Read to Learn

Main Idea **As the net force acting on an object increases, the object accelerates more.**

What Affects Acceleration?

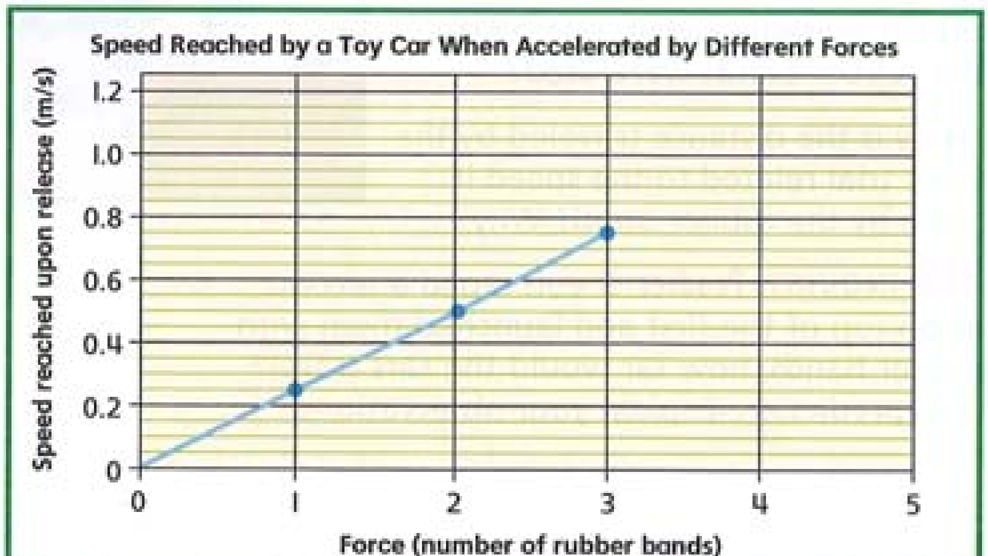
What if you use a rubber band to launch a toy car along the floor? The rubber band will apply a force to the car, and the force will cause the car to speed up. Once the rear of the car passes the starting line, however, the rubber band no longer is applying force. At this point the car will begin coasting until friction brings it to a stop. The farther the car travels before stopping, the faster it must have been going at the start.

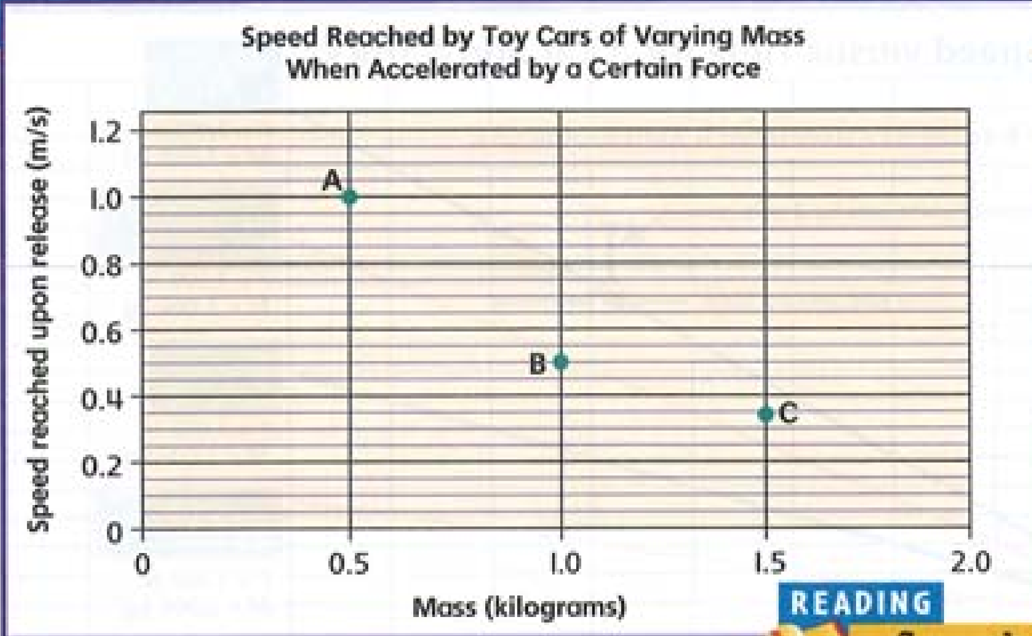
Force and Acceleration

What happens if you add extra rubber bands? Then you are applying more force to the car. As the force increases, the distance the car travels also increases. This, in turn, tells you that the car reaches its greatest starting speed when the force applied to it is greatest.

