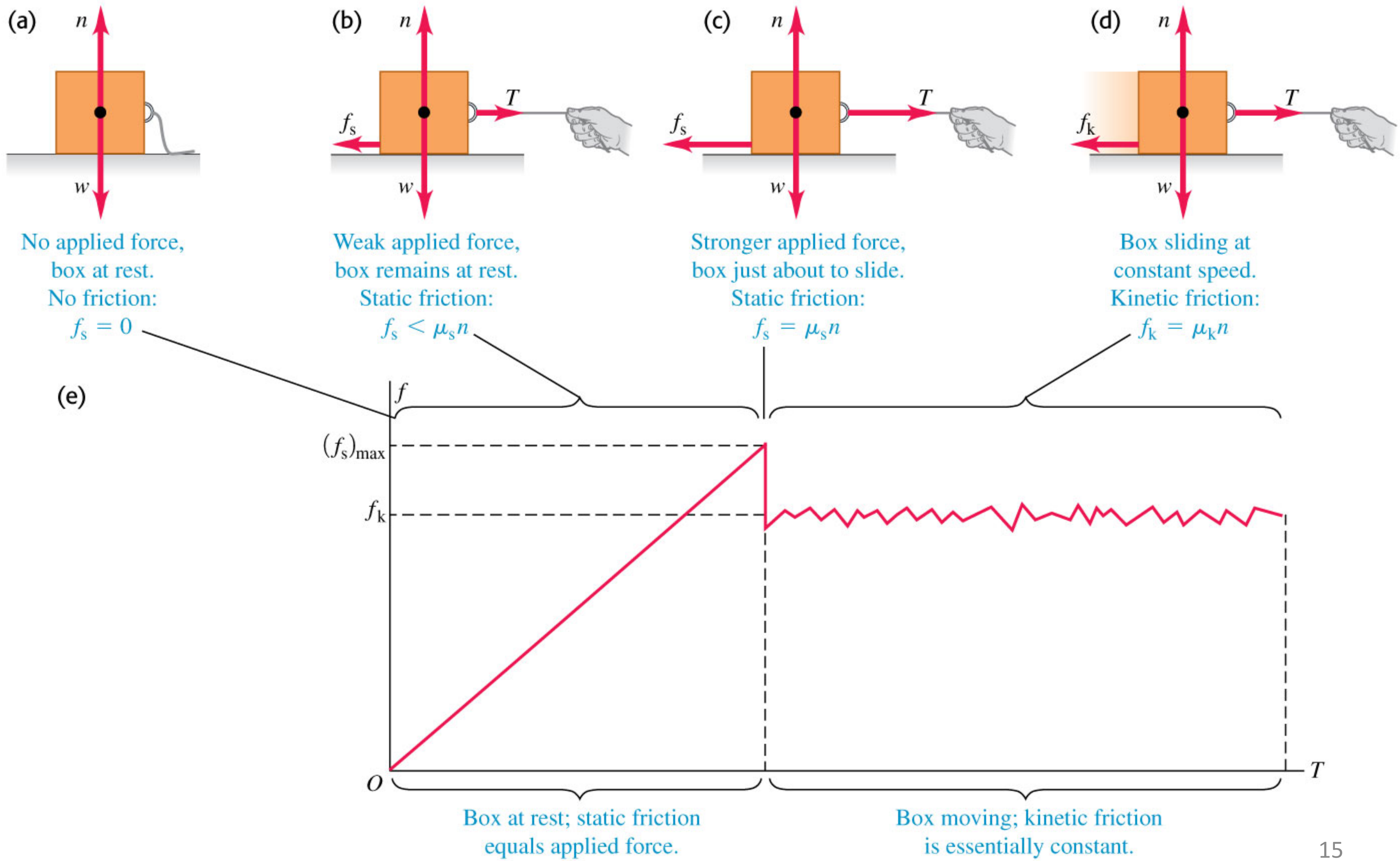



http://upload.wikimedia.org/wikipedia/commons/f/f0/Siliziumwafer.JPG

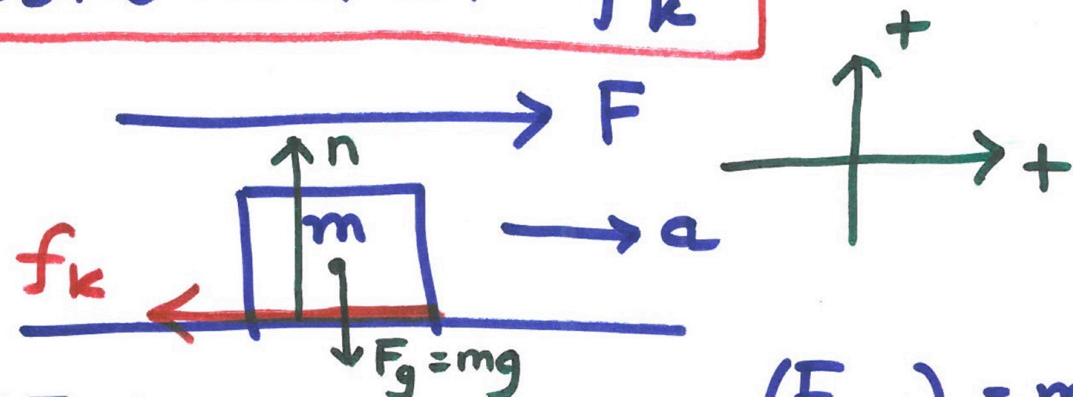
http://www.asylumresearch.com/Applications/SurfaceRoughness/SurfaceRoughness.pdf

# Transition from Rest to Motion (Sec 6.4)



# Sec 6.4

## KINETIC FRICTION '$f_k$'




$$(F_{net})_x = ma_x$$

$$F - f_k = ma \quad \text{— (i)}$$

$$(F_{net})_y = ma_y$$

$$n - mg = 0$$

