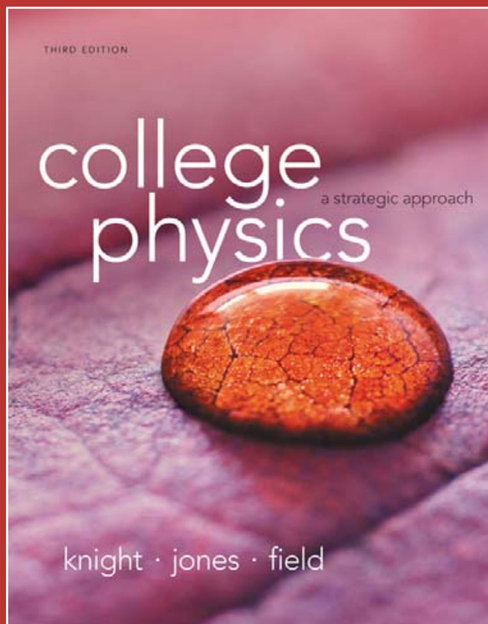


Material in this presentation comes from the following book [Ali]

Lecture Presentation

Chapter 4

Forces and Newton's Laws of Motion

Suggested Simulations for Chapter 4

- **PhETs**
  - *Forces in 1D*
  - *The Ramp*

Chapter 4 Forces and Newton's Laws of Motion

Chapter Goal: To establish a connection between force and motion.

 Slide 4-3

Chapter 4 Preview
Looking Ahead: Forces

- A force is a push or a pull. It is an interaction between two objects, the **agent** (the woman) and the **object** (the car).

- In this chapter, you'll learn how to identify different forces, and you'll learn their properties.

 Slide 4-4

Chapter 4 Preview
Looking Ahead: Forces and Motion

- Acceleration is caused by forces. A forward acceleration of the sled requires a forward force.

- A larger acceleration requires a larger force. You'll learn this connection between force and motion, part of Newton's second law.

Slide 4-5

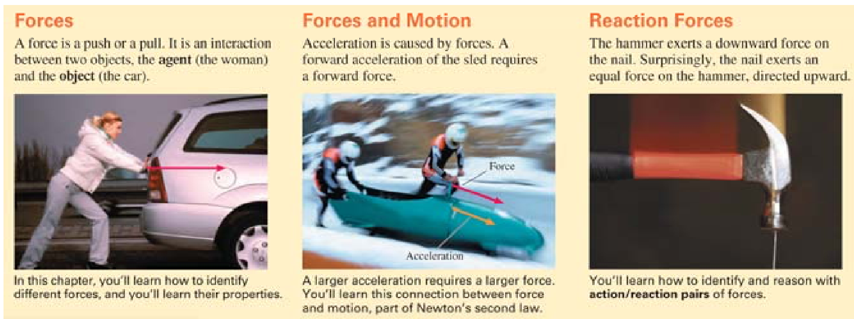
Chapter 4 Preview
Looking Ahead: Reaction Forces

- The hammer exerts a downward force on the nail. Surprisingly, the nail exerts an equal force on the hammer, directed upward.

- You'll learn how to identify and reason with **action/reaction pairs** of forces.

Slide 4-6

Chapter 4 Preview
Looking Ahead



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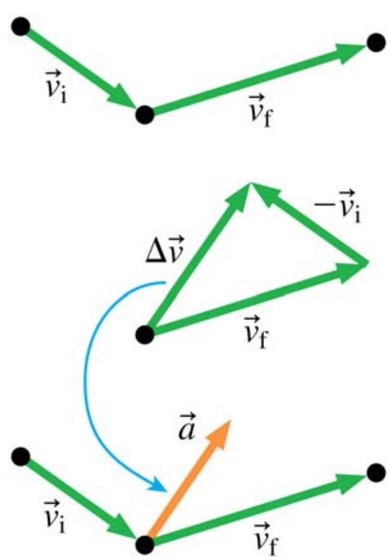
Chapter 4 Preview
Looking Back: Acceleration

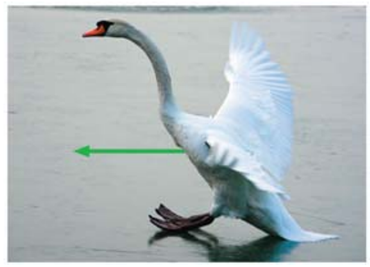
- You learned in Chapters 2 and 3 that acceleration is a vector pointing in the direction of the change in velocity.
- If the velocity is changing, there is an acceleration. And so, as you'll learn in this chapter, there must be a net force.