Sir Isaac Newton realized that forces produce acceleration. In other words, if we apply a force to an object, the object's velocity will change. The object might speed up, slow down, or change direction. It could even change both speed and direction.

Newton reasoned this way: If we multiply the force by a certain amount, we will change the acceleration by the same amount. (This assumes that no other changes are made.) For example, if we triple the force, the acceleration will also be tripled. What if you tried launching your toy car first using one rubber band, then using three rubber bands of the same size? You should see that as the force on the car is increased, the speed it reaches increases by about the same amount. The graph shows an example of how the car's acceleration would be related to the force acting on it, according to Newton's ideas.





Using the same amount of force, it is easier to accelerate a less massive object than a more massive object.

READING Graphs

What would the speed reached be for a mass of 2 kilograms?

Mass and Acceleration

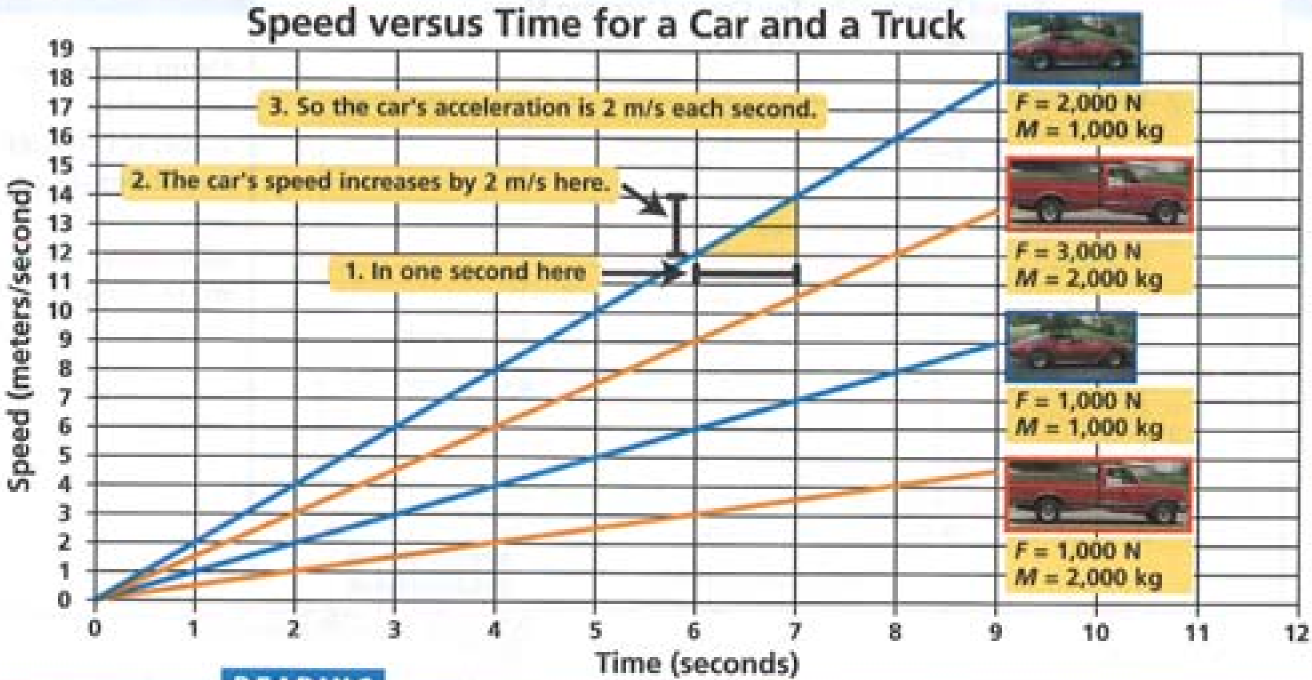
What happens if you tape a second car on top of the first? You double the mass being accelerated by the force from the rubber bands. Now the two cars together will travel only about half as far as one car would alone when launched by the same number of rubber bands. This tells you that doubling the mass resulted in about half the acceleration.

Isaac Newton understood that changing the force isn't the only thing that affects acceleration. He also understood that mass affects acceleration. However, while increasing the force increases the acceleration, increasing the mass decreases the acceleration.