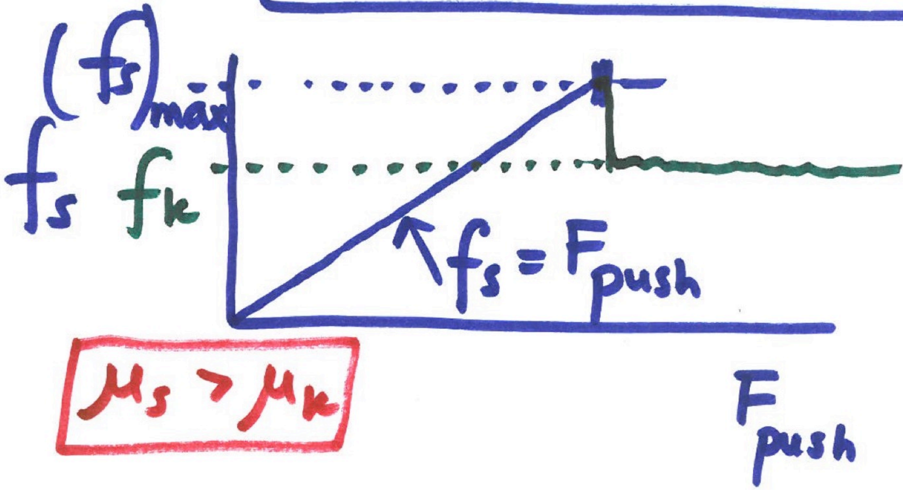
$$\Rightarrow n = mg \quad \text{— (i)}$$

WE EMPIRICALLY OBSERVE THAT $f_k \propto n$

$$f_k = \mu_k n$$

COEFFICIENT OF KINETIC FRICTION $\mu_k$ IS DIMENSIONLESS

# STATIC FRICTION '$f_s$'




$\mu_s > \mu_k$

$f_s$ SCALES w/ $F_{push}$ until $f_s$ attains $(f_s)_{max}$

$$(f_s)_{max} \propto n$$

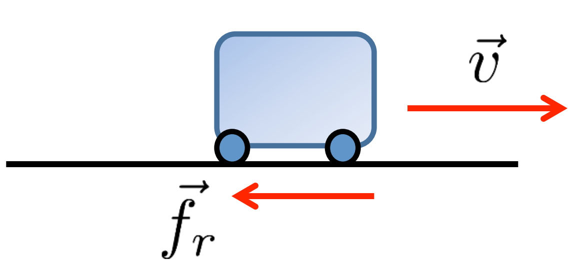
$$(f_s)_{max} = \mu_s n$$

$\mu_s$ → COEFFICIENT OF STATIC FRICTION !

