Objective 4

The student will demonstrate an understanding of motion, forces, and energy.

My Notes

Did You Know?

During fusion, hydrogen atoms combine to form helium atoms.

Remember!

Chemical energy is held in the bonds between the atoms in molecules. When molecules undergo a chemical change, they may release the energy held in their chemical bonds in another form, such as heat, light, or electricity.

Through your studies in science, you should be able to demonstrate an understanding of motion, forces, and energy.

What are motion, forces, and energy?

Motion, forces, and energy are three closely related ideas. Each helps explain how and why things happen the way they do in our physical world.

I think I know what energy means. We get most of our energy on Earth from the sun, right?

That's right. *Energy* is the ability to do work or cause change. *Light* from the sun is one form of energy. Sunlight is a product of a nuclear fusion reaction inside the sun. This process releases a tremendous amount of energy. Some of this energy reaches Earth in the form we call sunlight.

What happens to sunlight energy once it reaches Earth?

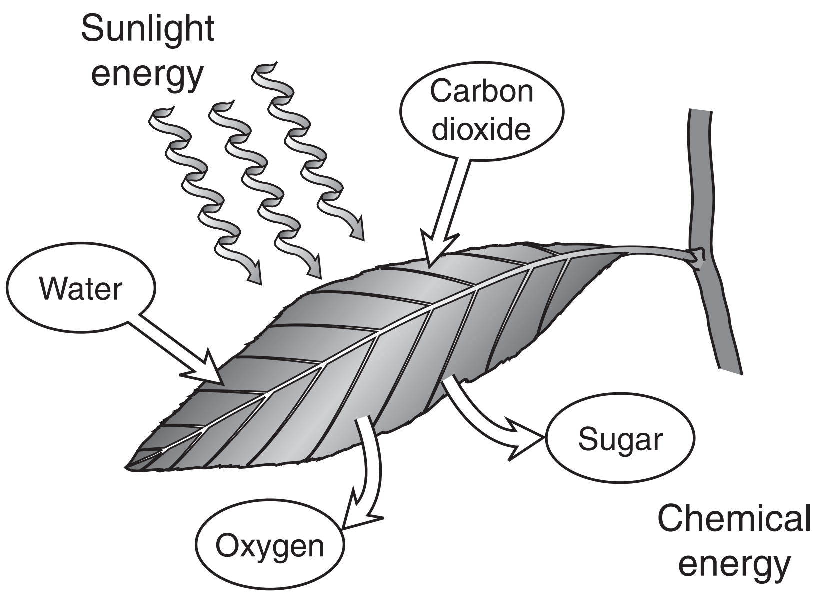
Quite a few things may happen to it. Let's first discuss how energy from sunlight enters ecosystems.

Remember our discussion of photosynthesis? Plants use energy from sunlight to change carbon dioxide and water into sugar during photosynthesis. So some of the energy in sunlight is converted to the energy in the bonds of the sugar molecules. This is one way light energy is converted to *chemical energy*.

My Notes

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Sunlight energy → Chemical energy



Are there ways besides photosynthesis that sunlight energy is transformed?

Yes. Another important energy transformation occurs when sunlight strikes water. What happens to water and land that are exposed to sunlight?

They heat up, right?

Right. The water absorbs the energy of the sunlight, and the water temperature rises. The increased temperature tells us that the water has gained *heat* energy. The same process occurs when sunlight strikes land and other solids. The ability of a substance to absorb heat energy is a property called specific heat.

So sunlight can be transformed into chemical or heat energy. Are there energy transformations that don't involve sunlight?

Sure. Think about what happens in a CD player. It needs energy to play music. Where does this energy come from?

Well, I just plug it in and get electricity from the wall outlet, don't I?

Yes, that's one way for the CD player to get energy. Plugging it in allows *electrical energy* to flow from the outlet to the CD player. A flow of electrons (current) through a conductor produces electrical energy. What causes electrons to flow in the conductors inside the wall outlet?

My Notes

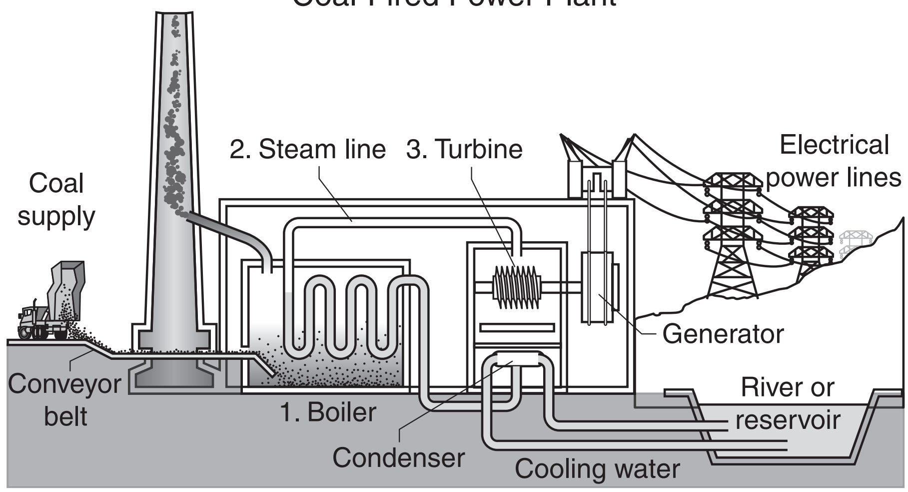
Remember!

