Physics 121 – September 19, 2017

Assignments:

This week:

- Finish reading chapter 5 of textbook
- Complete ETA Problem Set #5 and chapter 5 written problems 22, 34, 46, 48, 54, 66, due by Sept 25 at 4 PM
- Quiz in recitation this week (on projectiles… hints if we have time). Also practice problems 23, 36, 49, 52, 67
- Make sure that your clicker or phone app is registered for this class: "PHYS121_Minschwaner_F2017" The course ID is "NMTphys121_Minschwaner"
- Start reading Chapter 6

Key concepts for today:

- Forces (vectors)
- Mass (a scalar, always greater than or equal to zero)
- Weight as a force
- Inertial reference frames
- Free body diagrams
- Newton’s Laws

These are all rather straightforward. However, the following things might trip you up:

1. Mistakes in breaking vector forces into x and y components.
2. The “constant velocity” part of Newton’s first law.
3. Forgetting to use the ***net*** (vector sum) force acting ***on*** a given mass in Newton’s second law.

Forces

- Forces generally act *between* two objects.
- The objects have to be in physical contact for the forces that we'll consider this semester, except for one (can you name that force?)
- Forces have both magnitude and direction (vectors!)
- Examples of forces we'll consider: A push, a pull, tension in a string or rope, a stretched or compressed spring, gravity, normal force, friction or air drag, …
- Units are Newtons (N), where 1 N = 1 kg m s^{-2}

Mass

Mass is a property of a physical object.

It is not the same as weight (though the two are related when the mass is placed in a uniform gravitational field).

Mass is the measure of an object's resistance to acceleration when a net force is applied to that object (a simple restatement of Newton's 2^{nd} Law).

Mass is a scalar, and is always ≥ 0.

Free-Body Diagrams (FBDs)

I recommend that you draw two diagrams for most problems.

1. A cartoon or sketch showing the general situation.
2. An FBD showing coordinate system, forces, and any acceleration.

Problem-Solving Strategy: Drawing Free-Body Diagrams

1. Draw the object under consideration. If you are treating the object as a particle, represent the object as a point. Place this point at the origin of an *xy*-coordinate system.
2. Include all forces that act on the object, representing these forces as vectors. However, do not include the net force on the object or the forces that the object exerts on its environment.
3. Resolve all force vectors into *x*- and *y*-components.
4. Draw a separate free-body diagram for each object in the problem.