$\mu_s$ ALWAYS CORRESPONDS TO THE MAXIMUM STATIC FRICTION FORCE !!

# Rolling Friction

**Rolling Friction**: when there is rolling motion, there is friction present, but it is different than for sliding. A rolling friction force is modeled like a kinetic friction force. The coefficient of rolling friction is always much less than that for sliding motion.




$$\vec{f}_r = (\mu_r n, \text{ opposite the direction of motion})$$
$$\mu_r = \text{coefficient of rolling friction}$$
$$n = \text{magnitude of the normal force}$$

# Coefficients of Friction

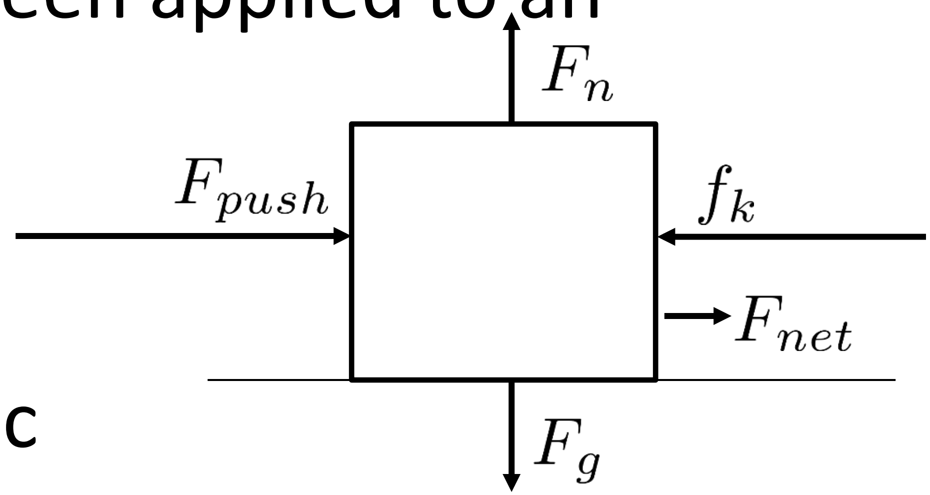
**Sec 6.4**
**Table 6.1**

| Materials | Static $\mu_s$ | Kinetic $\mu_k$ | Rolling $\mu_r$ |
|---|---|---|---|
| Rubber on concrete | 1.00 | 0.80 | 0.02 |
| Steel on steel (dry) | 0.80 | 0.60 | 0.002 |
| Steel on steel (lubricated) | 0.10 | 0.05 | |
| Wood on wood | 0.50 | 0.20 | |
| Wood on snow | 0.12 | 0.06 | |
| Ice on ice | 0.10 | 0.03 | |
| Synovial fluid in human joints | 0.01 | 0.003 | |

# Kinetic Friction (Sec 6.4 and 6.6)

Kinetic friction – opposes motion

Once enough force has been applied to an object it begins moving:




This implies $f_k < f_{s\ max}$

where $f_k$ is force of kinetic friction

Similarly: $f_\mathrm{k} = \mu_\mathrm{k} \left| \vec{F}_n \right|$

where $\mu_k$ is the coefficient of kinetic friction

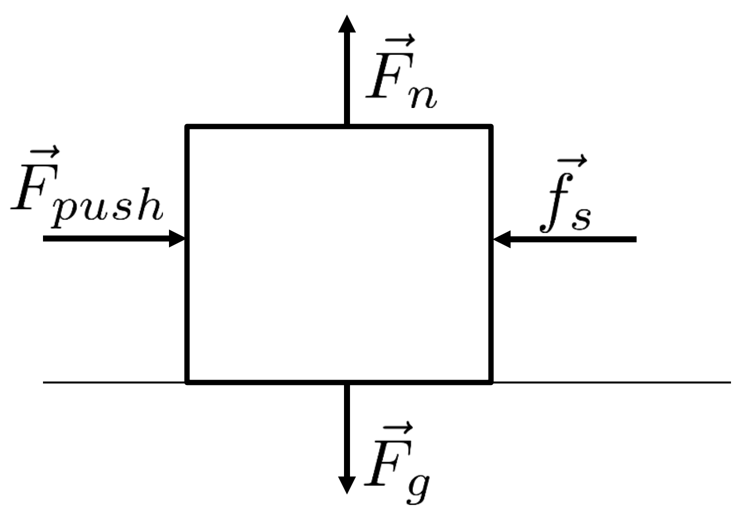
# Whiteboard Problem 6-8 (Sec 6.4, 6.6)

Bonnie and Clyde are sliding a 300 kg bank safe across the floor to their getaway car. The safe slides with a constant speed if Clyde pushes from behind with 385 N of force while Bonnie pulls from forward on a rope with 350 N of force. What is the safe's coefficient of kinetic friction on the bank floor?

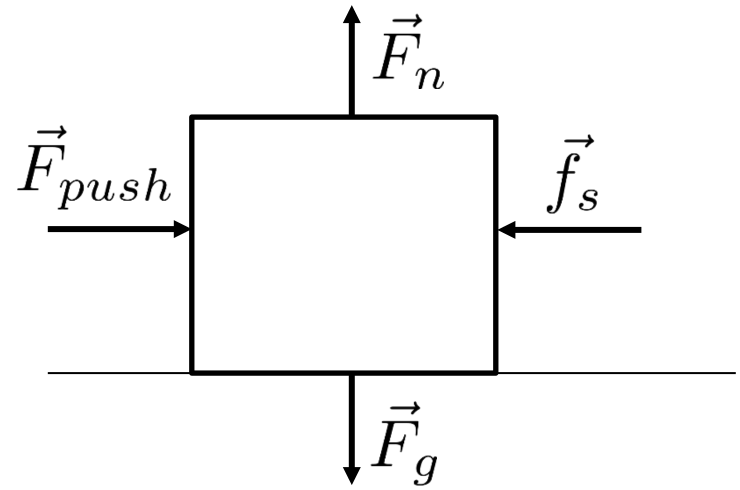
# Static Friction (Sec 6.4, 6.6)

Static friction – prevents the motion of an object when feeling an applied force:

This is a strange force, as it scales with the applied force.



# Static Friction




Static equilibrium: $f_s = F_{push}$

There must be a finite limit to this relation: otherwise nothing would ever move!

$$f_{\rm s} \leq \mu_s \left| \vec{F}_n \right|$$

where $\mu_s$ is the coefficient of static friction

NOTE! The normal force is not equal to the weight in many situations!

# Whiteboard Problem 6.9

Kristoff's sled is parked on a $5^{o}$ slope. He is carrying 500 kg of ice and the mass of the empty sled is 50 kg. How large is the friction force between the sled and the snow? $\mu_s = .12$

# Whiteboard Problem 6.10

In a fit of rage, Walter White hurls a pizza box up onto the roof of his house. The pizza has a mass of 1.5 kg and the slope of the roof is 22.6°. What is the force on the pizza due to static friction and if $\mu_s$ is 0.70 is the pizza in danger of sliding off of the roof?