During energy transformations, energy is often released as light, heat, or sound. Although energy can change into different forms, it is never lost. This is known as the law or principle of conservation of energy.

Power lines carry electricity to my house. But where does the electrical energy in the power lines come from?

Electrical power can be generated in several ways. For example, coal or natural gas may be burned to generate electricity. The energy transformations used in generating electrical power from burning coal are shown below.

Coal-Fired Power Plant



Energy Transformations in a Coal Power Plant

Process	Energy Transformation
1. Coal being burned	Chemical to Thermal
2. Water boiling to form steam	Thermal to Mechanical
3. Turning of a turbine	Mechanical to Electrical

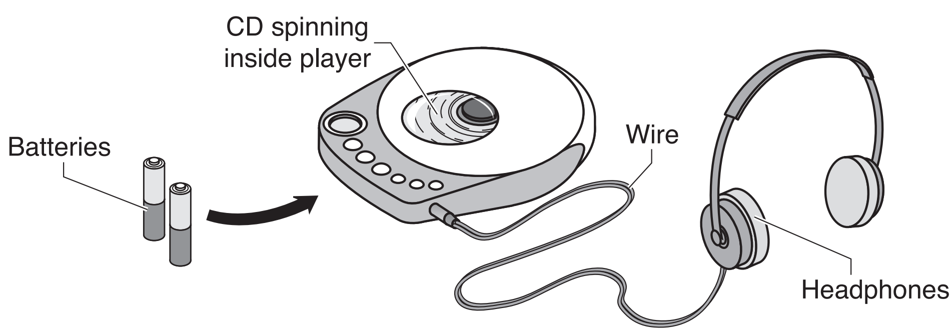
What ways of generating electrical power are there besides burning fuels?

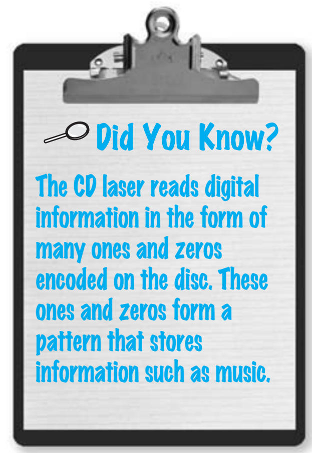
The water flowing through a dam in a river can be used to move turbines to generate electricity. Wind generators use the energy of moving wind to operate a generator that produces electricity. Nuclear power plants convert atomic energy into heat. This heat boils water to form steam and then follows the same energy transformations as in a coal power plant. The electrical energy generated in all these ways can then be sent through power lines to houses and other buildings.

My Notes

Wow! There are a lot of ways to generate electricity. Am I still using energy if I just run my CD player on batteries?

Yes, you are still using energy. Batteries store chemical compounds that react when they are used to power the CD player. This produces a flow of electrons in the circuits of the CD player. Chemical energy in the batteries is converted to electrical energy in the CD player. There are even more energy transformations that occur in the CD player to produce the actual music that you hear.





Really? What other transformations happen in the CD player to produce music?

Well, the CD player also uses electricity to spin the CD. The spinning CD has mechanical energy. *Mechanical energy* is the energy in an object due to its position or motion. So another energy transformation in the CD player is electrical energy to mechanical energy.

O.K., but how does the CD player produce the music from the CD?

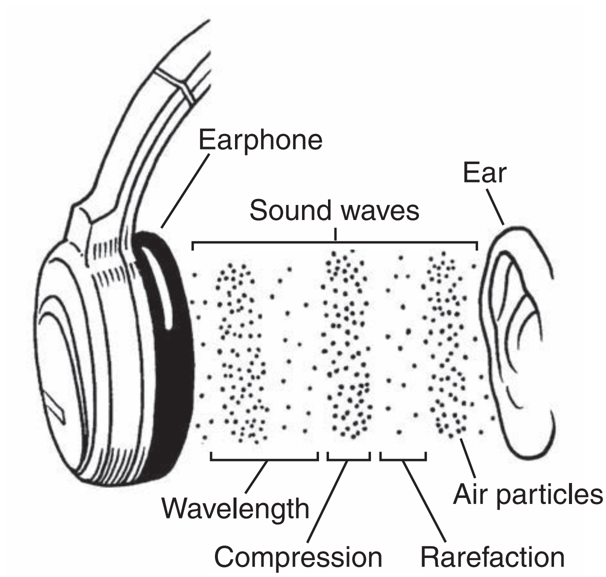
The CD player uses a laser to convert the digital information on the CD's surface into electrical energy. This energy is carried to the headphones. There is a material inside the headphones that vibrates in response to the electrical energy. What kind of energy do vibrating objects transmit?

My Notes

Isn't it sound energy?

That's right. *Sound* consists of mechanical energy waves created by vibrating objects. Sound must travel through something such as air, water, or a solid. This "something" is called a medium. The *medium* carries the energy of the wave from one place to another. In our example, air transmits the energy of the vibrating material in the headphones to your eardrums.

A *vacuum* is a space that contains little or no matter. Sound cannot travel through a vacuum since there are no particles to squeeze together (compression) or spread apart (rarefaction).



Did You Know?

Light waves travel at a constant speed in a vacuum. The constant speed of light is used to calculate the vast distances between objects in the universe.

Do other forms of energy travel by waves?

