3.1 Types of Forces

Forces are all around you, acting on every object that you see. The motion of cars, trucks, planes, and boats is determined by the forces acting on them. Engineers must consider forces carefully when designing bridges and buildings. You are always using forces to move around, to lift objects, or to turn the pages of this book. Forces are involved in every type of sport and activity. For example, when a pitcher throws a ball, she exerts a force on the ball that causes the ball to move forward (**Figure 1**). If the batter hits the ball, then the bat exerts a force on the ball to change its motion. An understanding of forces is essential for a scientific description of our environment.

Figure 1 Forces are all around you.

In simple terms, a force is a push or a pull. Forces can cause objects to change their motion. When you push on a chair to tuck it under a desk, you change the motion of the chair. The direction of a force is very important. If you push straight down on a book on a desk, the effect is usually very different than if you push sideways or pull up. This means that force has direction, making it a vector quantity.

In Unit 1, you studied a branch of mechanics called kinematics. Remember that kinematics is the study of how objects move without being concerned with why they move. In this unit, you will study dynamics. **Dynamics** explains why objects move the way they do. One way to understand why an object moves is to study the forces acting on it. These forces can cause the object to start moving, speed up, slow down, or remain stationary. In this chapter, you will be introduced to different types of forces and the laws that govern them.

dynamics the study of the causes of motion

Measuring Forces

Isaac Newton discovered many of the concepts in this chapter. For this reason the unit of force, the newton, is named after him. The **newton (N)** is a derived SI unit equal to 1 kg·m/s^2.

newton (N) the SI unit of force (1 N = 1 kg·m/s^2)

To measure force in the laboratory, you can use either a spring scale or a force sensor. A spring scale has a spring that stretches more when greater forces pull on it. A needle is attached to the spring to indicate the amount of force. Usually a spring scale must be zeroed (the reading must be set to zero when not pulling) before use. Most spring scales can only measure a pulling force. A force sensor is an electronic device that can be attached to a computer or used independently. This device provides an accurate digital reading of a force and can even graph how the force changes over time. A force sensor can measure both pushes and pulls.

Force Diagrams

To understand why an object will remain at rest, start moving, or change its motion, you need to be able to draw diagrams that show clearly which forces are acting on the object. These diagrams are essential, especially when several forces are acting on the object simultaneously. The first type of force diagram is called a system diagram. A **system diagram** is a simple sketch of all the objects involved in a situation. For example, if you are lifting a book up in the air, the system diagram will show your hand pulling up on the book (**Figure 2**).

system diagram a simple sketch of all objects involved in a situation

Figure 2 A system diagram is a sketch showing all the objects involved in a situation. A system diagram helps you determine which objects push or pull on other objects.

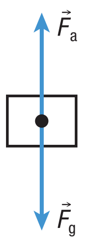


Figure 3 The FBD for the book shown in Figure 2. Since an FBD shows all the forces acting on a single object, two forces are drawn: the force of the hand pulling up and the force of gravity pulling down.

The other type of force diagram is called a **free-body diagram** (FBD). An FBD is a simple drawing representing the object being analyzed and all the forces acting on it (**Figure 3**). Usually the object is drawn as a rectangle or large dot. The forces are drawn as arrows originating from the outline of the rectangle or dot and pointing away from the centre. FBDs are not drawn to scale, but larger forces can be drawn longer than smaller ones to help predict the motion of the object. Each force is labelled with the symbol $\vec{F}$ and an appropriate subscript that indicates the type of force.

free-body diagram (FBD) a simple drawing of an object showing all the forces that are acting on it

Everyday Forces

To draw useful force diagrams, you need to be familiar with some common forces encountered every day. Imagine two children playing outside with a wagon. One child pulls forward on a rope tied to the front, while the other pushes on the wagon from behind (**Figure 4(a)**). What forces act on the wagon? To answer this question, we first need to study some everyday forces.