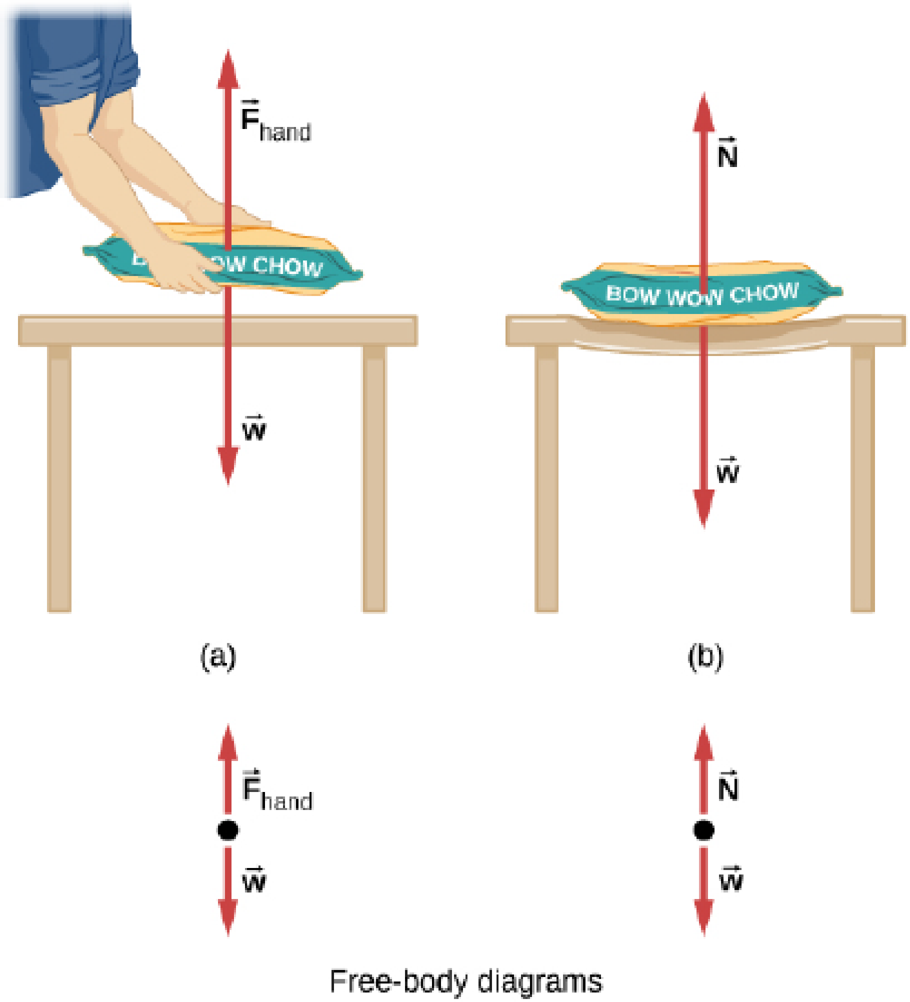


Figure 5.21 (a) The person holding the bag of dog food must supply an upward force $\vec{F}_{hand}$ equal in magnitude and opposite in direction to the weight of the food $\vec{w}$ so that it doesn't drop to the ground. (b) The card table sags when the dog food is placed on it, much like a stiff trampoline. Elastic restoring forces in the table grow as it sags until they supply a force $\vec{N}$ equal in magnitude and opposite in direction to the weight of the load.

Bad FBD.
No coordinates defined!

Here we have two "systems" and two FBDs.
Still no coordinates defined.