Sure. *Light waves* are in the sunlight we discussed earlier. Light waves don't need a medium to transmit energy. They can even travel through empty space. *Seismic waves* caused by earthquakes transmit mechanical energy through Earth's layers. *Water waves* are a form of wave that transmits mechanical energy across the surface of water.

Remember!

All energy is either potential or kinetic. Energy can be classified by its source (heat, chemical, electrical, etc.) and its type (potential or kinetic).

I've also heard my teacher talk a lot about potential and kinetic energy. What are these forms of energy?

Besides the types of energy we have already discussed, energy can also be classified as *kinetic energy* or *potential energy*. Kinetic energy is the energy an object has due to its motion. Potential energy is stored energy due to an object's position.

So whenever an object moves, it has kinetic energy?

That's right. Two things affect the amount of kinetic energy in a moving object: speed and mass. Speed is important because the faster an object moves, the greater its kinetic energy. We'll talk about mass later.

My Notes

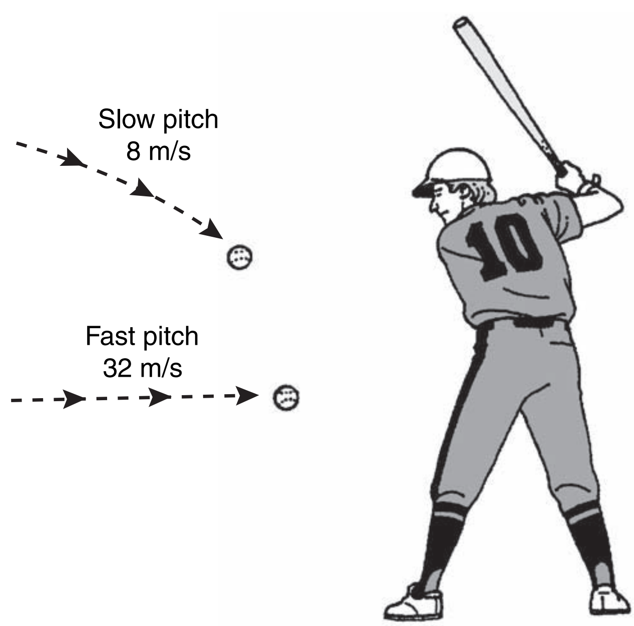
How do we know that a faster object has more kinetic energy?

Let's look at an example. Imagine you are at bat in a softball game. The pitcher throws a high pitch slowly toward home plate, but instead of passing over home plate, the ball hits you. How does it feel?

Well, it might hurt a little, but not much. Why does it matter how it feels to get hit by the softball?

Follow me a little further. Now imagine you are at bat in another softball game. This time the pitcher hurls a lightning-fast pitch straight toward you, and again the ball hits you. Now how does it feel?

Which Pitch Strikes with More Force?



Ouch! All right, I get your point. The faster ball will hit with a lot more force. What else besides speed affects the kinetic energy of an object?

The kinetic energy of objects is also related to the mass of the object. An object with more mass has more kinetic energy than an object with less mass if both objects are traveling at the same speed.

My Notes

How do we know that?

Let's use our imagination again. First let me ask you this: If I drop a pebble and a large rock from the same height at the same time, which one will hit the ground first?

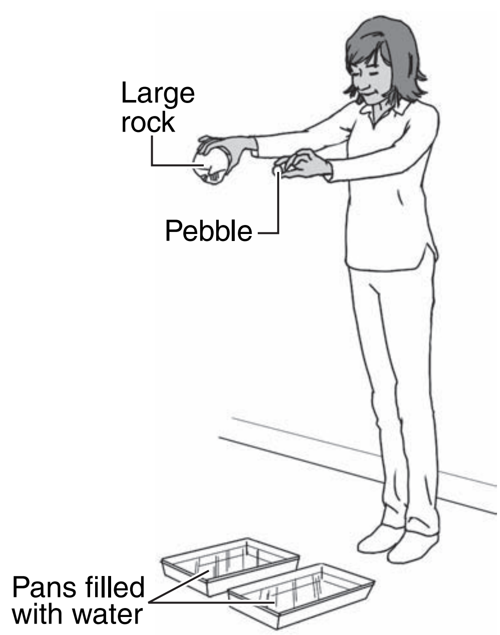
That's a trick question! But I know the answer. They will hit the ground at the same time.

Good answer! So they both travel at the same speed. Which one has a greater mass?

The large rock, of course. But how do we know it has more kinetic energy?

Well, imagine that you hold the pebble and the rock out in front of you at the same height. You drop both of them into identical pans filled to the top with water. Which object will create a bigger splash when the pebble and rock land in the water?

Which Object Will Make a Bigger Splash?



The large rock will make a bigger splash. So more mass means more force, which creates a bigger splash, right?

Right. Since the larger rock lands with more force than the pebble, we know that it has more kinetic energy.

O.K., I see. Both speed and mass affect the kinetic energy of an object, right?