First consider the applied forces. An **applied force** results when one object is in contact with another object and either pushes or pulls on it. The symbol for an applied force is $\vec{F}_a$. In our example, the child behind the wagon exerts an applied force forward on the wagon by pushing on the back. Another force is the tension force (often called tension). **Tension** is a pulling force exerted on an object by a rope or a string. The symbol for tension is $\vec{F}_T$. Ropes and strings are not rigid, which means that they cannot push on an object. If you try to push with a rope, the rope will just sag down and have no effect on the motion of the object. An easy way to remember the direction of the tension is that it always pulls the object toward the rope or the string. The child at the front of the wagon pulls on the rope, causing tension in the rope. The rope exerts tension on the wagon, pulling it forward. Notice that in **Figure 4(b)** both the applied force vector and the tension vector start from the outline of the rectangle representing the wagon and are directed forward, indicating the direction of each force.

applied force ($\vec{F}_a$) a force that results when one object makes contact with another and pushes or pulls on it

tension ($\vec{F}_T$) a pulling force from a rope or string on an object that always points toward the rope or string

Whenever an object is in contact with a surface, the surface can exert two different forces on the object. One is called the normal force. The **normal force** is a perpendicular force on an object exerted by the surface with which it is in contact. The normal force is given its name because this force always acts perpendicular (or normal) to the surface. The symbol for the normal force is $\vec{F}_N$. The normal force is always a push from the surface onto the object. For this reason, the normal force always points away from a surface. In Figure 4(b), the normal force from the ground on the wagon starts from the outline of the rectangle and points up, perpendicular to the ground. In this case, the normal force supports the wagon against the force of gravity.

normal force ($\vec{F}_N$) a perpendicular force exerted by a surface on an object in contact with the surface; the normal force always points away from the surface

The other force exerted by a surface on an object is friction. **Friction** is a force that resists the motion or attempted motion of an object. Friction is always parallel to the surface and acts opposite to the object's motion or attempted motion. The symbol for friction is $\vec{F}_f$. If the wagon is moving to the right, then the friction on the wagon acts toward the left, opposite to the motion. If the wagon is at rest even if the children are pushing and pulling on it, then the friction is left, opposite to the tension and applied force keeping the wagon at rest.

friction ($\vec{F}_f$) opposes the sliding of two surfaces across one another; friction acts opposite to the motion or attempted motion

(a) **(b)**

Figure 4 (a) The system diagram of a wagon and the two children pushing and pulling on it (b) The FBD showing all the forces acting on the wagon

force of gravity ($\vec{F}_g$) force of attraction between any two objects

Notice that all of the forces described on the previous page require one object to be in contact with another. For this reason, they are called contact forces. Some forces do not require contact. These forces are known as action-at-a-distance forces (sometimes called non-contact forces).

The **force of gravity**, also called the gravitational force, is the force of attraction that exists between any two objects due to their mass. The force of gravity is an action-at-a-distance force. The symbol for gravity is $\vec{F}_g$. In this course, you will only learn about the force of gravity between Earth and other objects close to Earth's surface. At Earth's surface, the force of gravity always points down toward Earth's centre. Even if the surface is sloped, such as the side of a mountain, the force of gravity still points down toward Earth's centre.

Mini Investigation

Measuring the Force of Gravity

Skills: Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A6.5

In this investigation, you will observe the relationship between mass and the force of gravity. You will also measure and calculate the magnitude of the force of gravity.

Equipment and Materials: spring scale or force sensor; set of objects of known mass

1. Create a table with the headings "Mass (kg)" and "Force of gravity (N)" to record your observations.
2. Select one of the objects. To measure the force of gravity on the object, hang the object from the spring scale or force sensor. Hold the object steady before taking a reading. Record your observations in your table.
3. Repeat Step 2 for all the objects in the set.

A. Graph your results with the force of gravity (N) on the *y*-axis and mass (kg) on the *x*-axis. T/I C

B. What is the slope of the line of best fit on the graph? What does the slope represent? (Hint: Think back to the projectile problems from Unit 1.) T/I C

C. Using your observations, predict the force of gravity acting on each object below. Use the spring scale or force sensor to check your predictions. How accurate were your predictions? T/I C
(i) 0.30 kg
(ii) 0.50 kg

D. Describe how you could calculate the force of gravity (N) acting on an object if you knew its mass (kg). T/I C

To calculate the magnitude of the force of gravity on an object, you multiply the mass of the object by the acceleration due to gravity. To calculate the force of gravity, you can use the equation

$$\vec{F}_g = m\vec{g}$$

where $\vec{g} = 9.8\ \text{m/s}^2$ [down]. The force of gravity is measured in newtons and the mass is in kilograms. You will learn more about gravity in Chapter 4.