# Whiteboard Problem 6.10: ANSWER

# ☺

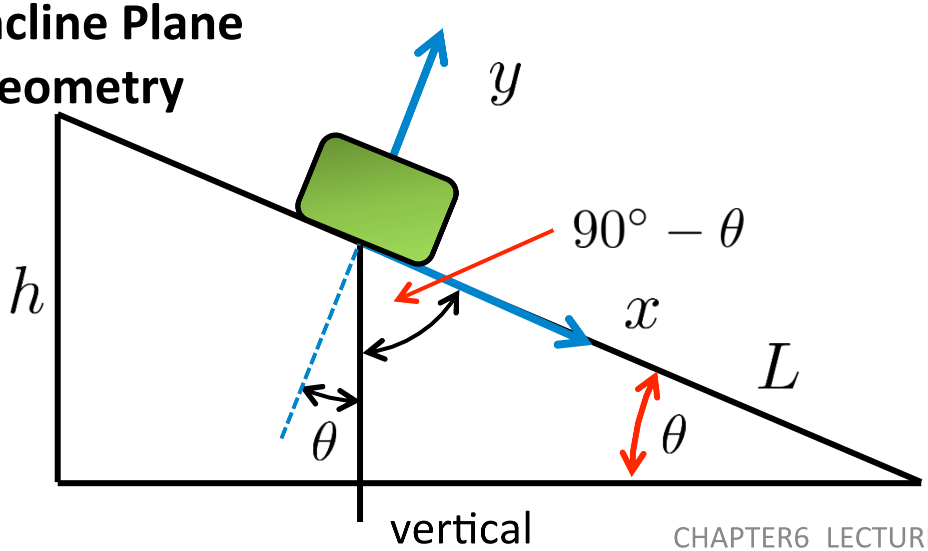
- Q: Three kittens are sitting on a sloped roof. Which one falls off first?
- A: The one with the lowest mew!

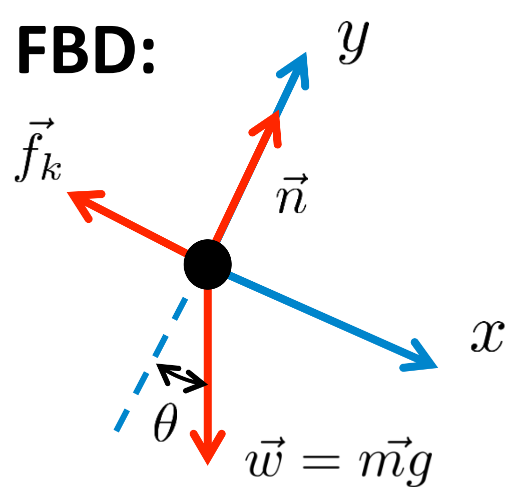
# Whiteboard Prob 6-11 (kinetic friction; Problem 6-48)

An object of mass $m$ is at rest at the top of a smooth slope of height $h$ and length $L$. The coefficient of kinetic friction between the object and the surface, $\mu_k$, is small enough that the object will slide down the slope if given a very small push to get it started. Find an expression for the object's speed at the bottom of the slope. (in terms of $m, L, h, \mu_k$)

**Hint:** get $v$ in terms of the incline angle, $\theta$, first; then use geometry to express it in terms of $L$ and $h$.

