Work & Simple Machines

Name: ______________________________
Date: _______________ Per: ___________

How Much Work?

Would you do more work on a car by pushing it up a long road to reach the top of a hill or by using a cable to raise the car up the side of a cliff to the top of the same hill? You would certainly need a different amount of force. Common use of the word *work* may make it seem that there would be a difference in the amount of work done in the two cases as well.

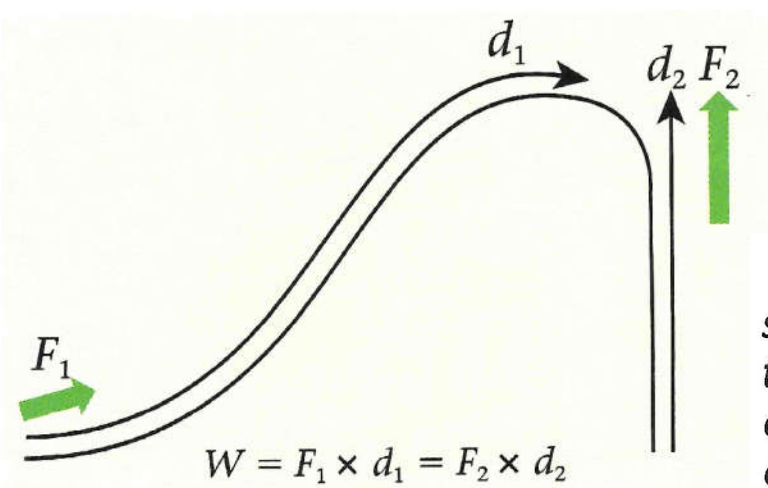
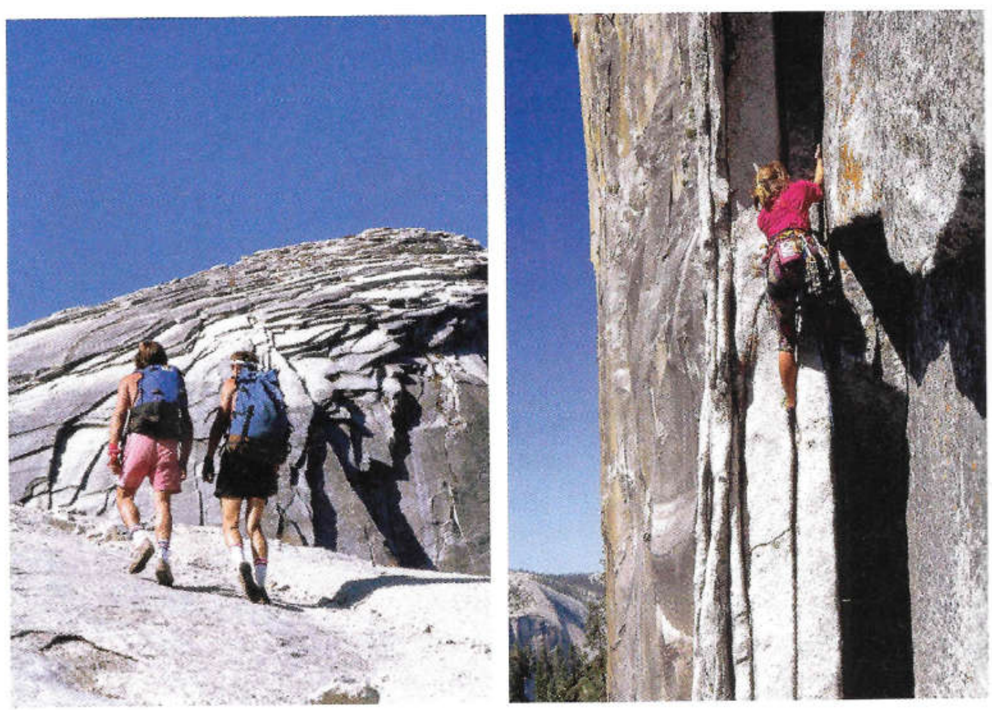


Figure 1 *For each path, the same work is done to move the car to the top of the hill, although distance and force along the two paths differ.*

Figure 2 *Climbers going to the top ot a mountain do the same amount of work whether they hike up a slope or go straight up a cliff.*



What Is a Machine?