When the mass is multiplied by a certain factor, the new acceleration is obtained by dividing the old acceleration by that factor. (Again, this assumes that nothing else has changed.) For example, what if the mass of an object being accelerated by a certain force is doubled? The new acceleration would then be the previous acceleration divided by 2. Put another way, if the mass is doubled, the acceleration is reduced to one-half of its previous value.

The relationship between acceleration and force is said to be direct—when one is increased, the other increases. The relationship between acceleration and mass, on the other hand, is inverse—when one goes up, the other goes down. The graph shows an example of how the acceleration of a toy car is inversely related to its mass.

What two factors determine how great an object's acceleration is?



READING Graphs

Describe two ways you could use the information on the graph to calculate the acceleration of the truck when a force of 3,000 N acts on it.

How Is Acceleration Calculated?

You learned in Lesson 1 that acceleration is a change in velocity. Recall that velocity describes both the speed and direction of a moving object. To calculate the acceleration of an object moving in a straight line you first must know three things—the object's starting speed, its new speed, and the amount of time it took for the change to occur.

Look at the lowest blue line on the graph above. In one second, the speed of the car has gone from zero to 1 meter per second. For each second that passes, the car's speed increases by another meter per second. The car is accelerating at 1 meter per second each second. Now look at the top blue line for the same 1,000-kg car. In one second the car's speed now increases by 2 meters per second. That means its acceleration is 2 meters per second each second.

What was changed to make the car's acceleration double? The force acting on the car was changed.

We can write an equation to show how acceleration is related to force and mass: $a = F \div m$. This equation says the acceleration is found by dividing the force by the mass. In the examples shown, forces are in units called newtons (N). A force of 1 newton makes the speed of a 1 kg mass change by 1 meter per second each second.

What do you need to know to calculate the acceleration an object will have?

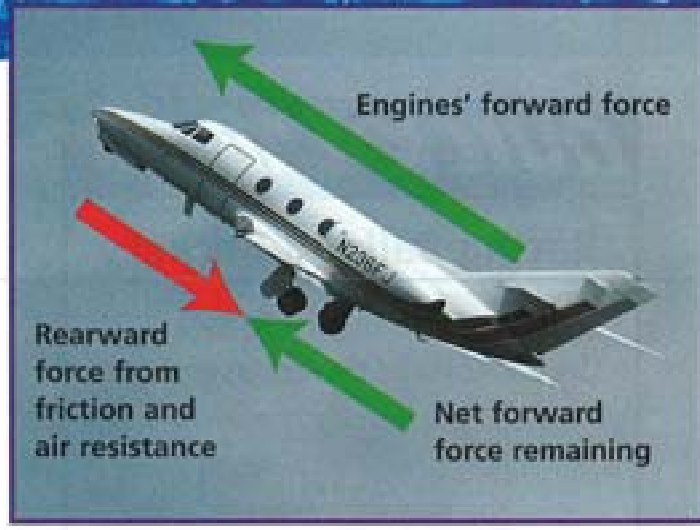
What Are Balanced and Unbalanced Forces?

The plane in the photograph below is flying at a constant speed in a constant direction. Its speed is not changing, nor is its direction of travel, so the plane cannot be accelerating. However, the pilot is using the throttle to make the plane's motor apply a forward force to it. How can the motor apply force to the plane without causing the plane to accelerate?

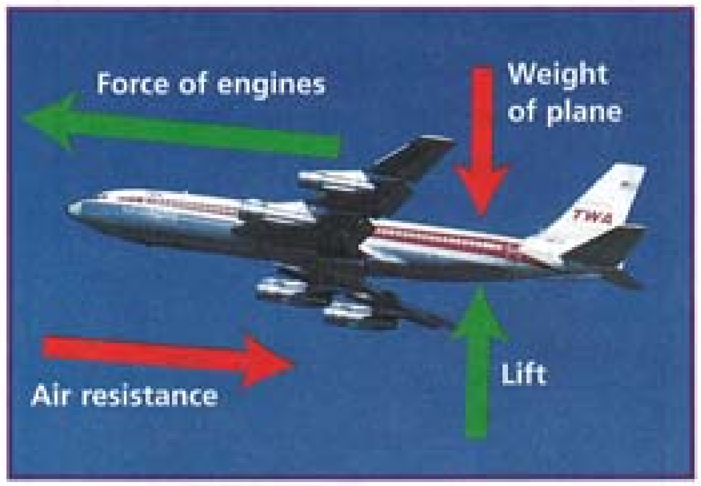
The explanation is that the force of the plane's motor is exactly offset by other forces acting in the opposite direction, as the diagram shows. In fact, there are a number of forces acting on the plane, but for each one there are others that cancel it out. When all of the forces on an object cancel one another out, the forces are said to be **balanced forces**.