Chapter 4 Preview
Stop to Think

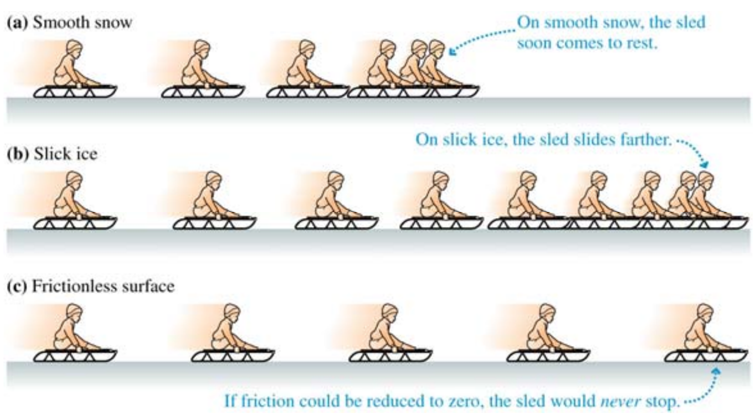
A swan is landing on an icy lake, sliding across the ice and gradually coming to a stop. As the swan slides, the direction of the acceleration is

A. To the left.
B. To the right.
C. Upward.
D. Downward.



 Slide 4-9

What Causes Motion?



- In the absence of friction, **if the sled is moving, it will stay in motion.**

 Slide 4-10

What Causes Motion?

Newton's first law An object has no forces acting on it. If it is at rest, it will remain at rest. If it is moving, it will continue to move in a straight line at a constant speed.

What Is a Force?

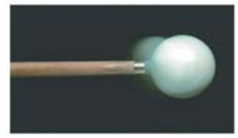
- A **force** is a *push* or a *pull*.

- **A force acts on an object.**

- Every force has an **agent**, something that acts or pushes or pulls.

What Is a Force?

- A **force** is a *vector*. The general symbol for a force is the vector symbol $\vec{F}$. The size or strength of such a force is its magnitude F.



- **Contact forces** are forces that act on an object by touching it at a point of contact.

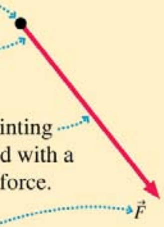
- **Long-range forces** are forces that act on an object without physical contact.

Force Vectors

TACTICS BOX 4.1 Drawing force vectors

MP

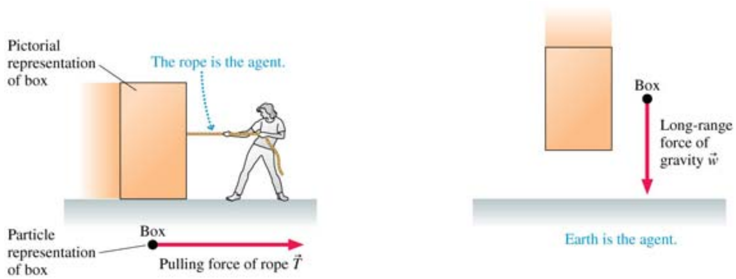
1. Represent the object as a particle.
2. Place the *tail* of the force vector on the particle.
3. Draw the force vector as an arrow pointing in the direction that the force acts, and with a length proportional to the size of the force.
4. Give the vector an appropriate label.