**Incline Plane Geometry**

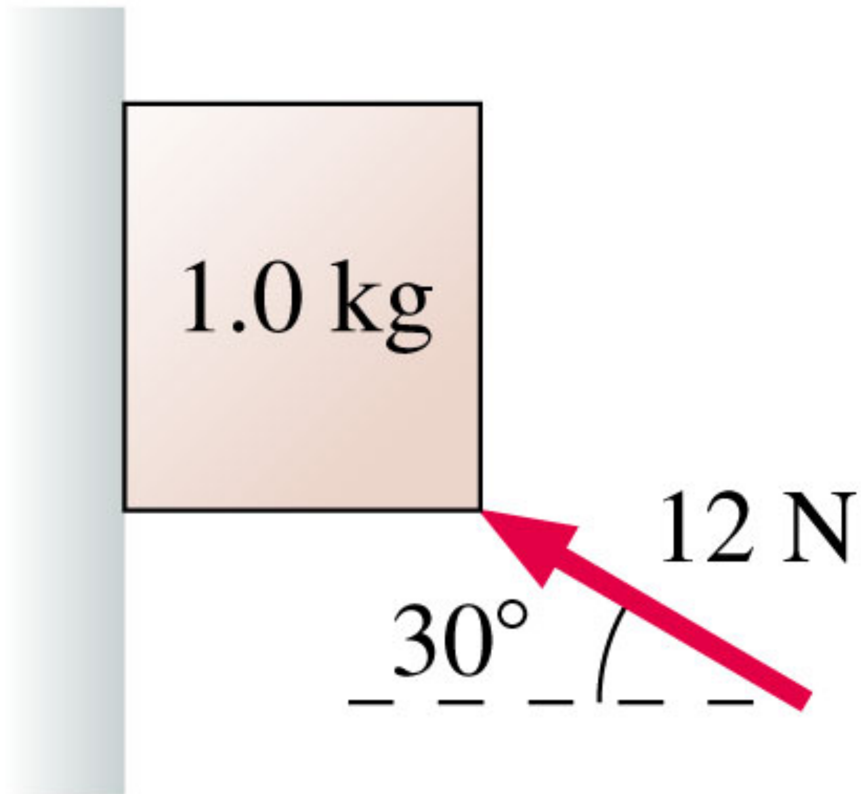


# Whiteboard Problem 6-12 (Static Friction; Problem # 6-57)

**(Don't be fooled by Conceptual-sounding Questions on the exam)**

A 1.0 kg wood block is pressed against a vertical wood wall by the 12 N force shown in FIGURE P6.55. If the block is initially at rest, will it move upward, move downward, or stay at rest?

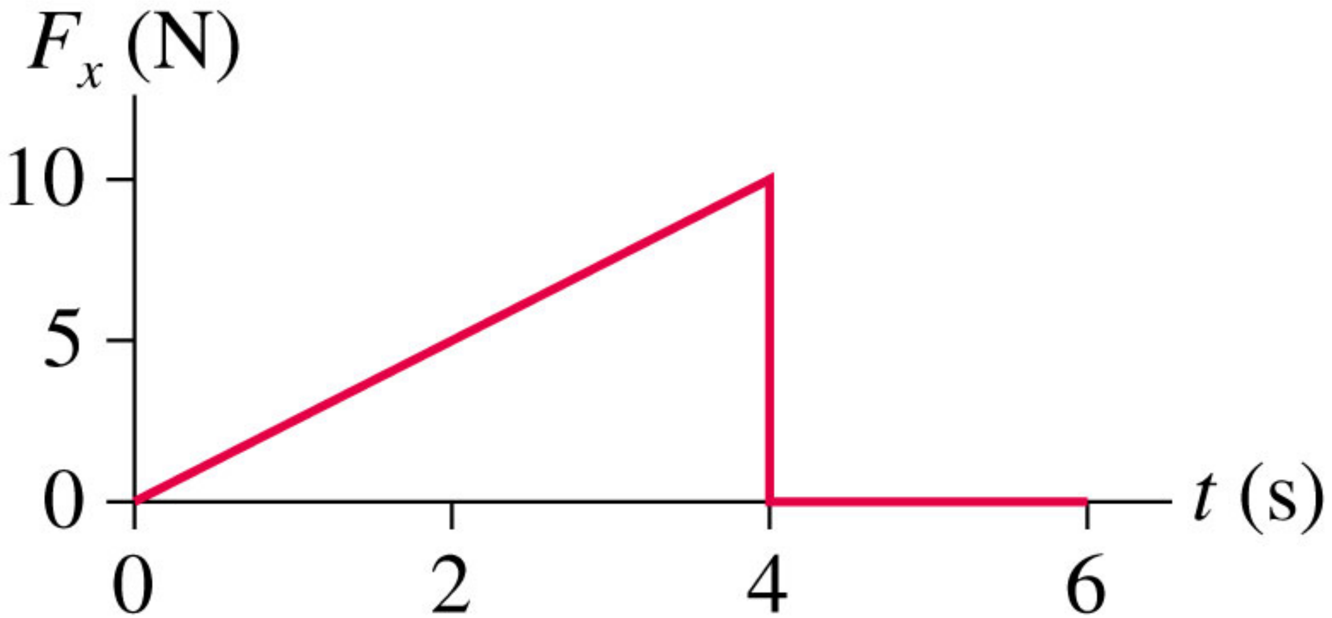





Show us your FBD before you write any equations.

# Don't be fooled: Prob. 6-38

A 5.0 kg object initially at rest at the origin is subjected to the time-varying force shown in FIGURE P6.26. What is the object's velocity at $t = 6$ s?






Why can't you use $v_1 = v_0 + a_x \Delta t$ ?

**The acceleration is not constant!**