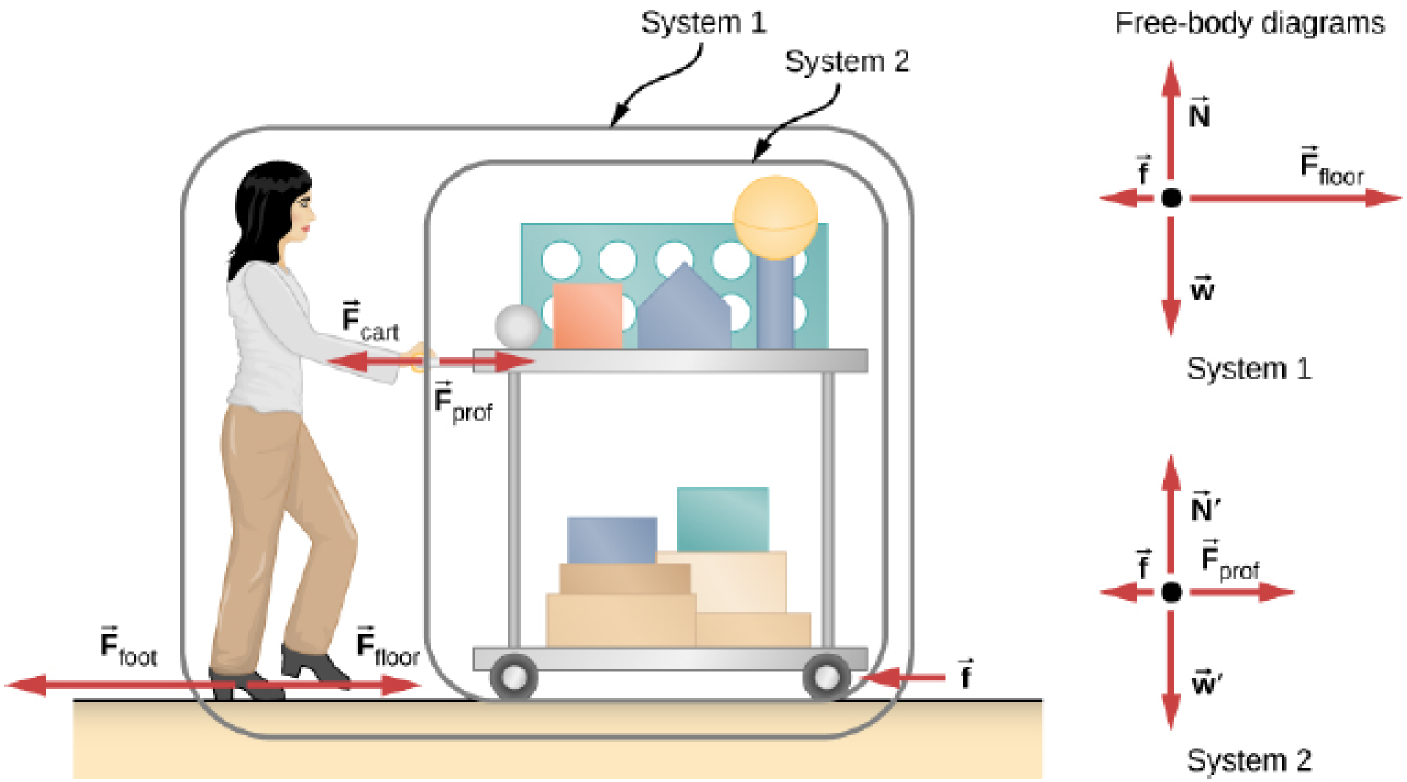


Figure 5.20 A professor pushes the cart with her demonstration equipment. The lengths of the arrows are proportional to the magnitudes of the forces (except for $\vec{f}$, because it is too small to drawn to scale). System 1 is appropriate for this example, because it asks for the acceleration of the entire group of objects. Only $\vec{F}_{floo}$ and $\vec{f}$ are external forces acting on System 1 along the line of motion. All other forces either cancel or act on the outside world. System 2 is chosen for the next example so that $\vec{F}_{prof}$ is an external force and enters into Newton's second law. The free-body diagrams, which serve as the basis for Newton's second law, vary with the system chosen.

Coordinates defined!

But I would recommend sketching in the acceleration vector on the FBD.