Exercise 1

Text: p. 100

Force Vectors

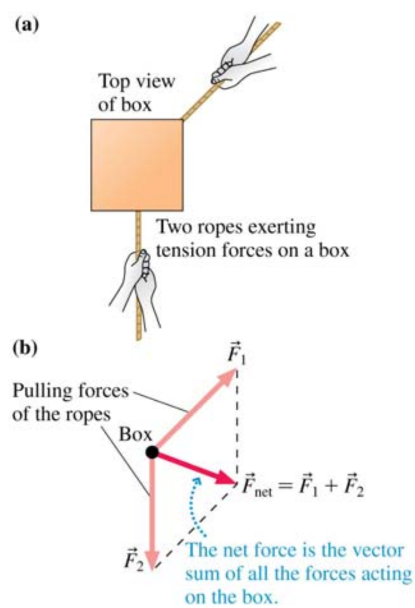


Combining Forces

- Experiments show that when several forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots$ are exerted on an object, the combine to form a **net force** that is the *vector sum* of all the forces:

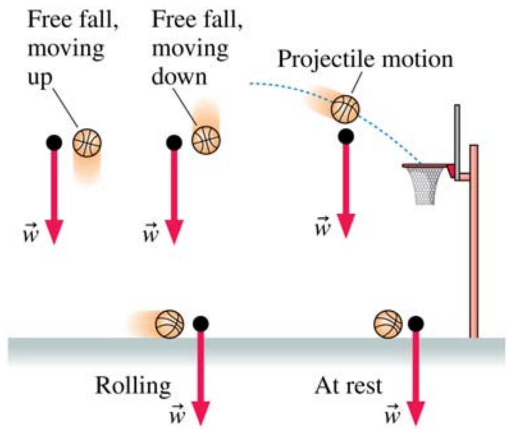
$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$$

- The net force is sometimes called the resultant force. It is not a new force. Instead, we should think of the original forces being *replaced* by $\vec{F}_{\text{net}}$.

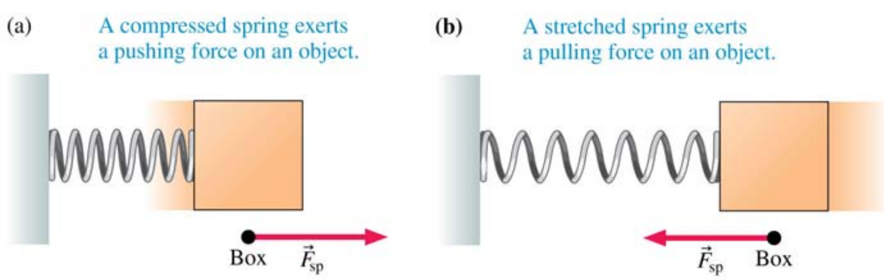


Weight

- The gravitational pull of the earth on an object on or near the surface of the earth is called **weight**.
- The agent for the weight forces is the *entire earth* pulling on an object.
- **An object's weight vector always points vertically downward,** no matter how the object is moving**.**

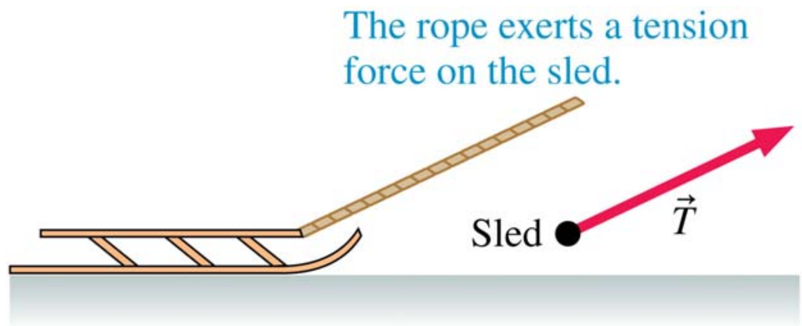


Spring Force



- Springs come in in many forms. When deflected, they push or pull with a spring force.

Tension Force

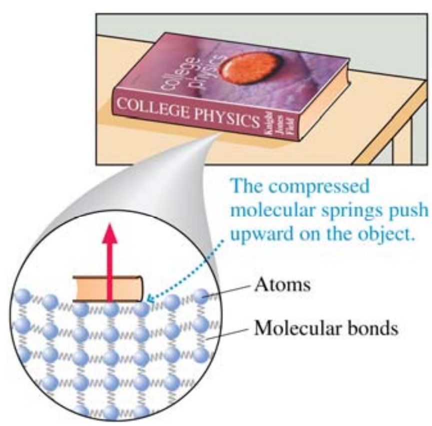


- When a string or rope or wire pulls on an object, it exerts a contact force that we call the **tension force**.
- **The direction of the tension force is always in the direction of the string or rope**.