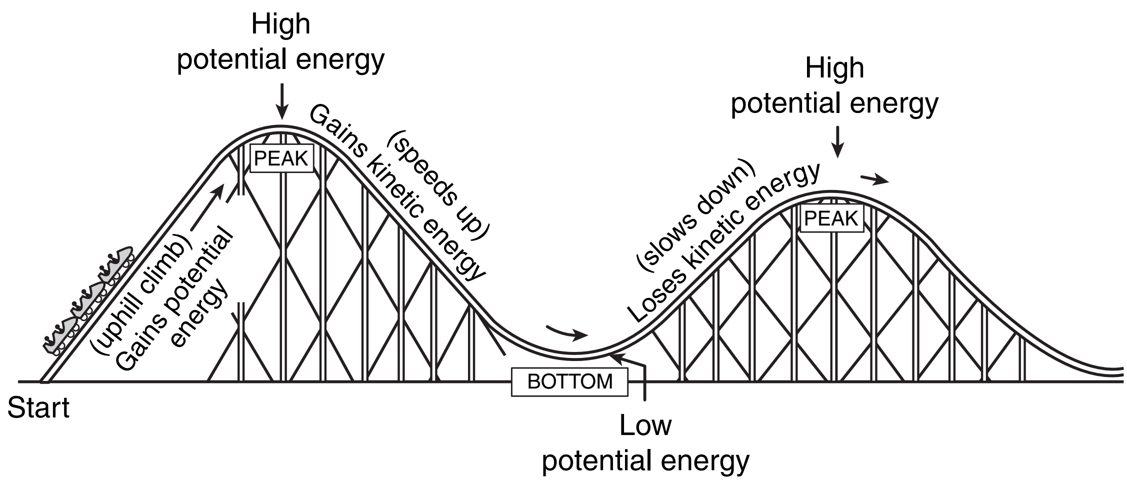
Yes, that's right.

My Notes

You said potential energy is stored energy or energy due to position. How does position give an object energy?

Think of a roller coaster at an amusement park. Have you ever noticed how the highest peak on the roller coaster is always the first one?

Roller Coaster Energy Diagram



Yes, I've noticed that on several roller coasters. Why is that?

It's because potential energy has to be built up in the roller coaster. The roller coaster is brought high above the ground so that gravity can pull it downward. The force of gravity then converts the potential energy of the roller coaster at the top of the track to kinetic energy as the coaster rolls downhill. This kinetic energy carries the roller coaster all the way to the end of the ride.

See, as the roller coaster moves uphill, it gains potential energy. Because the roller coaster gains this energy by being moved, we can say that it gains stored energy due to a change in its position.

Does the roller coaster lose potential energy when it starts going downhill?

Yes. But remember that the faster an object moves, the more kinetic energy it has. So as the roller coaster picks up speed going downhill, it gains kinetic energy. The roller coaster's speed and kinetic energy will be greatest at the bottom of the downhill run. This is also where the roller coaster's potential energy will be lowest.

As the roller coaster starts its climb to the next peak, it will slow down and lose kinetic energy. But as it gets higher, it gains potential energy again. This cycle repeats several times during the roller coaster ride.

My Notes

O.K., I think I understand. Gravity is the force behind the roller coaster's potential energy. So is there potential energy in anything that can be moved by a force like gravity?

Yes. A *force* is a pushing or pulling action that may change motion. Forces may move objects or transfer energy between objects. Water at the top of a waterfall has potential energy to be pulled down to the sea by the force of gravity. There are many other examples of potential energy in the world around us.

How do forces cause objects to move?

Motion is the change in position of an object. Anything that is moving is in motion. When you pick up a pencil, the pencil is in motion. After you put the pencil down or hold it still, it is no longer in motion.

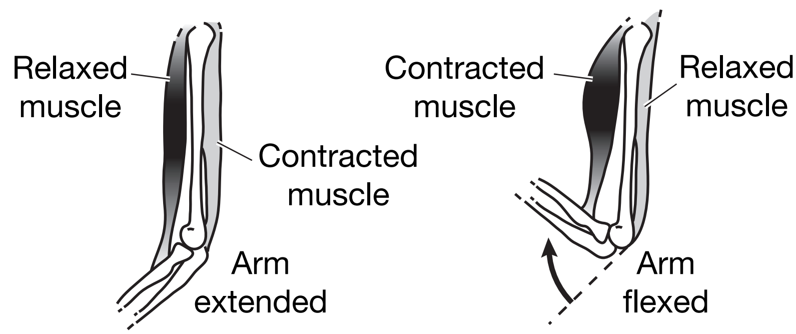
So I use force to move my body?

That's right. For example, when you bend your arm, your muscles contract, which applies force to your arm bones. Your arm responds to this force by moving.

Did You Know?

Skeletal muscles of many animals work in pairs. One muscle contracts to exert force while the other muscle relaxes.

Movement of Elbow Joint



Other systems in your body also use force. For example, during breathing, muscles contract (use force) to move air in and out of the lungs. The heart also contracts (uses force) to pump blood through the blood vessels, carrying oxygen to the muscles.

Remember!

Living organisms use energy to exert force to produce motion. Motion is one way that organisms respond to environmental changes.

Do all living things use force to move?

They sure do. Organisms rely on force to create motion. Emerging seedlings, for example, exert force on the surrounding soil. This force pushes the stem of the young plant out of the ground. Plants also exert force to open flower petals, curl and uncurl leaves, and push roots through the soil.

Fish exert force to swim by pushing against the water. Force is used to move materials in and out of cells. Force and motion can be found working together throughout the living world.