You are in the car with your mom on the way to a party when suddenly—KABLOOM hisssss—a tire blows out. "Now I'm going to be late!" you think as your mom pulls over to the side of the road.

You watch as she opens the trunk and gets out a jack and a tire iron. Using the tire iron, she pries the hubcap off and begins to unscrew the lug nuts from the wheel. She then puts the jack under the car and turns the jack's handle several times until the flat tire no longer touches the ground. After exchanging the flat tire with the spare, she lowers the jack and puts the lug nuts and hubcap back on the wheel.

"Wow!" you think, "That wasn't as hard as I thought it would be." As your mom drops you off at the party, you think how lucky it was that she had the right equipment to change the tire.

Machines: Making Work Easier

Now, imagine changing a tire without the jack and the tire iron. Would it have been easy? No, you would have needed several people just to hold up the car! Sometimes, you need the help of machines to do work. A **machine** is a device that makes work easier by changing the size or direction of a force.

When you think of machines, you might think of things such as cars, big construction equipment, or even computers. But not all machines are complicated. In fact, you use many simple machines in your everyday life. **Figure 1** shows some examples of machines.

Figure 1 Some Everyday Machines

Work In, Work Out

Suppose that you need to get the lid off a can of paint. What do you do? One way to pry the lid off is to use a common machine known as a *lever*. **Figure 2** shows a screwdriver being used as a lever. You place the tip of the screwdriver under the edge of the lid and then push down on the screwdriver's handle. The tip of the screwdriver lifts the lid as you push down. In other words, you do work on the screwdriver, and the screwdriver does work on the lid.

Work is done when a force is applied through a distance. Look again at **Figure 2.** The work that you do on a machine is called **work input.** You apply a force, called the *input force,* to the machine through a distance. The work done by the machine on an object is called **work output.** The machine applies a force, called the *output force,* through a distance.

machine a device that helps do work by either overcoming a force or changing the direction of the applied force

work input the work done on a machine; the product of the input force and the distance through which the force is exerted

work output the work done by a machine; the product of the output force and the distance through which the force is exerted

How Machines Help

You might think that machines help you because they increase the amount of work done. But that's not true. If you multiplied the forces by the distances through which the forces are applied in **Figure 2** (remember that $W = F \times d$), you would find that the screwdriver does not do more work on the lid than you do on the screwdriver. Work output can never be greater than work input. Machines allow force to be applied over a greater distance, which means that less force will be needed for the same amount of work.

Reading Check **How do machines make work easier?** (*See the Appendix for answers to Reading Checks.*)