Slide 4-19

Normal Force

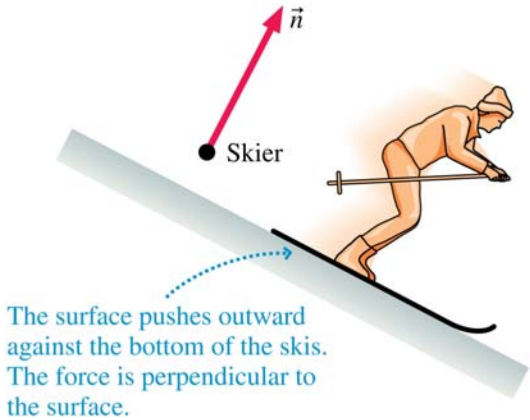
- The force exerted on an object that is pressing against a surface is in a direction *perpendicular* to the surface.
- The **normal force** is the force exerted by a surface (the agent) against an object that is pressing against the surface.



Slide 4-20

Normal Force

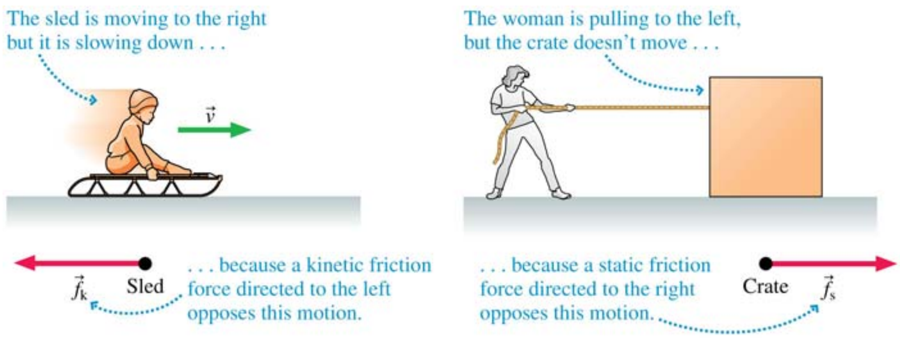
- The normal force is responsible for the "solidness" of solids.
- The symbol for the normal force is $\vec{n}$.



Friction

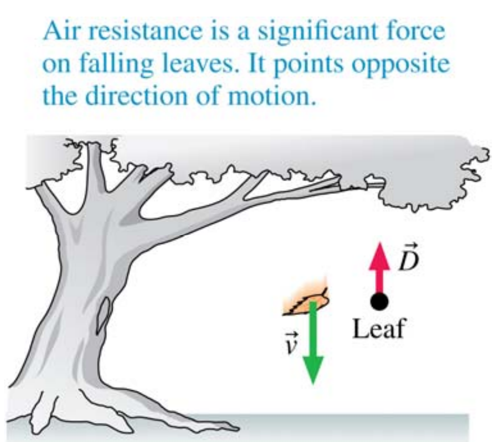
- Friction, like the normal force, is exerted by a surface.
- The frictional force is always parallel to the surface.
- *Kinetic friction,* denoted by $\vec{f}_k$, acts as an object slides across a surface. Kinetic friction is a force that always "opposes the motion."
- *Static friction,* denoted by $\vec{f}_s$, is the force that keeps an object "stuck" on a surface and prevents its motion relative to the surface. Static friction points in the direction necessary to *prevent* motion.