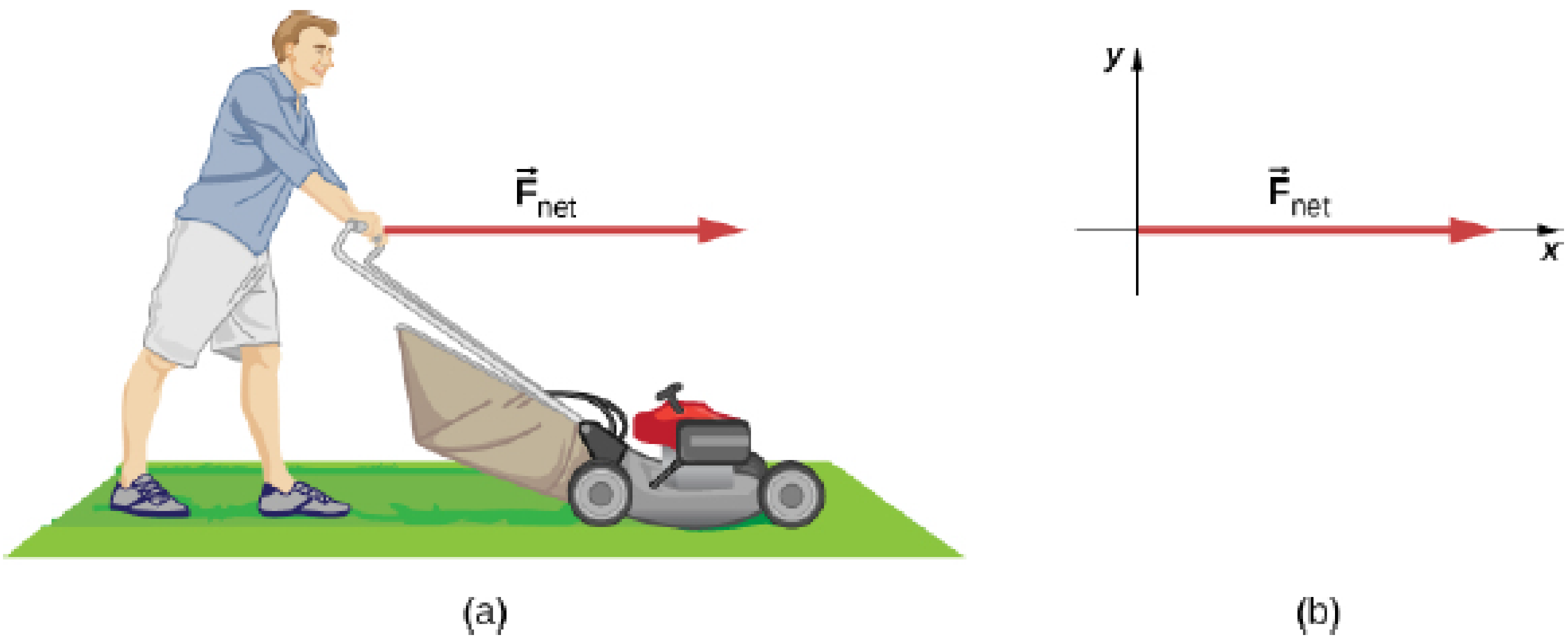


Figure 5.12 (a) The net force on a lawn mower is 51 N to the right. At what rate does the lawn mower accelerate to the right? (b) The free-body diagram for this problem is shown.

Mass and weight

Weight

The gravitational force on a mass is its weight. We can write this in vector form, where $\vec{\mathbf{w}}$ is weight and m is mass, as

$$\vec{\mathbf{w}} = m\vec{\mathbf{g}}. \tag{5.8}$$

In scalar form, we can write

$$w = mg. \tag{5.9}$$

A related concept is the *normal force* **N**

We must conclude that whatever supports a load, be it animate or not, must supply an upward force equal to the weight of the load, as we assumed in a few of the previous examples. If the force supporting the weight of an object, or a load, is perpendicular to the surface of contact between the load and its support, this force is defined as a **normal force** and here is given by the symbol $\vec{\mathbf{N}}$. (This is not the newton unit for force, or N.) The word *normal* means perpendicular to a surface. This means that the normal force experienced by an object resting on a horizontal surface can be expressed in vector form as follows:

$$\vec{\mathbf{N}} = -m\vec{\mathbf{g}}. \tag{5.11}$$

But this equation is only valid for the normal force on an object resting on a horizontal surface!

Example 5.12

Weight on an Incline

Consider the skier on the slope in Figure 5.22. Her mass including equipment is 60.0 kg. (a) What is her acceleration if friction is negligible? (b) What is her acceleration if friction is 45.0 N?