In this course, you will usually be concerned with external forces. External forces are those that are caused by one object pushing or pulling on another. An internal force occurs when an object exerts a force on itself. For example, when skater A pushes on skater B, the force on skater B is external. If skater B pulls forward on her own arm, then it is an internal force.

WEB LINK

To learn more about contact and action-at-a-distance forces,

GO TO NELSON SCIENCE

In the following Tutorial, you will use what you have learned about forces to draw system diagrams and FBDs.

Tutorial 1 Drawing Force Diagrams

Some force diagrams are easy to draw, while others require more care. The following Sample Problems will help you to sharpen your skills with force diagrams.

Sample Problem 1

Draw both the system diagram and the FBD for each object in italics.

(a) A *cup* is sitting at rest on a table.

(b) A large *trunk* in the basement is pulled by a rope tied to the right side of the trunk by a person. The trunk does not move.

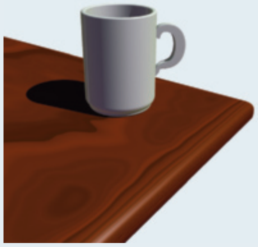
(c) A *baseball player* is sliding to the left across the ground.

(d) A *desk* is pushed to the left across the floor.

Solution

(a) **Step 1.** Identify the objects in the system diagram.

The system diagram shows the cup and also the desk because the desk exerts a force on the cup.



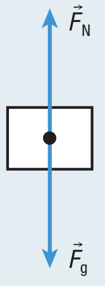
Step 2. Identify the forces acting on the cup for the FBD.

The forces acting on the cup are the normal force and gravity.

Step 3. Determine the direction of each force.

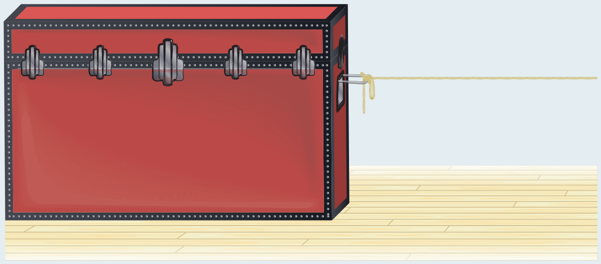
The normal force exerted by the desk pushes up on the cup and the force of gravity pulls the cup down. No one is pushing the cup so there is no applied force. There is no friction acting on the cup because the cup is not moving and friction is not required to keep it stationary.

Step 4. Draw the FBD as a rectangle representing the cup and the arrows representing each force and its direction. Each arrow must be labelled with the appropriate force symbol.



(b) **Step 1.** Identify the objects in the system diagram.

The system diagram shows the trunk, the rope, and the basement floor.



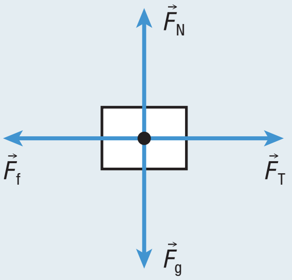
Step 2. Identify the forces acting on the trunk for the FBD.

The forces acting on the trunk are tension from the rope, the normal force, friction, and gravity.

Step 3. Determine the direction of each force.

The rope can only pull, exerting tension to the right. The basement floor exerts two forces on the trunk, the normal force and friction. The normal force is perpendicular to the surface and is directed up. The force of friction acts opposite to the applied force to keep the trunk stationary. The force of gravity on the trunk is directed down.

Step 4. Draw the FBD as a rectangle representing the trunk and the arrows representing each force and its direction. Each arrow must be labelled with the appropriate force symbol.



(c) **Step 1.** Identify the objects in the system diagram.

The system diagram shows the baseball player and the ground.

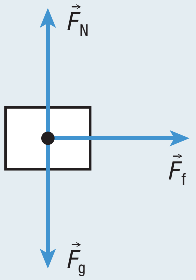
Step 2. Identify the forces acting on the baseball player for the FBD.

The forces acting on the baseball player are the normal force, friction, and gravity.

Step 3. Determine the direction of each force.

The normal force exerted by the ground pushes up on the baseball player. The force of friction is directed opposite to the direction of motion. The force of gravity pulls down on the baseball player.

Step 4. Draw the FBD as a rectangle representing the baseball player and arrows representing each force and its direction.



(d) **Step 1.** Identify the objects in the system diagram.

The system diagram shows the desk, the person pushing on it, and the floor.