Friction



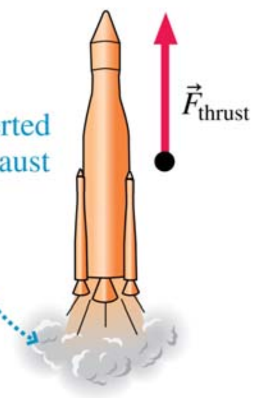
Drag

- The force of a fluid (like air or water) on a moving object is called **drag**.
- Like kinetic friction, drag points opposite the direction of motion.
- **You can neglect air resistance in all problems unless a problem explicitly asks you to include it.**



Thrust

- **Thrust** is a force that occurs when a jet or rocket engine expels gas molecules at high speed.
- **Thrust is a force opposite the direction in which the exhaust gas is expelled.**



Identifying Forces

TACTICS BOX 4.2 Identifying forces

1. **Identify the object of interest.** This is the object whose motion you wish to study.
2. **Draw a picture of the situation.** Show the object of interest and all other objects—such as ropes, springs, and surfaces—that touch it.
3. **Draw a closed curve around the object.** Only the object of interest is inside the curve; everything else is outside.
4. **Locate every point on the boundary of this curve where other objects touch the object of interest.** These are the points where *contact forces* are exerted on the object.
5. **Name and label each contact force acting on the object.** There is at least one force at each point of contact; there may be more than one. When necessary, use subscripts to distinguish forces of the same type.
6. **Name and label each long-range force acting on the object.** For now, the only long-range force is weight.

Exercises 4–8

Text: p. 105

Identifying Forces

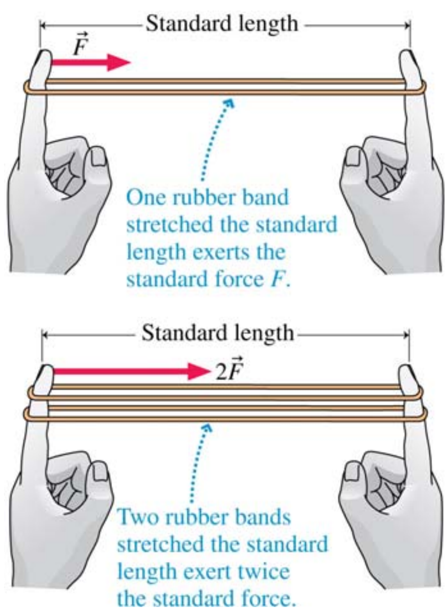
TABLE 4.1 Common forces and their notation

Force	Notation
General force	$\vec{F}$
Weight	$\vec{w}$
Spring force	$\vec{F}_{sp}$
Tension	$\vec{T}$
Normal force	$\vec{n}$
Static friction	$\vec{f}_s$
Kinetic friction	$\vec{f}_k$
Drag	$\vec{D}$
Thrust	$\vec{F}_{thrust}$

Slide 4-27

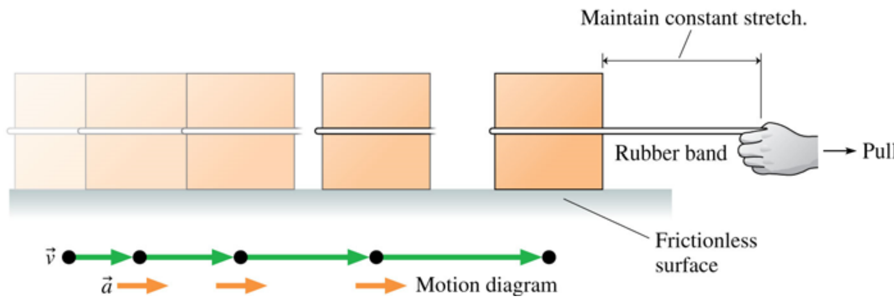
What Do Forces Do?

- How does an object move when a force is exerted on it?



Slide 4-28

What Do Forces Do?



- As the block starts to move, in order to keep the pulling force constant you must *move your hand* in just the right way to keep the length of the rubber band—and thus the force—*constant*.

What Do Forces Do?