In cases where a certain force is either only partially canceled or not canceled at all by other forces, the force is said to be an **unbalanced force**. For example, what if a plane's motor applies more forward force than the amount of friction and air resistance apply against its forward motion? The friction and air resistance will cancel some, but not all, of the forward force. This will leave an unbalanced forward force acting on the plane.

When we use the equation $a = F/m$ to find acceleration, F always stands for the unbalanced force. This equation is actually one possible way of stating *Newton's second law of motion*: When an unbalanced force acts on an object, the object's acceleration equals the force divided by the object's mass.



Are the forces acting on this plane balanced or unbalanced?



Are the forces acting on this plane balanced or unbalanced?

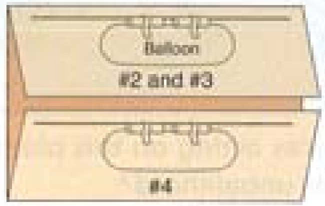
READING Draw Conclusions

What happens to an object's motion when the forces acting on it are unbalanced?

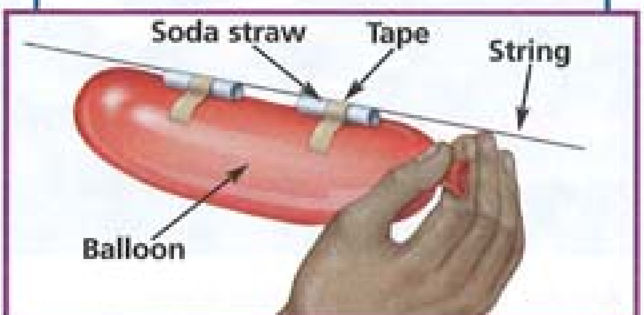
QUICK LAB

Racing Balloon Rockets

FOLDABLES Make a Shutter Fold. (See p. R 42.) Label the shutters as shown.



1. Pass thread or string through two short lengths of soda straw as shown. Then stretch the string tightly between two chairs.