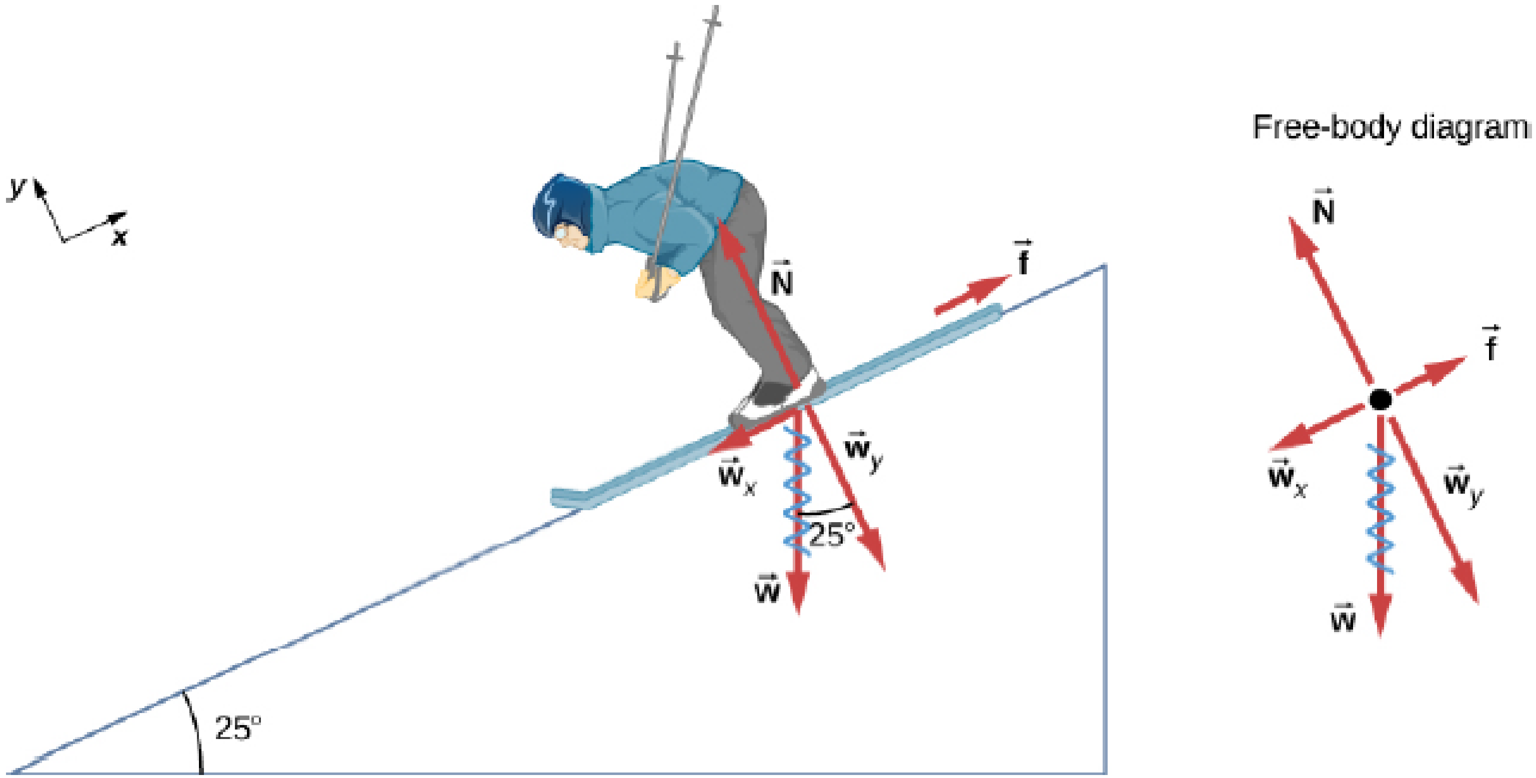


Figure 5.22 Since the acceleration is parallel to the slope and acting down the slope, it is most convenient to project all forces onto a coordinate system where one axis is parallel to the slope and the other is perpendicular to it (axes shown to the left of the skier). $\vec{N}$ is perpendicular to the slope and $\vec{f}$ is parallel to the slope, but $\vec{w}$ has components along both axes, namely, w_y and w_x. Here, $\vec{w}$ has a squiggly line to show that it has been replaced by these components. The force $\vec{N}$ is equal in magnitude to w_y, so there is no acceleration perpendicular to the slope, but f is less than w_x, so there is a downslope acceleration (along the axis parallel to the slope).

Newton’s 1st Law and Inertial Reference Frames

A reference frame is a coordinate system and the set of physical **reference** points that uniquely fix (locate and orient) that coordinate system.

By definition, an inertial reference frame is one in which Newton’s first law is valid.

Newton’s First Law of Motion

A body at rest remains at rest or, if in motion, remains in motion at constant velocity unless acted on by a net external force.