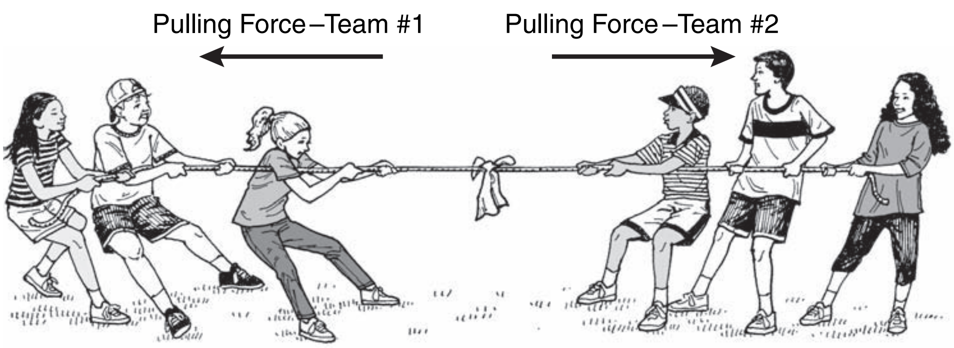
My Notes

Then force always results in motion?

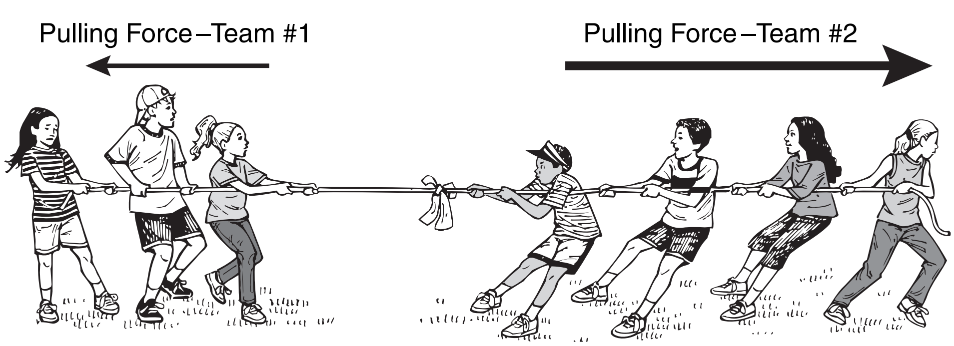
Not always. In order for a force to move something, it must be an *unbalanced force*. This means that a force is stronger in one direction than the forces in the opposite direction.

Oh, so it's like a game of tug-of-war?

Great example! In tug-of-war a team on one end of the rope is pulling with a force in one direction. A team on the other end of the rope is pulling with a force in the opposite direction. If they both pull with the same amount of force, the rope won't move at all. When forces have the same strength in opposite directions, we say the forces are *balanced*.



Now imagine that another person joins one team. That team now pulls with more force than the other team. The net force has now changed in favor of the team with more people. Both teams are pulling, but one team's force is greater than the other's.



When the forces acting on an object are not equal, we say they are *unbalanced*. The greater force will cause an object to move in the direction of its push or pull. In the game of tug-of-war, the rope will move toward the side of the team that pulls with the most force.

O.K., let's say I'm pushing my skateboard. How much force would it take to do that?

That's a good question. The answer depends on two things. First, we have to know how much mass you and your skateboard have together.

Did You Know?

Mass is the amount of matter in an object and is the same anywhere in the universe for a given object. Weight is the force that gravity exerts on an object, so it varies at different locations.

My Notes

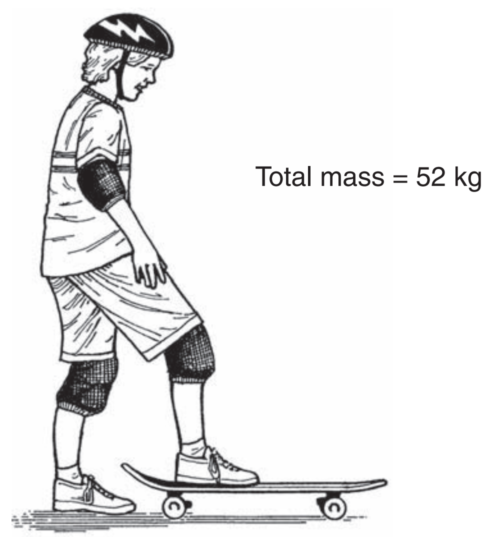
Second, we have to know how fast your skateboard is accelerating.

Why should I care about my mass or the mass of my skateboard?

Remember how the large rock exerted more force on the pan of water than the small pebble? Well, it takes more force to get that large rock moving in the first place. The greater an object's mass, the more force is required to make it move at a given speed.

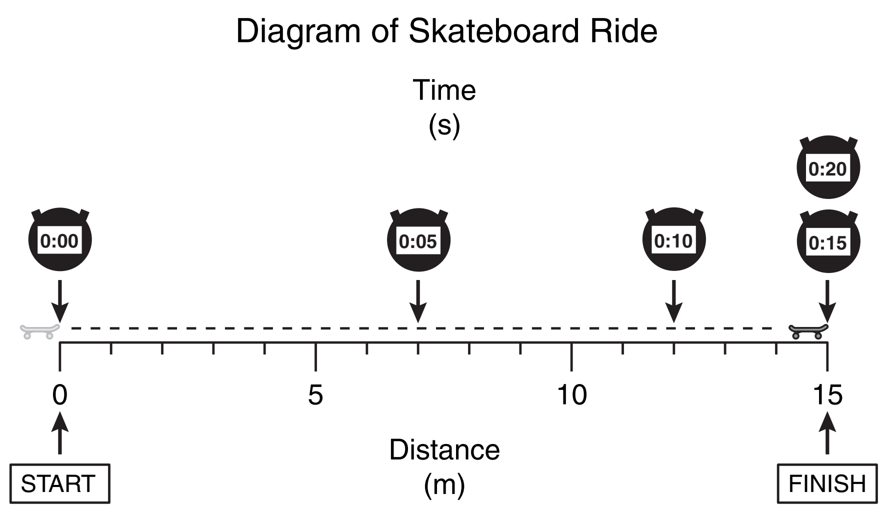
Well, I know my mass is 50 kilograms and my skateboard has a mass of about 2 kilograms.