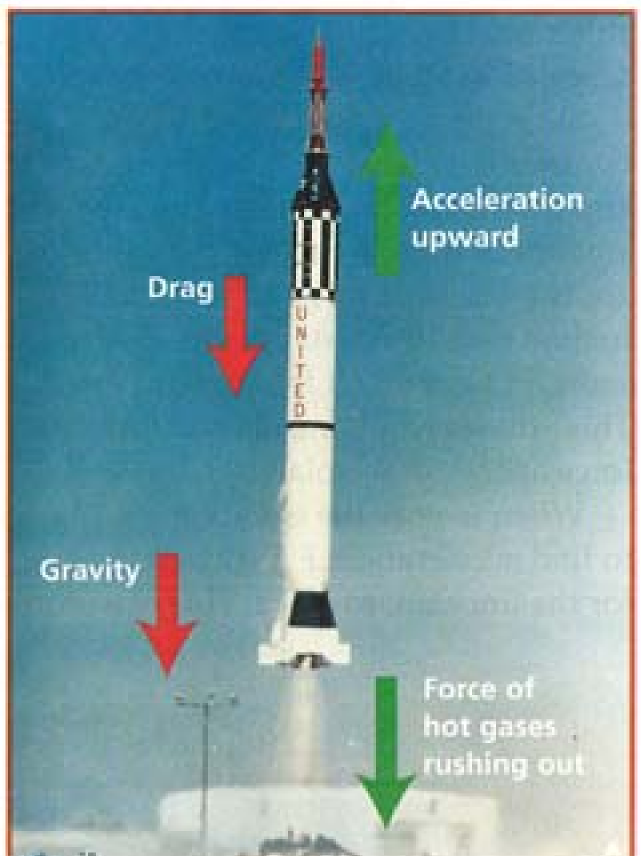


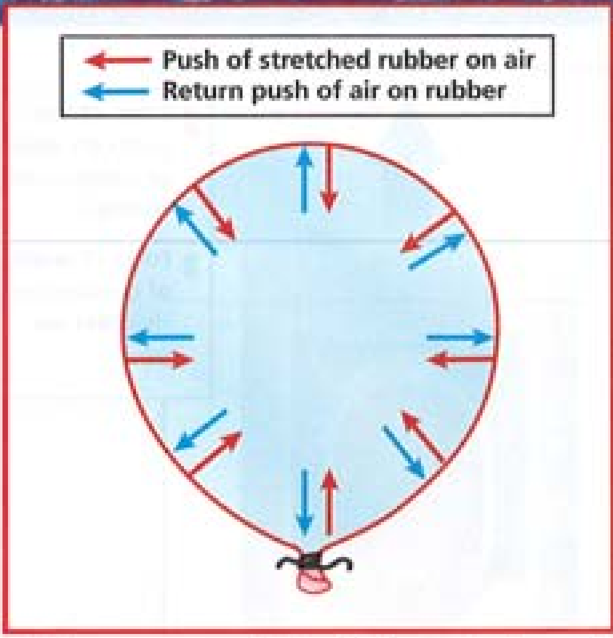
2. Inflate the balloon rocket. Hold the neck closed while your partner tapes it to the straws. Let go and record your observations in the Shutter Fold.
3. **Observe** Compare the direction the balloon moves with the direction of the escaping air.
4. **Infer** Is there an unbalanced force on the balloon? In which direction does it push?

Where Does the Force Come From?

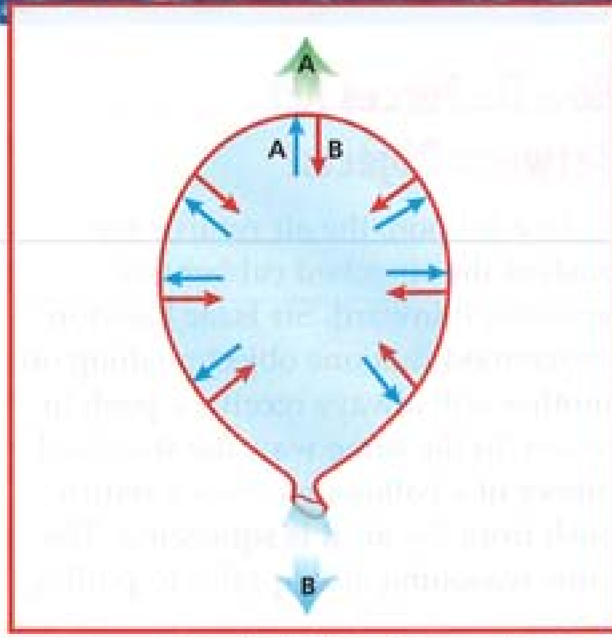
The rocket in the picture is accelerating upward due to the force provided by its engine. Fuel has been burned into hot gases in the engine's combustion chamber. The hot gases rush out of the engine nozzle in a downward direction. How is it that gases rushing down can cause the rocket to accelerate up?

If the rocket is accelerating, it must have an unbalanced force acting on it. Clearly, this force comes from the hot gases in its engines. Knowing the unbalanced force and the rocket's mass, we could calculate the acceleration of the rocket with Newton's second law of motion, $a = F/m$. However, as you will see, it takes another law of motion to explain how gases rushing one way can accelerate the rocket in the opposite direction.





All the way around the balloon, the inward push of the stretched rubber is balanced by the return outward push of the air. The balloon neither expands nor contracts, and it is not moved in any direction.



Force A pushes the balloon forward. When the balloon is opened, there are no longer any forces at the opening to offset forces A and B. Force B makes air rush out of the balloon, as shown by arrow B.

Making a Rocket Go

When you blow up a balloon and then release it without tying it closed, it flies through the air. You can take advantage of this behavior to make a balloon rocket. You know that air rushes out one end of the balloon, while the balloon itself moves in the opposite direction. Where do the forces come from that move the balloon and the air?

The air inside the balloon is "squeezed" by the stretched rubber. At the same time, the air resists being squeezed and pushes back on the rubber. When the balloon is inflated and tied off, these pushes are in balance and the balloon neither changes in size nor moves.

What happens if we leave the neck of the blown-up balloon open, instead? At the point of the opening, there is no stretched rubber squeezing the air. However, there *is* stretched rubber squeezing the air at a point opposite the opening. As a result, there is a net force on the air that pushes it out through the opening.

At the same time, the air pushes forward on the balloon opposite the opening. There is no such push at the opening itself, because there is no rubber surface on which the air can push. Since the push of the air forward on the balloon is not offset by any rearward push, an unbalanced force results that pushes the balloon forward.