An easier way to think of an inertial reference frame is:

Inertial Reference Frame

A reference frame moving at constant velocity relative to an inertial frame is also inertial. A reference frame accelerating relative to an inertial frame is not inertial.

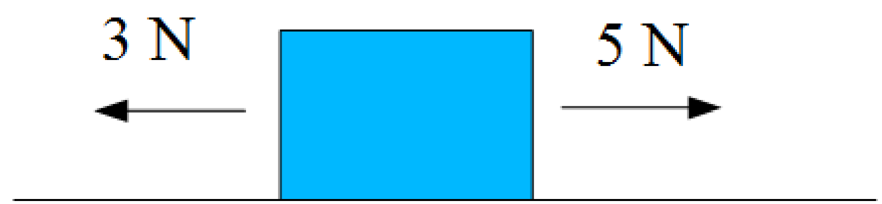
Newton's First Law of Motion

A body at rest remains at rest or, if in motion, remains in motion at constant velocity unless acted on by a net external force.

"net external force" here means the **sum of all forces acting on the body**

Iclicker question:

The block shown moves with constant velocity on a horizontal surface. Two of the forces acting on the block are shown. The only other force acting on the block is **friction**, which must be



A. zero

B. 2 N, leftward

C. 2 N, rightward

D. 5 N, leftward

E. 8 N (can be in *any* direction)

Newton's Second Law of Motion

The acceleration of a system is directly proportional to and in the same direction as the net external force acting on the system and is inversely proportion to its mass. In equation form, Newton's second law is

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

where $\vec{\mathbf{a}}$ is the acceleration, $\vec{\mathbf{F}}_{\text{net}}$ is the net force, and m is the mass. This is often written in the more familiar form

$$\vec{\mathbf{F}}_{\text{net}} = \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}, \tag{5.3}$$

but the first equation gives more insight into what Newton's second law means. When only the magnitude of force and acceleration are considered, this equation can be written in the simpler scalar form:

$$F_{\text{net}} = ma. \tag{5.4}$$

After you draw your FBD, you can easily break the 2nd Law up into components

Component Form of Newton's Second Law

We have developed Newton's second law and presented it as a vector equation in **Equation 5.3**. This vector equation can be written as three component equations:

$$\sum \vec{\mathbf{F}}_x = m\vec{\mathbf{a}}_x, \sum \vec{\mathbf{F}}_y = m\vec{\mathbf{a}}_y, \text{ and } \sum \vec{\mathbf{F}}_z = m\vec{\mathbf{a}}_z. \quad (5.5)$$

The second law is a description of how a body responds mechanically to its environment. The influence of the environment is the net force $\vec{\mathbf{F}}_{\text{net}}$, the body's response is the acceleration $\vec{\mathbf{a}}$, and the strength of the response is inversely proportional to the mass m. The larger the mass of an object, the smaller its response (its acceleration) to the influence of the environment (a given net force). Therefore, a body's mass is a measure of its inertia, as we explained in **Newton's First Law**.

Newton's Third Law of Motion

Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts. Mathematically, if a body *A* exerts a force $\vec{\mathbf{F}}$ on body *B*, then *B* simultaneously exerts a force $-\vec{\mathbf{F}}$ on *A*, or in vector equation form,

$$\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}. \tag{5.10}$$

i.e. – "forces come in pairs"

Do not draw both vectors of a 3rd law pair in the same FDB!
(however, use the 3rd law to equate forces in two separate FBDs)