O.K., that's about 52 kilograms total.



Now should we measure me riding my skateboard?

Sure. Let's say we time your ride and measure the distance you travel every five seconds. The diagram below shows the data we might collect from your ride.



My Notes

Can we put this data in table form?

Great idea! In the left column, let's record the time every five seconds for 20 seconds. You can see that your motion ended at 15 seconds, and from 15 to 20 seconds you were stopped. In the right column, let's record the total distance in meters you had traveled at each time measurement.

Table of Skateboard Ride Data

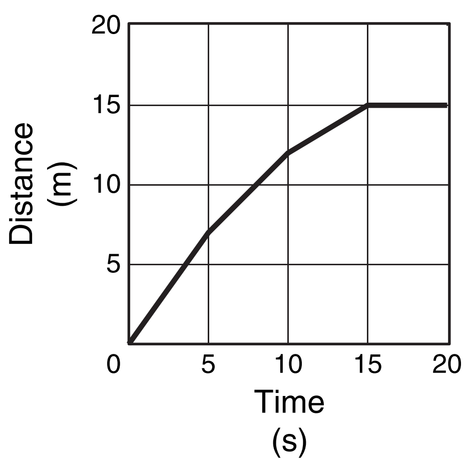
Time (s)	Distance (m)
0	0
5	7
10	12
15	15
20	15

← (Skateboard has stopped moving.)

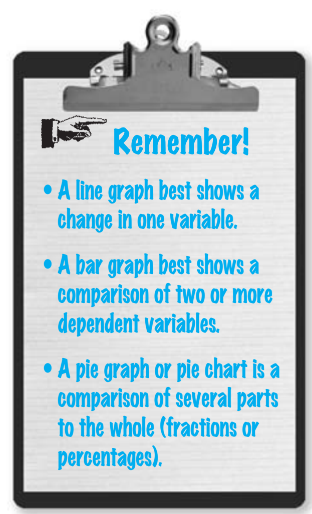
That looks good. Can we graph it, too?

Sure. From the data in the table, we can create a distance-time line graph. The distance-time graph of your skateboard ride is shown below.

Graph of Skateboard Ride Data

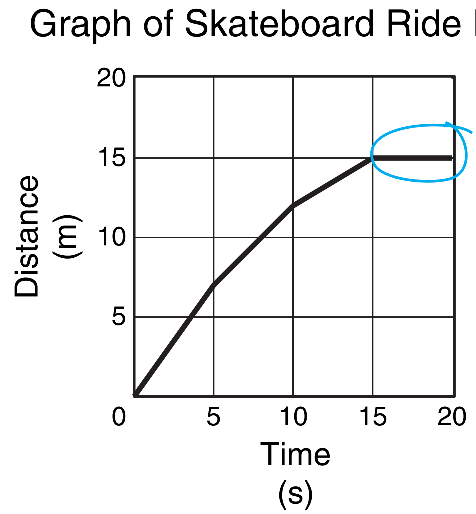


Look at your graph of distance over time. *Speed* is the change in distance divided by time. The unit for speed is meters per second (m/s). Since you went 15 meters in 15 seconds (15 meters/15 seconds = 1 meter/1 second = 1 m/s), your average speed was 1 m/s.



My Notes

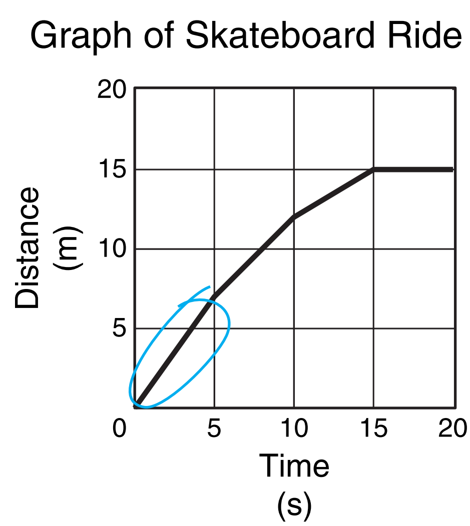
Looking at the graph, I can see that my speed changed several times.



That's right. Let's look closely at your graph. Notice the section where the line is flat (horizontal). I've circled that part in the graph above. On a distance-time graph, an object is not moving if the line is flat.

So, from 15 to 20 seconds I was stopped. But it looks like I started out really fast.

Yes, you did. Look at the line segment circled below from 0 to 5 seconds. The graphed line is steepest in this section. On a distance-time graph like this, the faster an object is moving, the steeper (more vertical) the line will be. From the graph we can see that you started out moving pretty fast, but then you slowed down and stopped after 15 seconds.