What force makes a balloon rocket go forward?

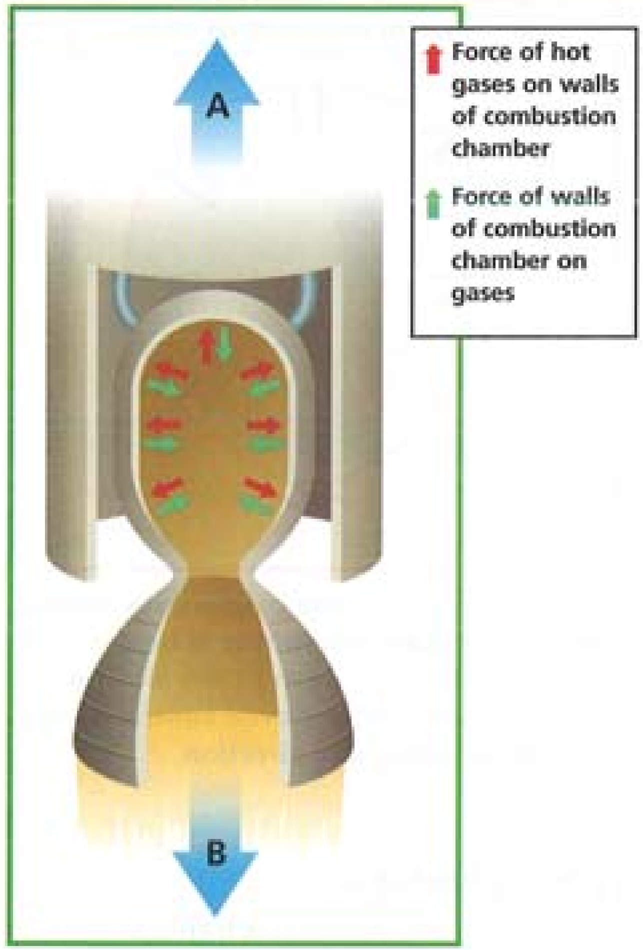
How Do Forces Act Between Objects?

In a balloon, the air returns the push of the stretched rubber that squeezes it inward. Sir Isaac Newton understood that one object pushing on another will always receive a push in return. In the same way, the stretched rubber of a balloon receives a return push from the air it is squeezing. The same reasoning also applies to pulling forces.

When one object applies a force to a second, we call this force the **action**. The force the second object returns to the first is called the **reaction**. Think about what happens when a 50-kg student on ice skates pushes forward on another 50-kg student on ice skates. Both of them wind up moving at the same speed, but in opposite directions. Newton realized that while the action and reaction act in opposite directions, they have the same strength. These ideas are summarized in *Newton's third law of motion*: For every action, there is an equal but opposite reaction.

An accelerating race car demonstrates Newton's third law. The car's tires push to the rear on the road surface. At the same time, the road pushes back on the tires in a forward direction. This reaction force is what propels the car ahead.

Gas rushing out of a rocket engine propels the rocket in the opposite direction. The hot gas tends to expand, so it applies an action force to the walls of the combustion chamber. The walls



Action A is an unbalanced force that propels the rocket ahead. Reaction B is an unbalanced force that pushes the hot gases out through the nozzle.

apply a reaction force to the gas similar to the balloon rocket. The gas pushes the rocket ahead, while the walls of the chamber push the gas to the rear, out through the nozzle.

When one object applies a force to another, both objects feel force. The second object feels the action force, while the first object feels the reaction force. If these forces are not balanced by other forces, *both* objects will accelerate.

What happens when one object exerts a force on another?

How Do Forces Affect Us?

Everywhere around us, forces act. Newton's laws of motion give us a useful picture of the way forces work. They also tell us how to predict what will happen when forces are applied to objects. Look at the examples of forces on this page. Think about how Newton's laws explain what is occurring in each case.

The water coming from this hose is under very high pressure. The water applies a large force back on the hose. The firemen have to use great strength to keep the hose from getting loose and flying around dangerously.

The bat applied a force to the ball and sent it flying to the outfield. At the same time, the ball applied a force to the bat, in this case enough to break it!

The hot gases in the jet engines push it forward, while the engines force the hot gases rearward.

How are forces affecting the racing boat?

The crew on this racing craft push on the water with their oars. The water, in turn, pushes back on the oars and moves the boat forward.