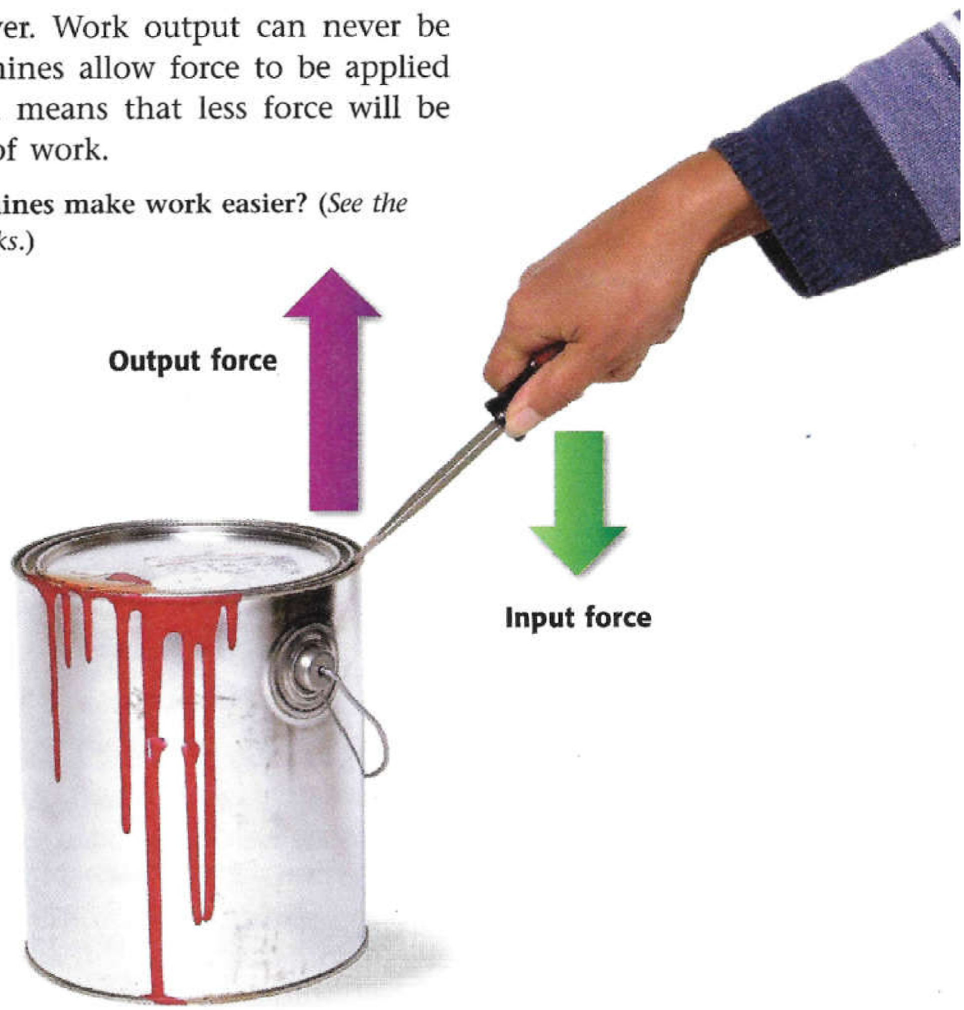


Figure 2 *When you use a machine, you do work on the machine, and the machine does work on something else.*

Same Work, Different Force

Machines make work easier by changing the size or direction (or both) of the input force. When a screwdriver is used as a lever to open a paint can, both the size and direction of the input force change. Remember that using a machine does not change the amount of work you will do. As **Figure 3** shows, the same amount of work is done with or without the ramp. The ramp decreases the size of the input force needed to lift the box but increases the distance over which the force is exerted. So, the machine allows a smaller force to be applied over a longer distance.

Figure 3 Input Force and Distance

Lifting this box straight up requires an input force equal to the weight of the box.

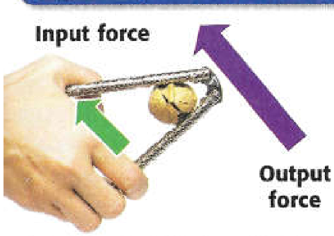
Using a ramp to lift the box requires an input force less than the weight of the box, but the input force must be exerted over a greater distance than if you didn't use a ramp.

The Force-Distance Trade-Off

When a machine changes the size of the force, the distance through which the force is exerted must also change. Force or distance can increase, but both cannot increase. When one increases, the other must decrease.

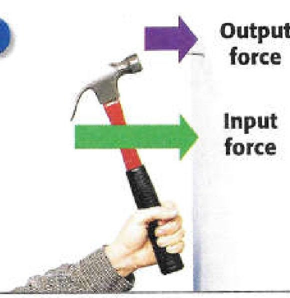
Figure 4 shows how machines change force and distance. Whenever a machine changes the size of a force, the machine also changes the distance through which the force is applied. **Figure 4** also shows that some machines change only the direction of the force, not the size of the force or the distance through which the force is exerted.

