READING PAGE: WHAT IS A FORCE?

People often think of force as something you apply using your muscles. When you push or pull on an object, you apply a force on it. You also apply force when you throw a baseball or kick a soccer ball, or sit on a soccer ball. Therefore, *a force is nothing else than a push or a pull*. When you apply a force on an object, its shape can change, as it might when you sit on a soccer ball, or on a sofa, or when you squeeze an orange. These are soft objects; but even rigid objects, such as a wall or a car, can be *deformed* (have their shape changed) if enough force is applied, such as with a sledgehammer or in a collision with another car.

CONTACT FORCES VS FIELD FORCES

Forces cause not only deformations (changes in shape), they can also cause motion – if you push or pull on a cart, it may move. When you played the broom ball game, you had to push the bowling ball with the broom to

make it move, stop or change its direction. You had to push harder on the bowling ball than on the soccer ball because the bowling ball was heavier than the soccer ball. If you push a cart on a rough surface, or if the cart is very heavy, you will need more force to move it than on a smooth surface. If you sit on a chair, the chair holds you up (you are not falling through it) and applies a force to you: the longer you sit in that chair, the more you will feel that force. These forces are examples of **contact forces** – they arise from physical contact between the applier of the force (called the *agent*) and the receiver of the force (called the *receiver*).

Field forces or long range forces, also called non-contact forces or forces at a distance, are another class of forces. These forces do not involve physical contact between the agent and the receiver, but act through space, through a field. For example, the force of gravity the Earth applies to us is what keeps us on the planet Earth and does not let us fly out in space. The effect of the gravitational force on all objects on the surface of the Earth can be described through a gravitational field. The Moon goes around the Earth because of the gravitational force between them; the solar system is kept together by the same force. The Moon itself has a gravitational field, applies a gravitational force to objects on its surface. Another example of a field force is the magnetic force: you feel a magnet being attracted or repelled by another magnet even if the two magnets do not touch each other. The third example of a field force is the electric force, often observed as static electricity, which causes your socks to stick to your sweaters when you take them out of the dryer or the hair on your head to stick to your brush or to stand up after brushing it.

While it is convenient to classify forces as *field forces* and *contact forces*, on a microscopic level the distinction is not so clear. For example, the force of friction might seem like a contact force, but it is caused by repulsive forces between electric charges, which are field forces. It might seem like there are a lot of forces in nature – gravitational force, friction forces, electric forces, magnetic forces, push and pull forces, elastic forces …the list is not short. These forces are macroscopic descriptions of phenomena. These descriptions are useful in designing, say, roller coasters, furniture, bridges, or highways. The atomic origins of these forces, however, can be traced to just four forces in nature:

1. The *gravitational force*, which describes the attraction between objects, is based on the mass of each object and the distance between them, and holds galaxies, stars, and planets together.
2. The *electromagnetic force*, which describes the attraction and repulsion between objects due to the charge on each object and the distance between them, is responsible for the binding of atoms and molecules.
3. The *nuclear strong force* is responsible for the binding of neutrons and protons into nuclei.
4. The *nuclear weak force* is a short-range nuclear force that produces instability in certain nuclei.

Each of these forces is described by a constant, a number, which gives the "strength" of this force. Ranked using these constants, the strengths of the forces are, in order, *strong*, *electromagnetic*, *weak* and *gravitational*. The strong and weak forces have a very short range of action, of the order of the radii of nuclei. These invisible forces keep things together, but are hard to observe except in the research laboratory. In everyday life, when we are not dealing with atomic-scale phenomena, the only forces that impact us are the two long-range forces: gravity and the electromagnetic force. While the gravitational force may be "weakest," when one factors in the large masses involved (such as that of earth, planets or stars), the gravitational force becomes a dominant force in everyday life. Close behind is the electromagnetic force, which causes static, gives us electrical power, makes cell-phones work, and makes for the conveniences of modern-day life.

READING PAGE: TYPE OF FORCES

The most common forces we deal with in everyday life and will study in this class are:

Gravitational Forces

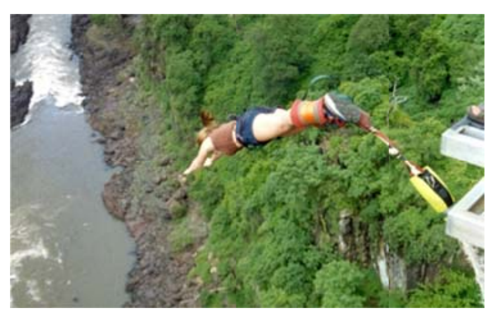
Gravitational forces occur because objects have mass. Gravitational forces have the largest effect when exerted by a large mass, such as the earth, sun, planets or the moon. Gravitational forces always attract objects. People, trains, and buildings remain "stuck" to the earth because the gravitational force due to the earth's mass attracts them. Even when you lift an object off the earth, the moment you let go, it falls back to the earth because of the earth's gravitational attraction. When you go sliding, the force of gravity is responsible for bringing you down that slide. When you throw a ball up into the air, it always comes back down because of the force of gravity acting on it. Have you ever held up a heavy object and felt it pulling down toward the earth? That's the gravitational force of the earth attracting it! This force acts at a distance, it is a field force and we say that it acts through a gravitational field. In everyday life, people refer to the gravitational force the earth exerts on all objects as the weight of that object. (Note: In everyday language we use the words mass and weight interchangeably, but scientists distinguish between mass, which measures how much "stuff" an object has, and weight, which measures the force with which the earth attracts that mass.)