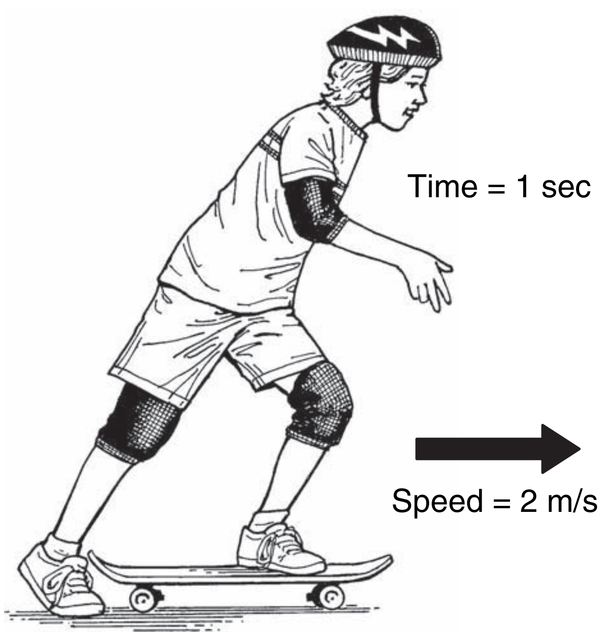
My Notes

That makes sense. But can you explain acceleration?

To understand acceleration, let's go back to the softball example. Remember the difference between the slow softball pitch and the fast softball pitch? It took a lot more force to get that softball moving quickly than to get it moving slowly. The two softballs were the same mass in both situations, so what was different in each case?

The speed of the pitch was different, right?

That's right. The ball went from being motionless in the pitcher's hand to moving toward you. The 32 m/s pitch accelerated faster than the 8 m/s pitch. *Acceleration* of an object moving in one direction is the change in speed (m/s) per unit of time (s), or change in speed divided by time. The unit for acceleration is m/s^2.



So let's say I go from 0 m/s at the start to moving 2 m/s one second after I push off down the sidewalk. What is my acceleration?

Your change in speed is 2 m/s, and the time it took you to change speed is one second. So $2 \text{ m/s} \div 1 \text{ s} = 2 \text{ m/s}^2$.

My Notes

But what's the relationship between force and motion?

Force is measured in units called *newtons* (N). One newton is the force on a 1 kg mass that will accelerate that mass to 1 m/s^2. Motion can be measured as either the speed of an object in a given direction or the distance an object travels in a given direction per unit of time.

Did You Know?

The unit called the newton was named in honor of Sir Isaac Newton, a scientist who made important discoveries about the relationship between force and motion.

Now can we calculate the force of my skateboard push?

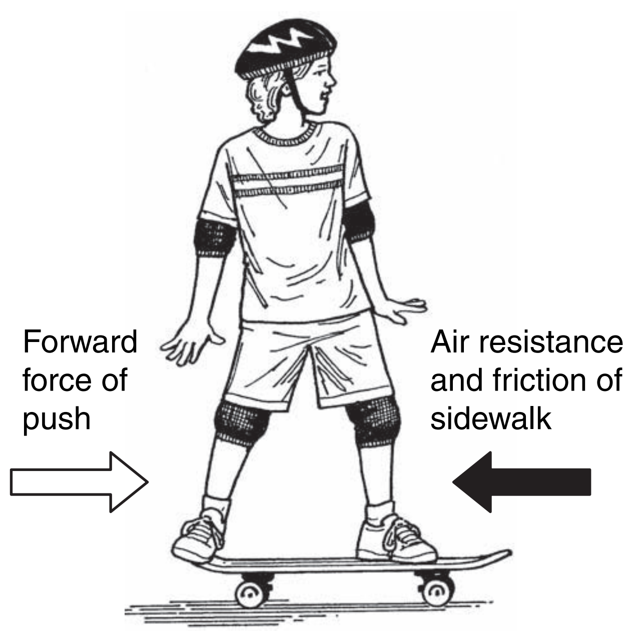
Yes. Once we know the acceleration and mass, the force can be calculated using the following formula: Force = mass × acceleration, or $F = ma$. So for your skateboard push: $F = 52\ kg \cdot 2\ m/s^2 = 104\ kg \cdot m/s^2 = 104\ N$ of force.

But when I ride my skateboard down the sidewalk, I slow down and eventually stop. Why don't I just keep moving at 2 m/s?

Remember how it takes an unbalanced net force to cause motion? You would continue at 2 m/s if the force of your push remained unbalanced. But as soon as you start moving forward, the force of air and the friction between the wheels and sidewalk both oppose the motion of your skateboard.

Remember!

The units of kilograms (kg) for mass, meters (m) for distance, and seconds (s) for time can be combined into one unit called the newton (N).
$1\ N = 1\ kg \cdot m/s^2$.



My Notes

How long will it take for me to stop?

That depends on the strength of the *resistance forces*. Resistance forces are those forces that oppose the motion of an object. For example, whether the wind is blowing with or against you affects the amount of air resistance. *Friction* is also a force that resists motion. The roughness or smoothness of the sidewalk also affects the amount of friction against the wheels.

I'm wondering why we would ever need to know how much force we use to do something.

Well, for one thing, it could help us make the work we do easier.

Work? You mean something like carrying out the trash?

Sure. You do work to lift the trash can. Lifting is one form of work. Work can be made easier with the help of a *machine*. A simple machine changes how much input force is needed to do work. *Input force* is the amount of force that is applied to a machine.

How do machines change how much input force is needed to do work?