Figure 4 Machines Change the Size and/or Direction of a Force

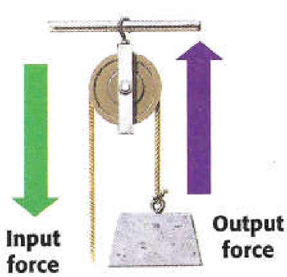


A nutcracker *increases* the force but applies it over a *shorter* distance.

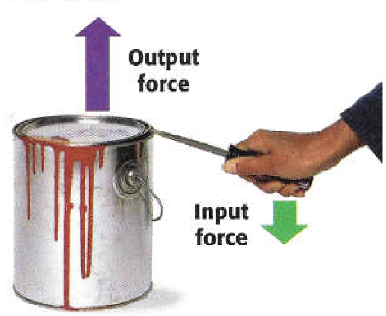
A hammer *decreases* the force, but applies it over a *greater* distance.



A simple pulley changes the *direction* of the input force, but the size of the output force is the same as the input force.



When a screwdriver is used as a lever, it *increases* the force and *decreases* the distance over which the force is applied.



Mechanical Advantage

Some machines make work easier than others do because they can increase force more than other machines can. A machine's **mechanical advantage** is the number of times the machine multiplies force. In other words, the mechanical advantage compares the input force with the output force.

Calculating Mechanical Advantage

You can find mechanical advantage by using the following equation:

$$\text{mechanical advantage (MA)} = \frac{\text{output force}}{\text{input force}}$$

For example, imagine that you had to push a 500 N weight up a ramp and only needed to push with 50 N of force the entire time. The mechanical advantage of the ramp would be calculated as follows:

$$MA = \frac{500\ \text{N}}{50\ \text{N}} = 10$$

A machine that has a mechanical advantage that is greater than 1 can help move or lift heavy objects because the output force is greater than the input force. A machine that has a mechanical advantage that is less than 1 will reduce the output force but can increase the distance an object moves. **Figure 4** shows an example of such a machine—a hammer.

Types of Machines

Imagine that it's a hot summer day. You have a whole ice-cold watermelon in front of you. It would taste cool and delicious—if only you had a machine that could cut it!

The machine you need is a knife. But how is a knife a machine? A knife is actually a very sharp wedge, which is one of the six simple machines. The six simple machines are the lever, the inclined plane, the wedge, the screw, the pulley, and the wheel and axle. All machines are made from one or more of these simple machines.

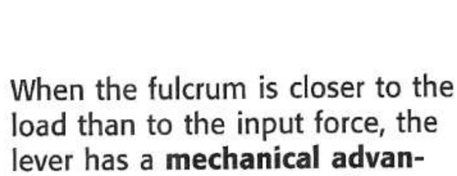
Levers

Have you ever used the claw end of a hammer to remove a nail from a piece of wood? If so, you were using the hammer as a lever. A **lever** is a simple machine that has a bar that pivots at a fixed point, called a *fulcrum*. Levers are used to apply a force to a load. There are three classes of levers, which are based on the locations of the fulcrum, the load, and the input force.

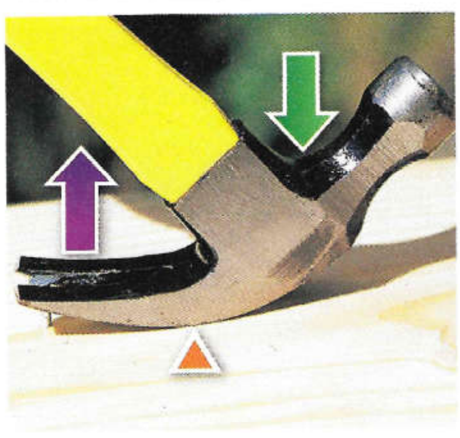
First-Class Levers

With a first-class lever, the fulcrum is between the input force and the load, as shown in **Figure 1.** First-class levers always change the direction of the input force. And depending on the location of the fulcrum, first-class levers can be used to increase force or to increase distance.