Friction Forces

Friction is often observed when we rub objects together, or when we slide an object on a surface. It is much easier to drag a box across a smooth surface than across a rough one. Also, it is much easier to walk (have better traction) if your shoes have treads on the bottom than if they have a smooth bottom. Generally, rough surfaces hinder the motion of an object more than a smooth surface does. Although friction may appear to be caused by surface texture, it is actually caused by electrical forces between molecules. Frictional forces between two objects depend on the type of surfaces that are in contact with each other: the rougher the surface, the bigger the friction. One method of reducing friction is to modify the texture of the contact surface by applying lubricants, such as oil or graphite. While friction is often considered a hindrance, there are situations where friction is necessary – compare walking on a dry sidewalk with walking on it on an icy day! Also, put grease on the handle of your spoon and then try and hold it when you eat; it is much more difficult!

Elastic force (also known as stretching or compressing force)

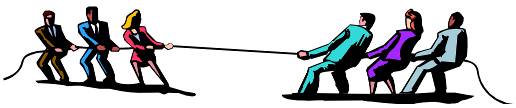
When you stretch a rubber band, you have to pull on it with a force. But the rubber band appears to pull back – in fact, you have to continuously apply the pulling force to keep the rubber band stretched. When you go bungee jumping, at the bottom of your jump the bungee cord starts extending and at one point starts pulling you back up. This "pulling back" is a manifestation of the elastic force that exists in the bungee cord or rubber band. If you let go, the rubber band will go back to its original length too. This elastic force also appears when you compress a spring – for example, when you push the "Jack in the Box" back in its box, the spring is compressed and when you open the lid, the elastic force in the spring (due to its compression) makes the toy pop-up from the box and brings the spring back to its unstretched length. Objects that stretch or compress when a force is applied to them, and then go back to their original form when the force is removed are called elastic. A force is called elastic force if once removed allows the object to



recover its original form, length, shape. This can happen to things other than springs, for example, a tree branch can be pulled down and it retracts to its original position. Have you ever pulled the tip of a ruler back like a catapult and hit a ball? There's the elastic force at work again.

Tension (also known as stretching force or pulling force)

Stretching forces or "tension" also occurs when you have something that is held taut. For example, when you play tug-of-war, the string/rope the two teams pull on is stretched taut and each team applies a force to its end. The force that shows up in the string/rope as the result of its stretching is called tension force. A picture



hanging on the wall has tension force in the string used to hang it. If the picture is very heavy and the string is not strong enough to support the tension force, the string will break.

Normal or Support Force

When you sit on your chair, your own weight pushes down on the chair. If so, why don't you fall through the

chair? Easy – because the chair is supporting you. How does it do it? Well, the strong material that makes up your chair deforms the chair a bit, and the molecules of the material that make up the chair feel their bonds deform a bit too. Just as a spring that is compressed pushes back at you, the springy bonds between the molecules push back too – and that is the origin of the normal or support force provided by the chair. The amount of support force is just enough to leave you sitting where you are. If it were a bit less, you would fall through the chair. If it were more, it would push you upward. The chair supports you with an equal and opposite force. If you think about the molecular origin of this force, it makes sense – if the person was heavy and deformed the chair a lot, the bonds between molecules would be deformed a lot, and the chair would push back a lot. If it were a light person – small deformation, smaller push-back, smaller support force. Support forces are pretty clever – they appear only when they are needed, and only in as much amount as needed. If the person got up from the chair, the deformation of the bonds is gone, and the support force vanishes! The support force is often called the normal force – normal being perpendicular. Support forces are always perpendicular to the surface at the point where the object touches it. (If they were in any other direction they would make the object slide in that direction!).

Commonly used symbols to denote the forces we discussed above are:

Symbol	Name of the Force	Type of Force	Direction of force
F_N or F_n	**Normal force**	Contact force	Perpendicular to the surface that applies it
F_G or F_g	**Gravitational force (or weight)**	Non-contact force (field force)	Always oriented down toward the earth
F_f	**Friction force**	Contact force	Along the surface in contact; opposes the relative motion of the two surfaces
F_T	**Tension force**	Contact force	Along the rope, always pulling
F_e	**Elastic force**	Contact force	Along the spring, always opposing the deformation of the spring

Note: any other contact force that is not one of the forces listed above can be called "applied force" and denoted with F_A.

After reading the "Reading Page: Forces" answer the following questions:

1. Do normal forces always point up?
2. Imagine that you are leaning against a wall. Your body is in contact with how many surfaces? How many normal forces act on you? How are those normal forces oriented?
3. How is the normal force acting on a truck stopped on a tilted ramp oriented? Make a drawing to help your explanations.
4. Add your conclusions from this activity to the "What is a force?" chart started in the Exerting Forces activity.

READING PAGE: DRAWING AND ANALYZING FORCES

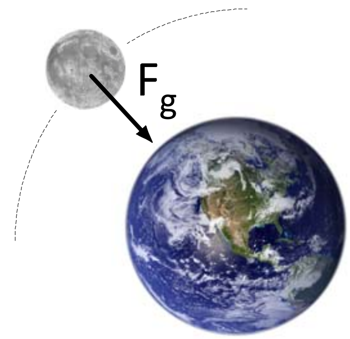
A force is always applied *by* an object or the result of a phenomenon. The object that applies the force is called the **agent**. This force is also applied *to* an object that experiences the force, called the **receiver**. And finally, something happens because the **agent** applied a force to the **receiver** – the **effect**. Let's see how we can apply this analysis to forces.