What Is a Simple Machine?

People use forces like pushes and pulls to do work. To a scientist, **work** means using force to move an object through a distance. Holding this book in your hand requires force, but no work is done because there is no movement. Opening this book and turning its pages is easy work. When you have to move a heavy object, work is not easy.

Simple machines are devices with few moving parts that make work easier to do. They lower the force needed to move and lift heavy objects and loads. There are six types of simple machines—levers, wheels and axles, pulleys, inclined planes, wedges, and screws.

Levers

Levers help you lift heavy loads or change the direction of a force. A **lever** consists of a rigid bar that rests on a pivot point or **fulcrum**. The lever turns up or down around the fulcrum.

The part of the lever you apply an input effort force to is the **effort arm**. The **resistance arm** of the lever produces an output force to lift the load. If the effort arm is longer than the resistance arm, the lever changes a small input force into a larger output force. In all machines, applying a small input force over a longer distance produces enough work to move a much heavier load a shorter distance. Both arms do the same amount of work. Energy is not being created.

ramp (inclined plane)

pliers (lever)

screw

pulley

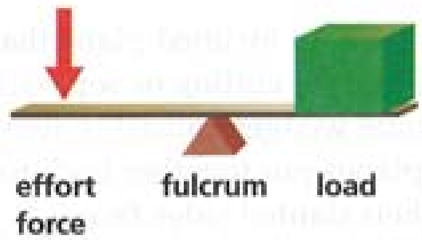
old-fashioned bicycle (wheel and axle)

ax (wedge)

There are three types of levers: first-class, second-class, and third-class. They differ in the positions of the effort arm, resistance arm, and fulcrum.

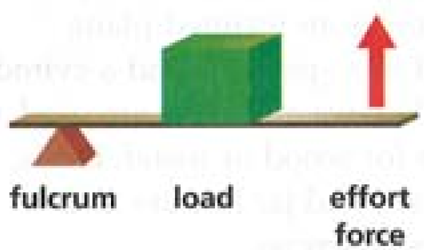
First-Class Levers

These change the direction of the force and include seesaws and rowboat oars.



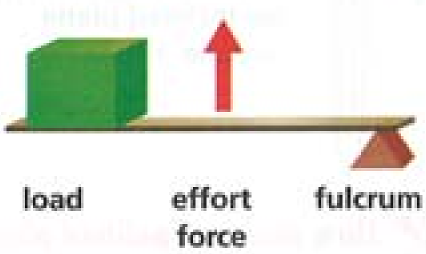
Second-Class Levers

These increase the force used and include wheel barrows and nutcrackers.



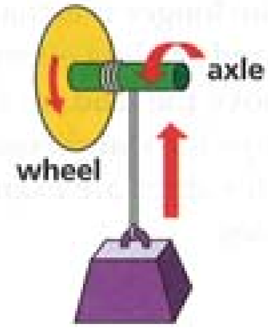
Third-Class Levers

These increase the speed and distance over which a force acts and include fishing rods and baseball bats.



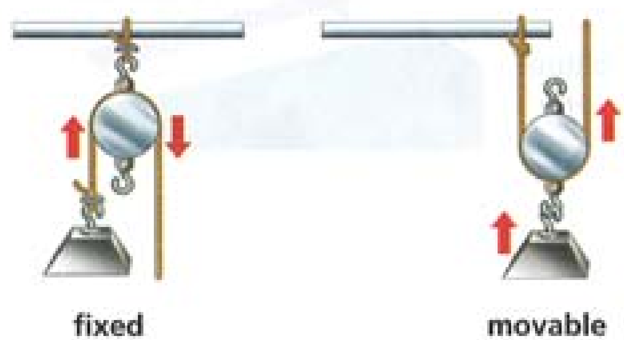
Wheels and Axles

A large-diameter wheel rotates in a circle around a small-diameter axle. A small amount of input force on the wheel becomes a large force on the axle. Doorknobs and screwdrivers use wheels and axles in this way.



Pulleys

A pulley is a wheel with a groove in the rim. A rope fits into the groove. A fixed pulley changes the direction of the effort force. However, the input force must equal the load. A movable pulley decreases the effort force needed to move the load. The rope moves a long distance to move the load a short distance. Pulley systems can combine fixed and movable pulleys.