The experimental findings of the motion of objects acted on by constant forces are:

- **An object pulled with a constant force moves with a constant acceleration.**
- **Acceleration is directly proportional to force.**
- **Acceleration is *inversely proportional* to an object's mass.**

Newton's Second Law

- **A force causes an object to accelerate.**
- **The acceleration *a* is directly proportional to the force *F* and inversely proportional to the mass *m*:**

$$a = \frac{F}{m}$$

- The direction of the acceleration is the same as the direction of the force:

$$\vec{a} = \frac{\vec{F}}{m}$$

Newton's Second Law

Newton's second law An object of mass m subjected to forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots$ will undergo an acceleration $\vec{a}$ given by

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

where the net force $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all forces acting on the object. **The acceleration vector $\vec{a}$ points in the same direction as the net force vector $\vec{F}_{\text{net}}$.**

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

Units of Force

$$1 \text{ basic unit of force} = (1 \text{ kg}) \times (1 \text{ m/s}^2) = 1 \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$

The basic unit of force is called a *newton*. One **newton** is the force that causes a 1 kg mass to accelerate at 1 m/s^2.

$$1 \text{ pound} = 1 \text{ lb} = 4.45 \text{ N}$$

Free-Body Diagrams

TACTICS BOX 4.3 Drawing a free-body diagram

MP

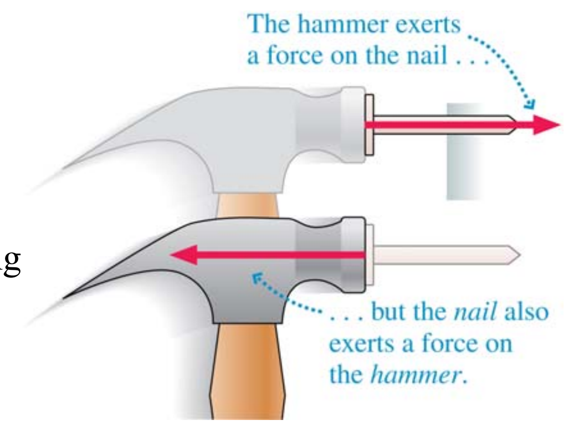
1. **Identify all forces acting on the object.** This step was described in Tactics Box 4.2.
2. **Draw a coordinate system.** Use the axes defined in your pictorial representation (Tactics Box 2.2). If those axes are tilted, for motion along an incline, then the axes of the free-body diagram should be similarly tilted.
3. **Represent the object as a dot at the origin of the coordinate axes.** This is the particle model.
4. **Draw vectors representing each of the identified forces.** This was described in Tactics Box 4.1. Be sure to label each force vector.
5. **Draw and label the *net force* vector $\vec{F}_{net}$.** Draw this vector beside the diagram, not on the particle. Then check that $\vec{F}_{net}$ points in the same direction as the acceleration vector $\vec{a}$ on your motion diagram. Or, if appropriate, write $\vec{F}_{net} = \vec{0}$.

Exercises 17–22

Text: p. 112

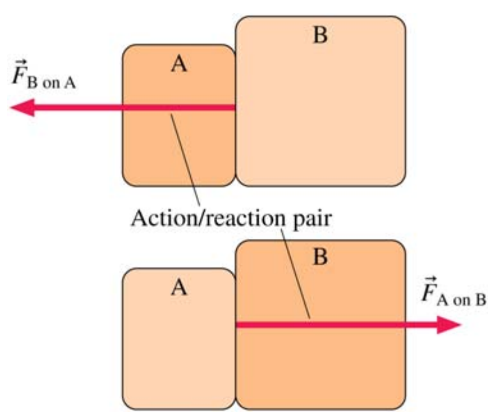
Newton's Third Law

- Motion often involves two or more objects *interacting* with each other.
- As the hammer hits the nail, the nail pushes back on the hammer.
- A bat and a ball, your foot and a soccer ball, and the earth-moon system are other examples of interacting objects.



Interacting Objects

- An **interaction** is the mutual influence of two objects on each other.
- The pair of forces shown in the figure is called an **action/reaction pair**.
- **An action/reaction pair of forces exists as a pair, or not at all.**



Reasoning with Newton's Third Law

Newton's third law Every force occurs as one member of an action/reaction pair of forces.

- The two members of an action/reaction pair act on two *different* objects.
- The two members of an action/reaction pair point in *opposite* directions and are *equal in magnitude*.