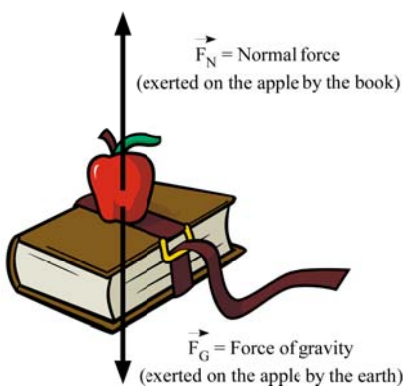
A force is a push or a pull and as such when describing a force we must specify not only its magnitude (how strong the force is) but also the direction of the force (pushing or pulling?). As such we can represent a force graphically by using an arrow. We place the tail of the arrow on the object that the force acts on, the receiver, and orient the arrow such that we show the direction of the force. The length of the arrow should represent the magnitude of the force.

<u>Examples:</u>

Examine the picture of the Moon going around the Earth: The Moon goes around the Earth because the Earth (the **agent**) applies a force to the Moon (the **receiver**) and as a result the Moon moves around the Earth (the **effect**). The force applied by the Earth is the force of gravity

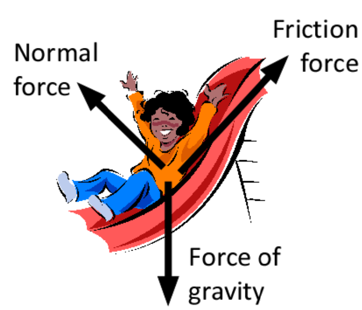
(Note: This analysis is somewhat simplified in the sense that we have separated out the agent and the receiver. To produce the attractive gravitational force you need at least two masses; technically the Earth and the Moon are both agents, and they are both receivers. However, at this time we chose to examine the Moon as the receiver.)



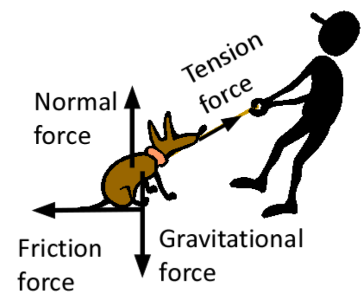


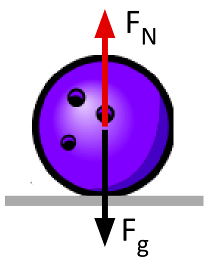
An apple is sitting at rest on a book placed on a table. The apple represents the receiver. There will be two forces acting on the apple: the force of gravity, applied by the Earth (agent Earth) and the normal force applied by the book (agent book). The force of gravity pulls down on the apple. The normal force supports the apple, pushing upward on it. The two forces balance each other out because the apple is not falling; neither is it floating in the air. The apple is at rest and the forces acting on it balance each other.

Frequently there is more than one force at work. Let's look at the picture of the boy on the slide. In this case, we consider forces acting on the boy, therefore the boy is the **receiver**. The boy is in contact with the slide, thus the slide is one **agent** applying forces on the boy. The friction force applied by the slide slows down the boy. The normal force applied by the slide holds the boy from falling through the slide. The boy slides down on the slide because the force of gravity applied by the earth (second agent) brings him down. The **effect** of all these forces is that the boy moves down the slide and his motion is slowed down by the friction with the slide, but if there is too much friction, the boy may not be able to slide down.



Here's another example of several forces: A man pulls on the leash of a dog. We are interested in the forces applied to the dog, therefore the dog is the **receiver**. The force of gravity applied by the Earth (**agent**) pulls down on the dog. The man (**agent**) pulls on the leash and the tension force in the leash pulls on the dog. The dog is in contact with the ground, and the ground (**agent**) applies a friction force to the paws of the dog. The **effect** of all these forces combined is that the dog does not move as the man pulls on its leash. All forces acting on this dog are balanced.





Now let's go back to the broom ball lab. How did the ball move in the "no touch" zone? It moved with constant speed. Were there any forces acting on the bowling ball when moving through the "no touch" zone? Yes, there were! The force of gravity was pulling down on the ball and the normal force was supporting the ball. The two forces balanced each other, and as a result, the ball moved with constant speed. Thus we can say that if forces acting on an object are balanced, the object can be either at rest or moving with constant speed.

Whenever analyzing forces acting, follow the steps below:
1. Determine the object that is the **receiver** (has forces applied to it).
2. Identify the **agents** (objects that apply forces to the receiver).
3. For each agent, identify the **force** it applies. (Note: remember that we live on Earth and therefore Earth (**agent**) always applies a force (**gravity**) to every single object (**receiver**) on its surface).
4. Represent the direction of the force with an arrow starting on the receiver.
5. Describe the **effect** of the identified forces on the receiver.

READING PAGE: MEASURING WEIGHT

One of the simplest methods of measuring a force is to use a spring scale. If you pull on the hook of a spring scale with a force, the spring inside the scale stretches. The amount a spring stretches is proportional to the amount of force applied. For example, if we apply a force of 40 N and we find that a spring gets 8 cm longer than its original length, then we know that if we apply 20 N of force, it should get 4 cm longer. This allows us to construct a scale (10 N = 2 cm of stretch). Once we have a scale, we can measure other amounts of force.