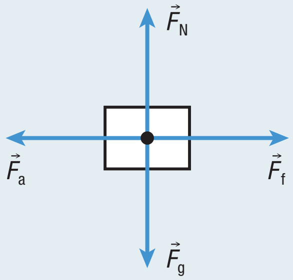
Step 2. Identify the forces acting on the desk for the FBD.

The forces acting on the desk are an applied force, the normal force, friction, and gravity.

Step 3. Determine the direction of each force.

The desk is being pushed to the left, so the applied force is directed to the left. The normal force pushes up on the desk. The force of friction is directed to the right, opposite to the direction of motion. The force of gravity pulls down on the desk.

Step 4. Draw the FBD as a rectangle representing the desk and the arrows representing each force and its direction.



Sample Problem 2

A player kicks a soccer ball that is sitting on the ground. The ball moves up into the air. Ignore air resistance.

(a) Draw the FBD of the ball after it has moved away from the player but is still in the air.

(b) A student draws the FBD shown in **Figure 5** to represent the soccer ball while it is coming back down. What is wrong with the FBD? Explain your reasoning.

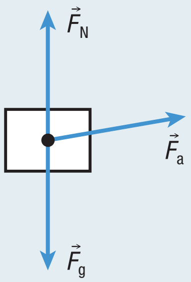


Figure 5

Solution

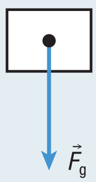
(a) **Step 1.** Identify the forces acting on the ball.

The soccer ball has moved away from the player so there is no applied force. The ball is in the air so there is no normal force exerted by the ground. The only force acting on the soccer ball is gravity.

Step 2. Determine the direction of the force.

The force of gravity pulls down on the soccer ball.

Step 3. Draw the FBD as a rectangle representing the ball and the arrows representing each force and its direction.



(b) When the soccer ball is in the air, there is no applied force or normal force. Both of these forces are contact forces. Since the ball is no longer in contact with the player's foot or the ground, these forces no longer act on the ball and should not be included in the diagram. The FBD that the student drew in Figure 5 would be appropriate at the start when the ball is still on the ground and the player is kicking it.

Practice

1. Draw a system diagram and an FBD for each object in italics. K/U C
   (a) A *book* is at rest on top of a desk.
   (b) A *basketball* falls through the hoop. Ignore air resistance.
   (c) A large *trunk* is pushed horizontally from behind toward the east across a rough floor.
2. **Figure 6(a)** shows a system diagram of a block sliding up a ramp. A student draws the FBD for the block (**Figure 6(b)**). Discuss the validity of the FBD. K/U C

(a) **(b)**

Figure 6

Calculating Net Forces

In many force problems, you must combine all the forces acting on a single object into one combined force. The total force is also called the **net force** or the resultant force. To determine the net force, you need to use FBDs. Keep in mind that force is a vector quantity and the direction of each individual force must be considered before determining the net force. Net force is represented by the symbol $\vec{F}_{net}$. In the following Tutorial, you will draw FBDs to determine the net force acting on an object.

net force ($\vec{F}_{net}$) the sum of all forces acting on an object

Tutorial 2 Using FBDs to Determine Net Force

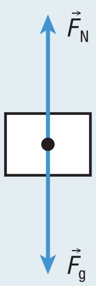
To determine the net force from the FBD of an object, it is necessary to define the *x*- and *y*-axes and to define which directions are positive. You may omit one axis or the other, if there are no forces parallel to that axis. In the following Sample Problems, we will practise this technique.

Sample Problem 1: Calculating the Net Force on a Stationary Object

The floor exerts a normal force of 36 N [up] on a stationary chair. The force of gravity on the chair is 36 N [down]. Draw the FBD of the chair and use the FBD to determine the net force on the chair.

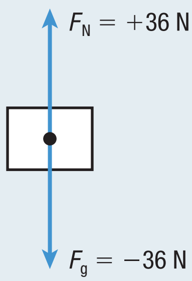
Solution

Step 1. Draw the FBD of the object.



Step 2. Identify which directions are positive.

Define up as the positive *y*-axis and down as the negative *y*-axis. This means the normal force exerted by the floor on the chair is positive and the force of gravity on the chair is negative. The values of the forces on the FBD are now



Step 3. Add the forces on each axis to determine the net force.

$$\vec{F}_{net} = \vec{F}_N + \vec{F}_g$$
$$= +36 \text{ N} + (-36 \text{ N})$$
$$F_{net} = 0 \text{ N}$$

There is no net force on the chair.