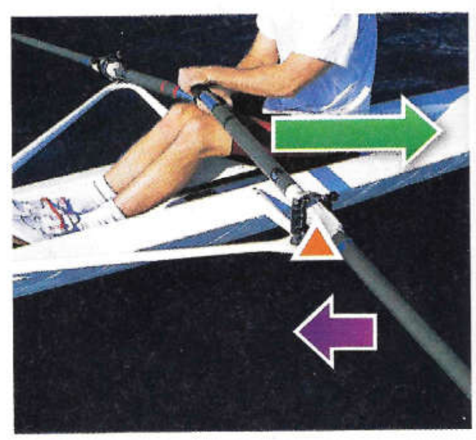
Figure 1 **Examples of First-Class Levers**



When the fulcrum is closer to the load than to the input force, the lever has a **mechanical advantage of greater than 1.** The output force is increased because it is exerted over a shorter distance.



When the fulcrum is exactly in the middle, the lever has a **mechanical advantage of 1.** The output force is not increased because the input force's distance is not increased.



When the fulcrum is closer to the input force than to the load, the lever has a **mechanical advantage of less than 1.** Although the output force is less than the input force, distance increases.

Figure 2 Examples of Second-Class Levers

In a **second-class lever,** the output force, or load, is between the input force and the fulcrum.

Using a second-class lever results in a **mechanical advantage of greater than 1.** The closer the load is to the fulcrum, the more the force is increased and the greater the mechanical advantage is.

Second-Class Levers

The load of a second-class lever is between the fulcrum and the input force, as shown in **Figure 2.** Second-class levers do not change the direction of the input force. But they allow you to apply less force than the force exerted by the load. Because the output force is greater than the input force, you must exert the input force over a greater distance.

lever a simple machine that consists of a bar that pivots at a fixed point called a *fulcrum*

F =

L =

E =

Third-Class Levers

The input force in a third-class lever is between the fulcrum and the load, as shown in **Figure 3.** Third-class levers do not change the direction of the input force. In addition, they do not increase the input force. Therefore, the output force is always less than the input force.

Reading Check **How do the three types of levers differ from one another?** (*See the Appendix for answers to Reading Checks.*)

Figure 3 Examples of Third-Class Levers

In a **third-class lever,** the input force is between the fulcrum and the load.

Using a third-class lever results in a **mechanical advantage of less than 1** because force is decreased. But third-class levers increase the distance through which the output force is exerted.

Pulleys

pulley a simple machine that consists of a wheel over which a rope, chain, or wire passes

When you open window blinds by pulling on a cord, you're using a pulley. A **pulley** is a simple machine that has a grooved wheel that holds a rope or a cable. A load is attached to one end of the rope, and an input force is applied to the other end. Types of pulleys are shown in **Figure 4.**

Fixed Pulleys

A fixed pulley is attached to something that does not move. By using a fixed pulley, you can pull down on the rope to lift the load up. The pulley changes the direction of the force. Elevators make use of fixed pulleys.

Movable Pulleys

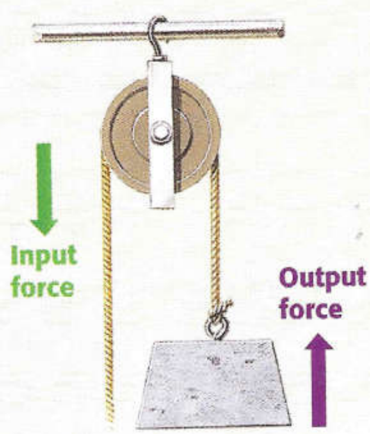
Unlike fixed pulleys, movable pulleys are attached to the object being moved. A movable pulley does not change a force's direction. Movable pulleys do increase force, but they also increase the distance over which the input force must be exerted.

Block and Tackles

When a fixed pulley and a movable pulley are used together, the pulley system is called a *block and tackle*. The mechanical advantage of a block and tackle depends on the number of rope segments.