A common use of a spring scale is to measure weight, the amount of gravitational force applied by the earth. In everyday language we think that weight is a measure of how much "stuff" an object contains. Scientists distinguish between mass, which measures how much "stuff" an object has, and weight, which measures the force with which the earth attracts that mass. Since the force with which the earth attracts all objects scales with the mass of the object, the mass and weight of an object are proportional to one another. From the "Measuring the gravitational field strength lab" you have obtained a mathematical relationship between the gravitational force applied by Earth (or weight) and the mass of the object:

$$\text{slope} = 9.8\,\frac{\text{N}}{\text{kg}} = \frac{\text{force of gravity (or weight)}}{\text{mass}}$$

Note: the slope had a numerical value of 9.8 and was measured in N/kg (units of force/units of mass)

We will call this slope the "gravitational field strength" and will denote it with the letter "g". We can then rewrite the above mathematical relationship using symbols, as:

$$g = \frac{F_g}{m} \text{ where g = 9.8 N/kg on Earth}$$

From the above expression, we can calculate the gravitational force F_g (or weight) on Earth as:

$F_g = mg$ or Weight (in N) = mass (in kg) x 9.8 (in N/kg)

The numerical factor of 9.8 will change if we use different units.
For example, in the cm-mg-sec system,

Weight (dynes) = mass (mg) x 980 (dyne/mg)

In the British system,

Weight (lbs) = mass (slugs) x 32 (lb/slug)

Because weight and mass are related just by a numerical factor, we can use the same device to measure both and just mark the device with the appropriate scales. Spring scales often have markings to measure both mass and weight. When you go to the store to buy apples, and you want to check how much mass the apples have, you are using a spring scale. The reading of the scale is in lb (pounds) which is a unit of force.

A bathroom scale is another device to measure weight – a person has to stand on it, his/her mass is pulled down toward the earth due to the earth's gravity, and the person pushes down on the scale. A spring inside the scale gets compressed due to this force, and rotates a dial or displays a number that displays this force. The force may be displayed in pounds of force, or it may be rescaled and displayed as kilograms of mass. Or it could equally have been displayed as slugs of mass or newtons of force! Marking equivalent units is not unusual – many car speedometers have speed displayed as km/hour and miles/hour; thermometers may also read Celsius or Fahrenheit. Spring scales are a bit different in that the two units are for different factors – mass and weight, but the principle is the same. In a digital balance (like the ones used in class), the weight of the object compresses a spring or a strain gauge inside the balance. The amount of compression is related to the mass of the object. In a classical beam balance, the weight in the left pan is balanced by the weight in the right pan.

How can you tell mass and weight apart?
Mass and weight have different units. Weight is a force and it is measured in units of newtons (abbreviated N) in the metric system, or pounds (lb) in the British system. Mass is a measure of how much stuff an object contains and it is measured in units of grams or kilograms (g or kg) in the metric system and slugs in the British system. Mass will remain the same on the Earth or the Moon or anywhere else. Weight, however, is the force with which the object is attracted. If the object were on the Moon, it would be attracted by a different amount of force than on the Earth, since the gravitational field strength of the Moon is smaller than the gravitational field strength of the Earth (the mass of the moon is smaller than that of the earth, and the object is also closer to the center of the moon). So its weight would be different (in fact it would be about 1/6 as much). Below you have a table with the gravitational field strength of each planet in the Solar System:

Planet	Earth	Moon	Sun	Mars	Jupiter	Pluto
Gravitational Strength	9.8 N/kg	1.6 N/kg	273.4 N/kg	3.7 N/kg	25.8 N/kg	0.6 N/kg

Additional readings on weight and gravitational field strength:

http://en.wikipedia.org/wiki/Gravitation

http://www.exploratorium.edu/ronh/weight/

After reading the "Reading Page: Measuring Weight" answer the following questions:

1. Explain what would happen to your data if you were to take the same equipment to the moon and perform the experiment.

2. If you were able to travel to the moon, do you think the strength of the gravitational force will change? In what way? If you were to draw a Force vs. mass graph with two curves, one measured on earth and one measured on the moon, how would the graph look? Explain your reasoning.

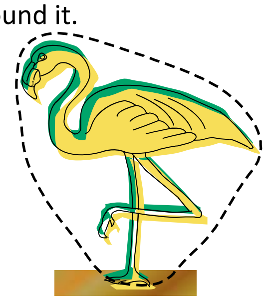
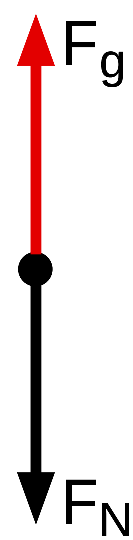
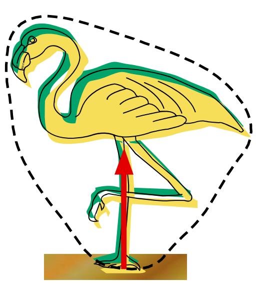
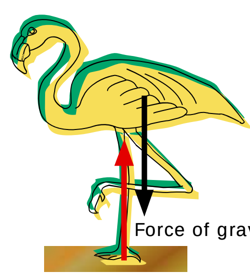
3. Carefully examine the spring scale which is calibrated in grams. Put a 500 g object on this scale. Is the reading correct? What would the scale read if you were to put the same 500 g object on it on the moon? Is there anything wrong with this scale? Explain.

READING PAGE: DRAWING FORCE DIAGRAMS

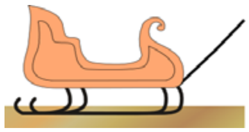
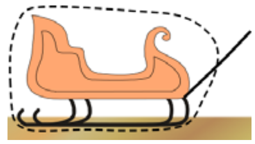
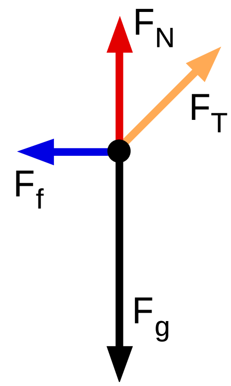
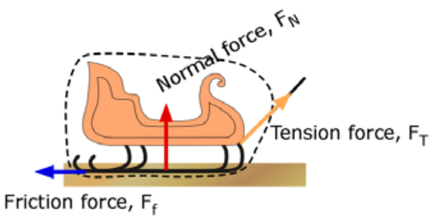
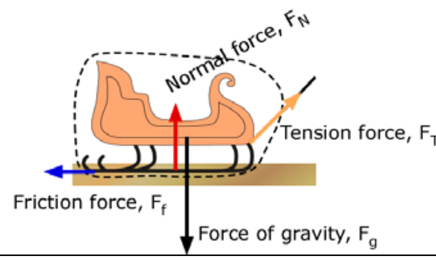
What is a force diagram? A force diagram (often called a free-body diagram) is a tool to represent all the forces acting on an object. In some situations it might be easy to identify all the forces that act on an object. However, situations tend to get complicated quickly, especially if there are both contact and long-range forces. Therefore it is a good idea to have a process that helps us identify all the forces in situation. Here is a method that works well:

1. Draw a picture of the problem, showing the object and everything in the environment that touches the object – ropes, tables, springs are all part of the environment.
2. Identify the receiver – which is the object or objects of interest – by drawing a closed curve around the receiver, with the object inside the curve and everything else (environment) outside the curve.
3. Locate every point in the receiver at the boundary of the curve where the environment touches the receiver and identify by name all the contact forces at each point of contact (there may be more than one force), then give each one an appropriate symbol.
4. Identify any long-range forces acting on the receiver. Name the force and write its symbol in the picture.
5. Draw the force diagram. Start by representing the receiver with a dot. Draw all forces with the tail on the dot and keep the direction of those forces the same.

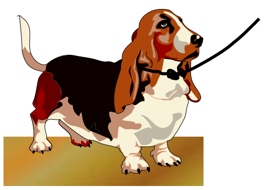
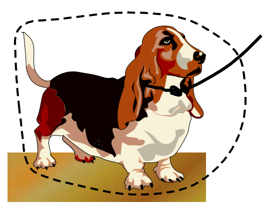
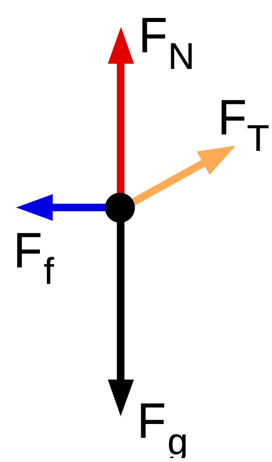
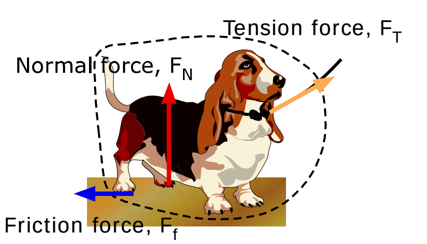
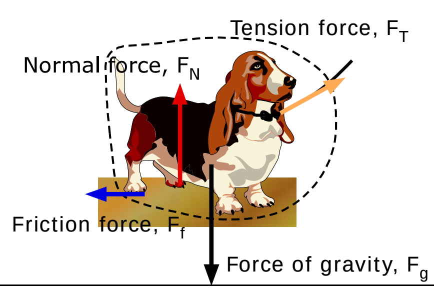
<u>Example 1</u>: A flamingo stands on the ground. Draw the force diagram for the flamingo.

<table>
<tr>
<td>1. The picture
</td>
<td>2. Identify the receiver with a closed curve around it.
</td>
<td rowspan="2">5. Make the force diagram

</td>
</tr>
<tr>
<td>3. Identify all contact forces.

</td>
<td>4. Identify all long range forces.

</td>
</tr>
</table>

<u>Example 2</u>: A sled on level ground is being pulled by a rope. Draw the force diagram for the sled.

<table>
<tr>
<td>1. The picture
</td>
<td>2. Identify the receiver with a closed curve around it.
</td>
<td rowspan="2">5. Make the force diagram

</td>
</tr>
<tr>
<td>3. Identify all contact forces.

</td>
<td>4. Identify all long range forces.

</td>
</tr>
</table>

<u>Example 3</u>: A dog is being pulled by her leash on level ground. Draw the force diagram for the dog.
Note: one might think that we need to have four normal forces, and four friction forces, one for each paw. However, we are going to represent the dog by a point in the force diagram, so it is all right to represent the normal force and the friction force at one point (paw) only.

<table>
<tr>
<td>1. The picture
</td>
<td>2. Identify the receiver with a closed curve around it.
</td>
<td rowspan="2">5. Make the force diagram

</td>
</tr>
<tr>
<td>3. Identify all contact forces.

</td>
<td>4. Identify all long range forces.

</td>
</tr>
</table>

READING PAGE: NEWTON'S FIRST LAW

To explain in the most general way how force and motion are connected Newton came up with three physics laws.

NEWTON'S FIRST LAW

Newton's first law of motion is also known as the law of inertia. It states that:

An object moving with constant velocity continues to do so unless acted upon by a nonzero net force.

This law may sound simple but it has many nuances that must be clarified in order to be understood.

1) The phrase "moving with constant velocity" in the statement of this law means that the object is traveling in a straight line, with constant speed, i.e. it is neither speeding up, nor slowing down, nor changing direction. This law says that the natural state of motion is that of constant velocity. Since the law does not distinguish the constant velocity of zero (at rest) from any other constant velocity, it says that all constant velocities are equivalent.

Newton's First Law can be restated as:

An object in constant velocity motion, or at rest, will continue its constant velocity motion, or remain at rest, unless acted upon by a net force.