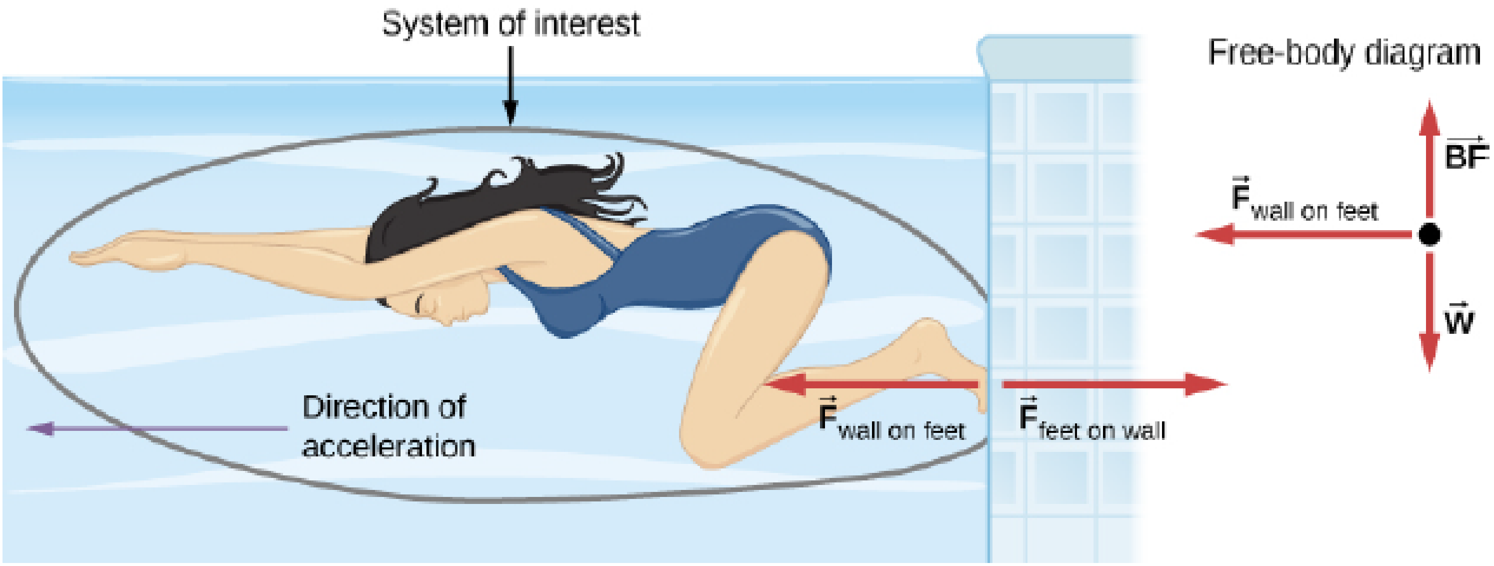
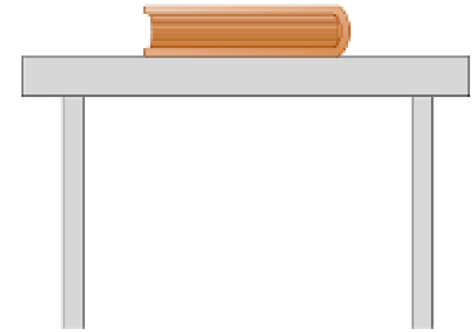


Figure 5.16 When the swimmer exerts a force on the wall, she accelerates in the opposite direction; in other words, the net external force on her is in the direction opposite of $F_{\text{feet on wall}}$. This opposition occurs because, in accordance with Newton's third law, the wall exerts a force $F_{\text{wall on feet}}$ on the swimmer that is equal in magnitude but in the direction opposite to the one she exerts on it. The line around the swimmer indicates the system of interest. Thus, the free-body diagram shows only $F_{\text{wall on feet}}$, w (the gravitational force), and *BF*, which is the buoyant force of the water supporting the swimmer's weight. The vertical forces *w* and *BF* cancel because there is no vertical acceleration.

Iclicker Question

A book rests on a table. A **downward** force of 5 N is exerted on the book by gravity. An **upward** force of 5 N is exerted on the book by the table. Which pair of forces constitute an action-reaction pair according to Newton's 3rd law?



A. Downward force of gravity on book, upward force of table on book.

B. Downward force of gravity on book, upward force of gravity on Earth.

C. Downward force of book on table, upward force of gravity on Earth.

D. There are no 3rd law force pairs in this problem because the book is at rest.