Sample Problem 2: Calculating the Net Force When the FBD Is Given

Figure 7 shows all the forces acting on an object. Use the FBD to calculate the net force.

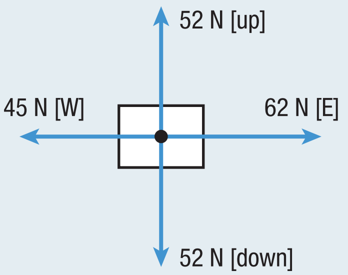


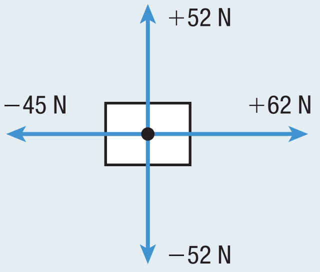
Figure 7

Solution

Since the FBD is given, you can skip the drawing step.

Step 1. Identify which directions are positive.

Choose up and east as positive. So down and west are negative. The values of the forces on the FBD are now



Step 2. Define east and west forces as being along the *x*-axis. So up and down forces are along the *y*-axis.

Add the forces along each axis to determine the net force.

First, find the sum of all the forces parallel to the *y*-axis.

$$(F_{net})_y = +52 \text{ N} + (-52 \text{ N})$$
$$= 0 \text{ N}$$

The net force on the *y*-axis is 0 N.

Now find the sum of all the forces parallel to the *x*-axis.

$$(F_{net})_x = +62 \text{ N} + (-45 \text{ N})$$
$$= +17 \text{ N}$$

The net force along the *x*-axis is 17 N [E].

Therefore, the net force on the object is 17 N [E].

Practice

1. Calculate the net force when each set of forces acts on the same object. Draw an FBD for each object. K/U C
   (a) 5.5 N [W], 3.4 N [W], 4.2 N [E] [ans: 4.7 N [W]]
   (b) 92 N [up], 35 N [down], 24 N [down] [ans: 33 N [up]]
   (c) 15 N [up], 15 N [down], 35 N [E], 12 N [W] [ans: 23 N [E]]
2. A chain exerts a force of 1200 N [up] on a beam which experiences a force of gravity of 1100 N [down]. Draw the FBD of the beam and determine the net force on the beam. K/U C [ans: 100 N [up]]
3. You push a book across a table to your friend with a force of 6.5 N [E]. The force of friction on the book is 4.5 N [W]. The normal force and the force of gravity have a magnitude of 7.5 N. Draw the FBD of the book and calculate the net force on the book. K/U C [ans: 2.0 N [E]]

The Four Fundamental Forces

It might seem like there are many different kinds of forces in everyday life and even more involved with research and technology. Physicists have grouped all known natural forces into four categories called fundamental forces. These four fundamental forces are the gravitational force, the electromagnetic force, the strong nuclear force, and the weak nuclear force.

You have already learned a little about the force of gravity, and you will expand that knowledge in Chapter 4. Not only is the force of gravity responsible for pulling objects down toward Earth's centre, but it also exists between any two masses in the universe. The force of gravity keeps the Moon in orbit around Earth and Earth in orbit around the Sun. You do not notice the force of gravity between smaller objects such as a pair of basketballs because the masses are small and the force of gravity is too weak compared to Earth's gravity.

The electromagnetic force is caused by electric charges. Electric force exists between charges, and magnetic force exists between magnets. The electromagnetic force is an action-at-a-distance force. Unlike gravity, this force can both attract and repel. For this reason, these forces often cancel each other out. The electromagnetic force holds atoms and molecules together: it makes concrete hard and a feather soft and governs the properties of chemical reactions.

In the nucleus of atoms, the positively charged protons are very close and repel each other. They do not fly apart because the strong nuclear force of attraction between the neutrons and the protons keeps them in place. In some cases, protons and neutrons can transform into other particles. The weak nuclear force is responsible for the interactions involved during these particle transformations.

Table 1 gives a brief comparison of the four fundamental forces. The electromagnetic, strong nuclear, and weak nuclear forces are studied in later physics courses.