2) Newton's First Law can seem counterintuitive: in real life objects in motion stop moving sooner or later. Prior to Newton, people believed that the "natural state" of an object was at rest.
Example: push your physics textbook across the table. As long as you keep pushing it (applying a force to it), the book will move and as soon as you stop pushing, it will start slowing down and eventually stop moving. It may seem that the only force acting on your book is the force applied. In reality there is another force that acts on the book: the force of friction between the book and the table. The book comes to a stop once the pushing force is gone not because rest is its "natural state" but because the force of friction is still there acting on the book. If the same book was pushed along a smooth icy surface it would travel much farther before it stops. Now imagine an ideal case where there is no friction: the book would continue to move forever as a result of one push from your hand.

3) The word inertia describes the tendency of all objects to continue with their previous motion when the net force is zero. We correlate the inertia of an object with its mass. Mass can be thought of as a measure of the matter content of an object; but for motion, mass is a measure of its inertia. It is harder to make an object with a lot of mass (lot of inertia) deviate from its path than an object with less mass (and less inertia).

Newton's First Law can be restated as:

An object with a lot of inertia (i.e. a lot of mass) is harder to deviate from its trajectory (i.e. it takes a lot of force to change its motion) than an object with less inertia.

4) Now let's get back to the example of your book moving forever if there is no friction acting on it. Newton's First Law actually says two things: a) in the absence of a net force, an object keeps moving as it was moving and b) in the presence of a net force, a body changes its motion.

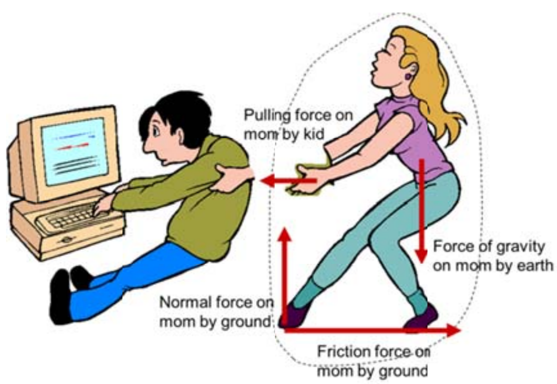
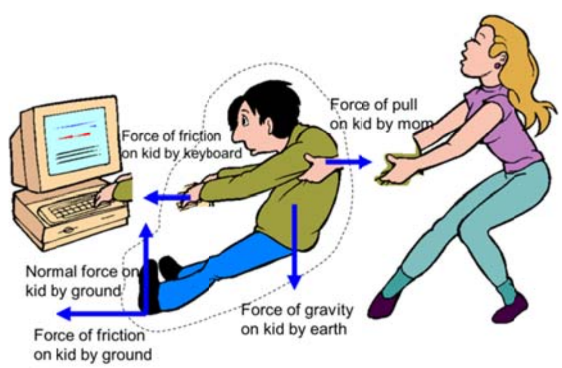
Now that you have learned how to draw force diagrams, we can add motion maps to the problems.

READING PAGE: NEWTON'S THIRD LAW

What is the connection between forces acting on two objects interacting with each other? Let's consider the simple interaction between a hammer and a nail. The hammer exerts a force on the nail as it drives it into the wall. At the same time, the nail exerts a force on the hammer. If you are not sure that it does, imagine hitting the nail with a banana or a glass hammer. It is the force of the nail on the banana that pokes holes into it or shatters the glass.

Let's look now at the picture on left: a mom is pulling on her son, trying to get him away from his computer. The mom interacts with her son, and her son interacts with the computer. We have already learned how to identify all the forces acting on the boy, or on the mom or on the computer. But how do we deal with objects that interact with each other, such as the mom and the boy, or the boy and the computer?

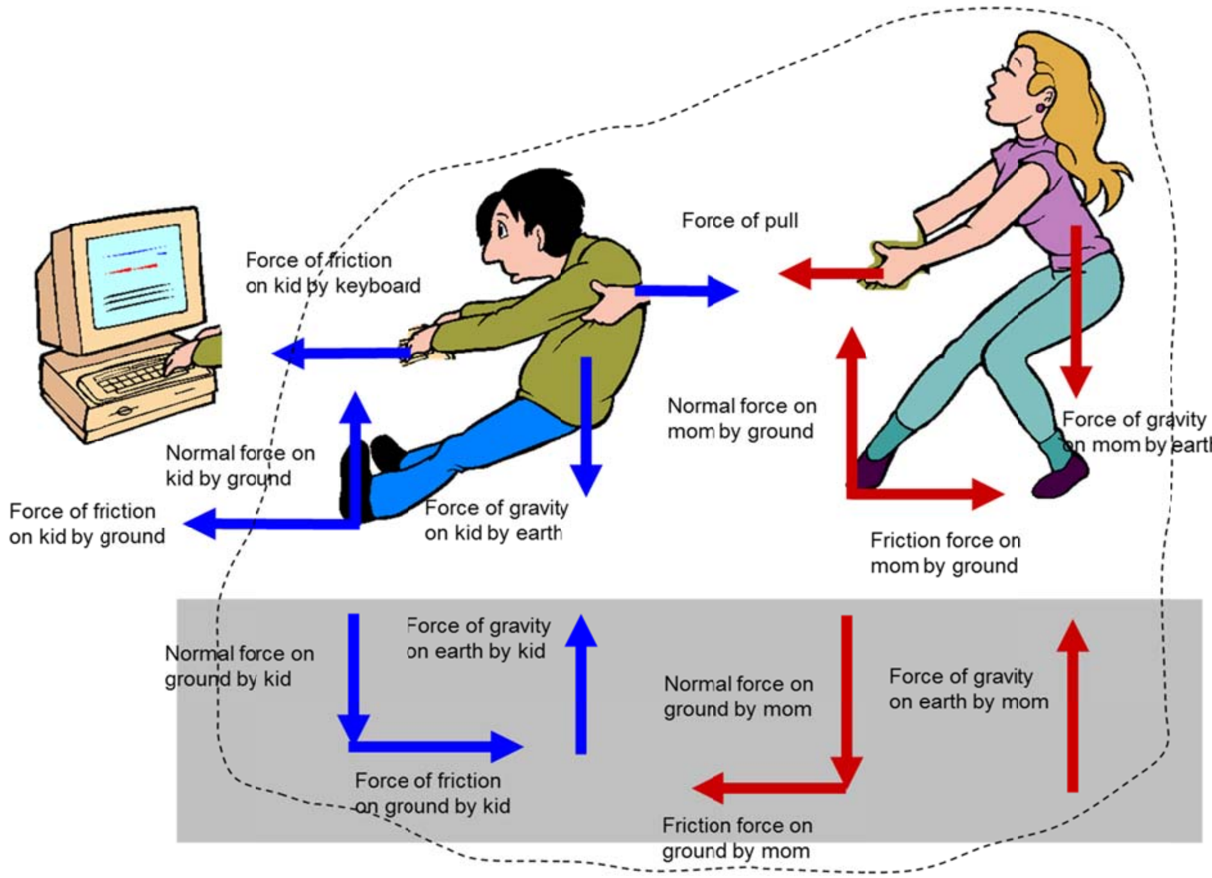
Newton's Third Law explains how two objects/systems interact with each other. Every time an object A pushes or pulls on an object B, object B pushes or pulls back on object A. When the mom pulls on the boy, the boy pulls back (and she feels this in her arms). The two objects, mom and boy, are interacting. An interaction is the mutual influence of two systems on each other. The boy and mom are also interacting with the ground/earth.