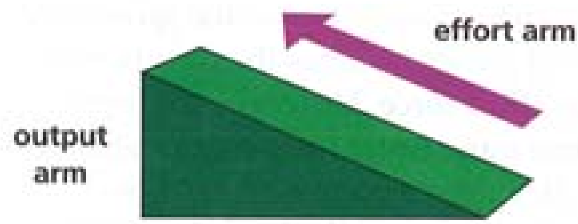


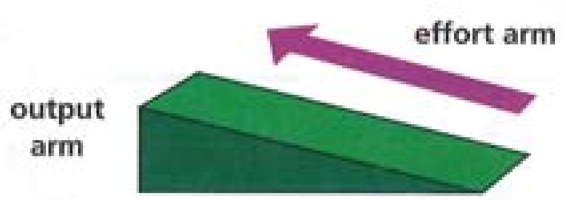
How does a small input force become a big output force?

What Is an Inclined Plane?

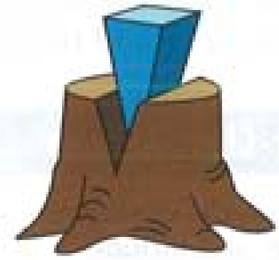
An inclined plane is a flat, slanted surface that makes it easier to move heavy objects to higher levels. The slanted surface is the effort arm. The vertical end of the plane is the output arm. The less steep the slope of the effort arm, the longer it is than the output arm and the less effort is needed to move the load up the ramp. Loading ramps for warehouses and gangplanks for ships are examples of inclined planes.

Inclined plane





Wedge



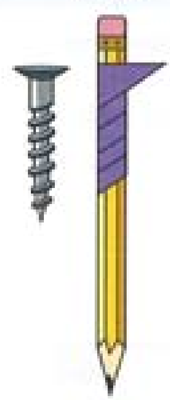
Wedges

A wedge is an inclined plane that is used as a tool for cutting or separating things. Some wedges consist of two inclined planes put together back to back so their slanted sides face outward. The thinner the wedge, the greater is the output force. Needles, ax blades, knife blades, and log splitters are examples of wedges.

Screws

A screw is an inclined plane wrapped in a spiral around a cylinder or cone. Screws and bolts are used as fasteners for wood or metal. Drills, corkscrews, and jar lids are also examples of screws.

Screw



To make a screw, wrap an inclined plane around a cylinder.

How does an inclined plane make loading a truck easier?

Lesson Review

Why It Matters

In the weightlessness of outer space, it is important to be aware of even small accelerations. While weight seems to disappear in orbit, small accelerations remain, such as gradual slowing due to tiny amounts of air resistance. Measuring these accelerations is important in studying things such as crystal growth and fluid flow in space.

e-Journal Visit our Web site **www.science.mmhschool.com** to do a research project on force and motion.

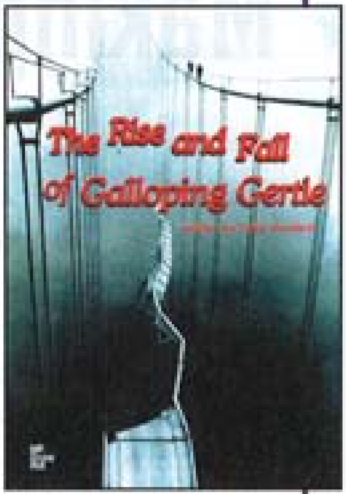
Think and Write

1. How do you find an object's acceleration from its mass and the force acting on it?
2. How can a boat move at constant velocity if its propeller provides a steady force to it?
3. A 1-kg magnet and a 0.5-kg piece of steel are 25 cm apart. Then they are attracted together. How do they move?
4. How does a lever increase the output force?
5. **Critical Thinking** If you hold a helium-filled balloon in a car with the windows up, the balloon moves forward when the car speeds up and backward when it slows down. Why do you think this happens?

L·I·N·K·S

LITERATURE LINK

Read *The Rise and Fall of Galloping Gertie,* to learn about a bridge that was destroyed by wind. When you finish reading, think about how you would design a safer bridge. Try the activities at the end of the book.



WRITING LINK

Personal Narrative What kinds of simple machines do you use every day? Write a letter to a friend telling about the machines you use that make your life easier. Use the correct form for writing a friendly letter.

MATH LINK

Solve this problem. Examine the equation $a = F/m$. Without using numbers, explain what happens to the acceleration if the force increases. Prove it using the equation. What happens to acceleration if mass increases?

TECHNOLOGY LINK

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