WEB **LINK**

To review the four fundamental forces,

GO TO NELSON SCIENCE

Table 1 Comparing the Fundamental Forces

Type of force	Approximate relative strength	Range	Effect
gravitational	1	infinite	attract only
electromagnetic	10^{20}	infinite	attract and repel
strong nuclear	10^{38}	less than 10^{-15} m	attract and repel
weak nuclear	10^{25}	less than 10^{-18} m	attract and repel

3.1 Summary

- A force is a push or a pull. Forces are responsible for changes in motion.
- Force is a vector quantity measured in newtons (N).
- There are two types of force diagrams. A system diagram is a simple sketch of the situation showing the objects involved. A free-body diagram (FBD) shows all the forces acting on a single object.
- You can use FBDs to calculate the net force on an object. Indicate the direction of the positive *y*-axis and the positive *x*-axis to determine the signs of each force acting on the object. Add up the forces parallel to each axis to determine the net force.
- To calculate the force of gravity, you can use the equation $\vec{F}_g = m\vec{g}$, where $\vec{g} = 9.8 \text{ m/s}^2$ [down].
- The four fundamental forces are the gravitational force, the electromagnetic force, the strong nuclear force, and the weak nuclear force.

3.1 Questions

1. Assume that you are sitting at your desk facing north with a book on the desk directly in front of you. K/U
   (a) If you push on the side of the book that is closest to you, in which direction is the applied force?
   (b) If you pull on the side of the book that is closest to you, in which direction is the applied force?
2. Name the force or forces that cause these objects to experience changes in motion. Neglect air resistance. K/U
   (a) A ball falls toward the ground.
   (b) A person accelerates up in an elevator.
   (c) A car gradually slows down while approaching a red light.
3. A student forgets to zero the force sensor before performing an investigation. What effect, if any, will this have on the data collected during the investigation? T/I
4. Some everyday forces are gravity, tension, friction, an applied force, and the normal force. It is important that you be able to determine the direction of each of these forces when drawing an FBD. Create a table or a graphic organizer to help you remember the direction of these forces. K/U
5. Draw both the system diagram and the FBD for each object in italics. K/U C
   (a) A *car* is parked on the road.
   (b) A small *fish* is hanging from a fishing line.
   (c) A *football* is falling toward a player.
   (d) A *puck* is being pushed forward across the ice by a hockey stick.
6. Create a poster to teach students about common everyday forces. Include at least two system diagrams in your poster and the corresponding FBDs. You may include several everyday forces in your poster or concentrate on just one. K/U C
7. Determine the force of gravity acting on each object. T/I C
   (a) A 2.0 kg object falls straight down.
   (b) A 62 kg person stands on the floor.
8. Your teacher says, "Any applied force can also be called a normal force." Discuss the validity of this statement. K/U C
9. You tie a long string to a cart on the ground. Explain why you can only pull the cart forward but cannot push the cart away with the string. Draw diagrams to help explain your answer. K/U C
10. Describe the main difference between contact forces and action-at-a-distance forces. What implication does this difference have when drawing an FBD? K/U C
11. Explain the difference between system diagrams and FBDs. Describe why both are used to solve force problems. K/U C
12. For a physics project, you are given a small block of wood, a paper clip, some masking tape, a balloon, a magnet, and an elastic band. The objective is to move the block from one end of a long hallway to the other in the least amount of time using only the materials listed, without touching the wood directly. Draw a system diagram showing how you would complete the task. Draw an FBD of the block of wood. Include a brief description of what you would do. T/I C
13. Examine **Figure 8**, showing a spider in a web. The web is currently under construction and consists of only a few fine strands. Draw the FBD of the spider. T/I C

Figure 8

14. A doctor states, "The bones in the human arm can exert forces that can either push or pull other objects. The muscles are made of small fibres and can only cause tension forces." C A
   (a) What does the doctor mean when he says muscles can only cause tension forces?
   (b) Why can bones both push and pull whereas muscles cannot?
15. Calculate the net force when each set of forces acts on a single object. T/I
   (a) 56 N [up], 35 N [down]
   (b) 12.3 N [right], 14.4 N [right], 32.7 N [left]
   (c) 45 N [up], 45 N [down], 21 N [W], 21 N [E]
16. (a) List the four fundamental forces from weakest to strongest.
   (b) Describe two ways that gravity is different from the other three fundamental forces.
   (c) Explain why friction and tension are not fundamental forces. K/U C