<table>
<tr><td>Let's analyze all forces acting on the mom:

</td>
<td>And now let's analyze all forces acting on the boy:

</td></tr>
</table>

The pulling force applied by the mom on the boy is the action force, and the pulling force applied by boy on his mom's arms is the reaction force. Although we name one force the action and the other force the reaction for convenience, these two forces occur simultaneously and one cannot strictly specify which one is the "action" and which one is the "reaction". An action/reaction pair of forces exists as a pair, or not at all. Also, paired action and reaction forces have (a) the same magnitude, (b) act in opposite directions and (c) act on different objects.

But how about the rest of the forces acting on the boy and mom? Are they part of an action/reaction pair? Yes, all forces in the universe are part of action/reaction pairs – there are no forces that act alone. If you look only at the forces acting on the boy it may seem that these forces are isolated but that is because we have chosen our system to be one single object: the boy. All forces acting on the boy arise from his interaction with the environment (which is outside for the chosen system). To be able to identify all the action reaction forces we must consider the expanded system which consists of boy, his mom and the ground.

Let's now identify all the action reaction pairs that act in the system. In the diagram below the action reaction forces are connected through a dotted line.



For each force applied on the boy, there is a force the boy applies to another object. The same holds true for the mom. All interaction forces between boy and mom, boy and ground, and mom and ground are contact forces. The exception is the weight applied by earth, which is a long range force.

How do action reaction pairs work for long range forces?

If you let a ball fall, it will move down toward the earth because the earth pulls on it with a force called weight, the action force. But does the ball pull on the earth? Is there a "reaction" force acting on the earth? Indeed there is. The ball also attracts the earth with the same amount of force – the weight of the object. Does the earth then fall toward the ball? Yes, it does. But since the earth is huge and the ball is very small what one observes is a larger effect on the small ball. A similar effect occurs with two magnets: two magnets attract or repel each other through a long range force that can act at a distance. If you hold a magnet in each hand, you can feel the force acting on each magnet because long range forces come in pairs too.

There is only one force in the boy + mom + ground diagram for which a force pair is not drawn: the friction force applied by the keyboard on the boy's fingers. Is there no pair for this force? Yes, there is: the force with which the boy's fingers act on the keyboard. We have not drawn the reaction for that force intentionally.

Whenever we deal with Newton's Third Law we must define the system of interacting object. In our case the system was boy + mom + ground/earth. The computer was an external object to our system and thus the force applied by the computer to the boy's fingers is considered an external force.

Newton's Third Law states that:
1. *Every force occurs as one member of an action/reaction pair of forces.*
2. *The two members of an action/reaction pair act on two different objects.*
3. *The two members of an action/reaction pair point in opposite directions, and are equal in magnitude.*

Rules to follow when identifying action/reaction pairs:
1. Identify the objects that are systems of interest. Other objects whose motion you don't care about are part of the environment.
2. Draw each object separately. Place them in the correct position relative to other objects. Don't forget to include objects like the earth that may not be mentioned in the problem.
3. Identify every force. Draw the force vector on the object on which it acts. Label each with a subscripted label. The usual force symbols can be used.
4. Identify the action/reaction pairs. A force goes with a force. Connect the two force vectors of each action/reaction pair with a dotted line. When you're done, there should be no unpaired forces.
5. Draw a free-body diagram for each object within the system. Include only the forces acting on the objects in your system, not forces that the objects in your system exert on other objects.

Newton's third law is one of the fundamental symmetry principles of the universe. Since we have no examples of it being violated in nature, it is a useful tool for analyzing situations which are somewhat counter-intuitive. For example, when a small truck collides head-on with a large truck, your intuition might tell you that the force on the small truck is larger. Not so! Both cars experience the same force. But why does the small car sustain much more damage than the truck? That has to do with Newton's Second Law!

READING PAGE: NEWTON'S SECOND LAW

Newton's first law told us what happens when no net external force acts:

a) Things that are sitting still will not move on their own, they need an outside force to make them move.
b) Things that are moving in a straight line will not stop, slow down or speed up on their own, they need an external force to change their motion.
c) Things that are moving in a straight line will not change direction unless a force makes them do so.