It takes a certain amount of force to get a given amount of work done. Let's look at your example of lifting. For our purpose let's say it's a heavy rock you are trying to lift instead of a trash can. It's too heavy for you to lift just by pulling up on it. Your lifting force is not enough to overcome the force of gravity pulling the rock downward.

My Notes

Did You Know?

Simple machines can reduce the amount of input force, but the amount of work always remains the same.

Did You Know?

Objects in the same general location are pulled toward Earth at the same rate. This rate varies slightly depending on location. On Earth the average acceleration of objects due to gravity is 9.8 m/s².

So I need to increase my input force, right?

Perhaps you could, but you've already exerted all your force once, and it wasn't enough to lift the rock. In this case the trick is not to increase your force. What a machine can do for you is decrease the input force needed to lift the rock.

But gravity keeps pulling down on the rock with the same force. How can I decrease my input force and still lift the rock?

You can take advantage of the relationship between work, force, and distance. When you do *work*, you are applying a force over a distance. This is shown in the formula Work = force × distance, or $W = fd$. Since the unit for force is newtons and the unit for distance is meters, work is expressed in newton-meters (N·m).

Distance and force combine to produce work. So, to lift your heavy rock without applying more force, you can increase the distance over which you apply the force.

But wouldn't that just lift the rock higher?

Good question. We could lift the rock higher, but that would require more work. We are trying to reduce the amount of input force used to do the same amount of work. So we need to lift the rock the same distance but use less input force to do it.

That's where machines come into the picture. We need a machine that will allow you to apply your force over a greater distance than you are lifting the rock.

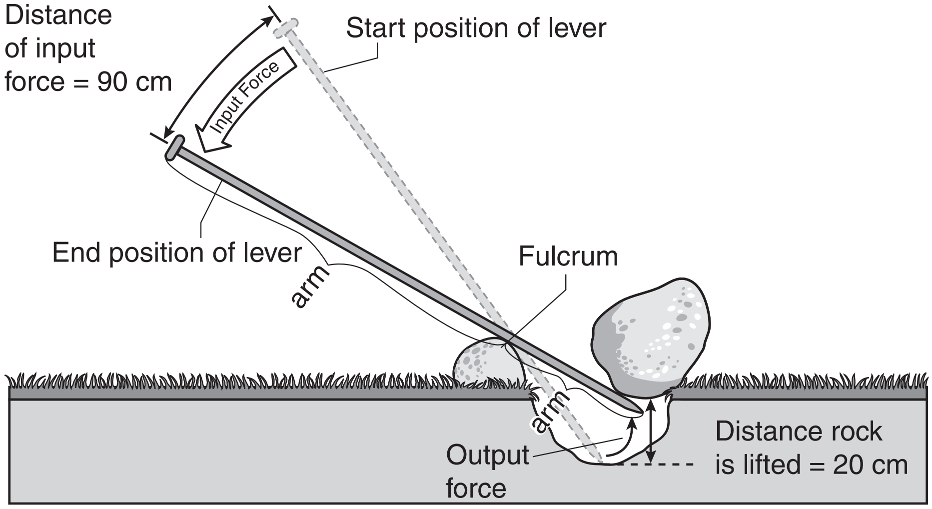
What kind of machine can do that?

Let's look at a simple machine called the *lever*. A lever has two *arms*: one that does the lifting and one that is used to apply the input force. The lever has a pivot point called the *fulcrum* that changes the direction of the force. Moving the fulcrum changes the distance each arm moves under a force.

O.K., so how does the distance one arm moves reduce the input force I need to lift the rock?

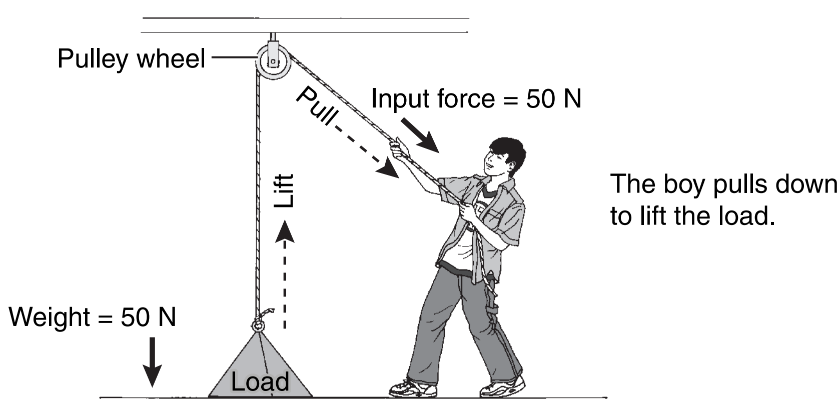
Let's say that you use a lever to lift the rock the same distance that a strong person could lift it by hand. The work done in each case is the same since the same rock is being moved the same distance. However, the distance one arm moves under your applied force is much greater than the distance the other arm moves to lift the rock. So your work is being done over a longer distance. The force you apply to lift the rock with the lever is less than the force required to lift the rock without a machine.

My Notes



Are there simple machines besides levers that help us do work?

Yes, there are several simple machines. Another example of a simple machine is the *pulley*. Pulleys use wheels and rope to move a load. When a rope passes over a wheel, it changes the direction of effort (pull) needed to move the load.



This pulley system has one wheel, so it changes the direction of pull one time. The input force is the same as the weight using this pulley.

Did You Know?

Simple machines include the pulley, the wedge, the lever, the inclined plane, and the wheel and axle.