So it is pretty clear that if a net external force does act,

a) Things that are sitting still can begin to move.
b) Things that are moving can be made to slow down, speed up or even stop.
c) Things that are moving in one direction can be made to change direction.

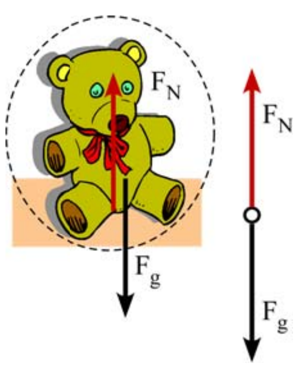
In the previous activity we saw that a net external force changes the motion of an object by making it accelerate. How does that go along with the statements above?

→ Things that are sitting still can begin to move: the object had a velocity of zero to begin with, and after a force is applied, it accelerates to a higher velocity.
→ Things that are moving can be made to slow down (force is applied to change a high velocity to low velocity) speed up or even stop.
→ Things that are moving in one direction can be made to change direction – this is also a change in velocity, namely, the amount of velocity may not have changed, but the direction has, so there is a net acceleration.

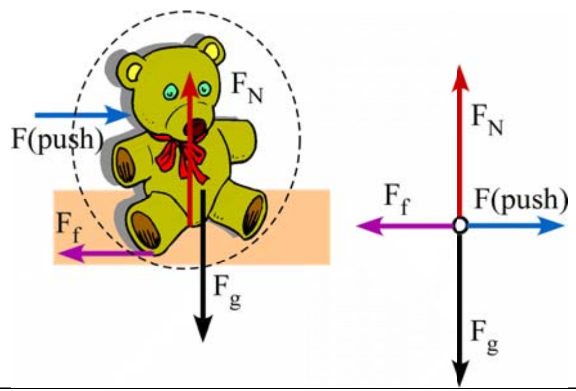
We also saw in the previous activity that the amount of mass affects the force applied. In other words, for two masses to have the same acceleration, the larger mass needs a larger force. In equation form,

n $F = ma$

A lot of the applications of Newton's second law deal with the fact that several forces can act on an object, but if the forces don't all balance out then there is a net external force. This net force causes acceleration – and the acceleration will be along the direction of that net force. If all forces balance out, the object will either be at rest (or in equilibrium) or move with a constant velocity. In the examples below all forces are drawn and a motion diagram is associated to each example.

<u>Example 1</u>: A Teddy Bear sits on a table. 	The weight acts downward, and the normal force acts upward. They balance each other out; the bear does not move. We know the two forces are equal because; a) if $F_G > F_N$ the bear would fall downward b) if $F_N > F_G$ the bear would fly upward c) since it stays put, $F_N = F_G$

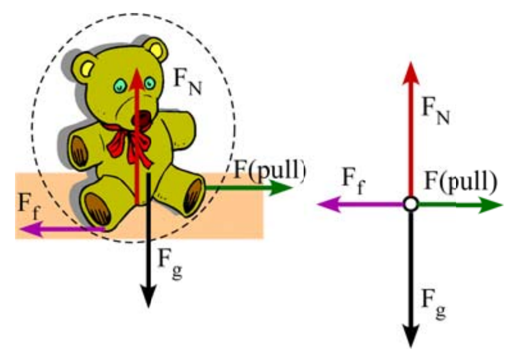
Example 2: A bear sitting on a table is pushed gently to the right but does not move.



In the vertical direction:
The weight acts downward, the normal force upward. They balance each other out; bear does not move in the vertical direction.

In the horizontal direction:
The pushing force F_{push} to the right is opposed by the force of friction, F_f; Since there is no motion along the horizontal direction, the pushing force must balance the force of friction: $F_{push} = F_f$.

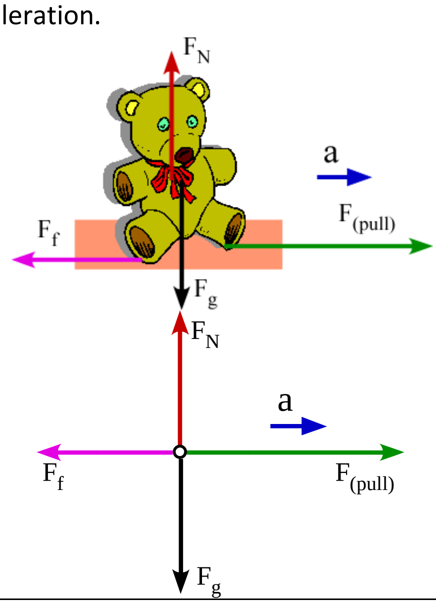
Example 3: The bear is being pulled on a table and moves to the right with constant speed.



Vertical:
The weight acts downward, the normal force upward. They balance each other out; bear does not move along the vertical direction.

Horizontal:
Since the bear moves to the right, the force of friction acts toward the left since friction always opposes motion. Constant velocity means that there are no net forces acting in the horizontal direction. Therefore the pulling force and the force of friction balance each other:
$F_{(pull)} = F_f$

Example 4: The bear is being pulled on a table and moves to the right with constant acceleration.



Vertical:
The weight acts downward, the normal force upward. They balance each other out; bear does not move along the vertical direction.

Horizontal:
Since the bear accelerates to the right, the force of friction acts toward the left since friction always opposes motion. Acceleration to the right means that the net force acting in the horizontal direction is to the right. Therefore the pulling force must be stronger than the force of friction for the bear to accelerate to the right.

$F_{net} = ma$ where $F_{net} = F_{pull} - F_f$