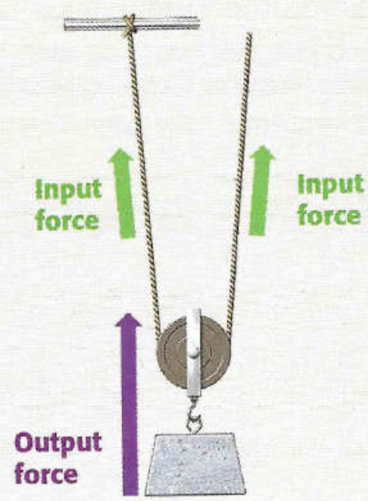
Figure 4 **Types of Pulleys**

Fixed Pulley



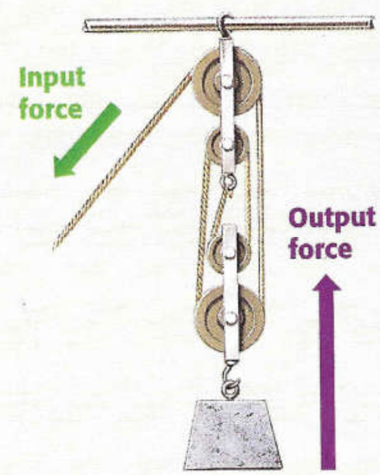
A **fixed pulley** only spins. So the distance through which the input force and the output force are exerted—and thus the forces themselves—are the same. Therefore, a fixed pulley provides a mechanical advantage of 1.

Movable Pulley



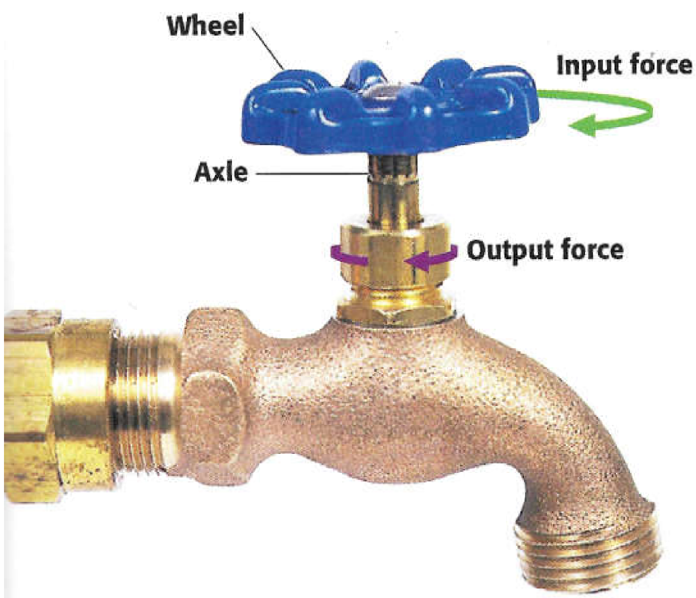
A **movable pulley** moves up with the load as the load is lifted. The mechanical advantage of this movable pulley is 2.

Block and Tackle



The mechanical advantage of this **block and tackle** is 4 because there are four rope segments. It multiplies your input force by 4, but you have to pull the rope 4 m just to lift the load 1 m.

Figure 5 How a Wheel and Axle Works



a When a small input force is applied to the wheel, the wheel rotates through a circular distance.

b As the wheel turns, so does the axle. But because the axle is smaller than the wheel, it rotates through a smaller distance, which makes the output force larger than the input force

Wheel and Axle

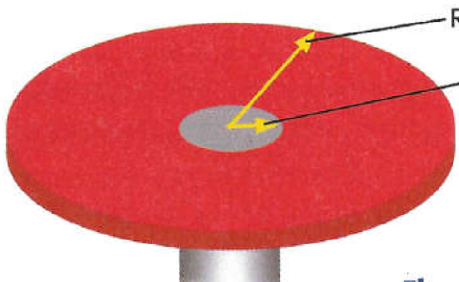
Did you know that a faucet is a machine? The faucet shown in **Figure 5** is an example of a **wheel and axle,** a simple machine consisting of two circular objects of different sizes. Doorknobs, wrenches, and steering wheels all use a wheel and axle. **Figure 5** shows how a wheel and axle works.

wheel and axle a simple machine consisting of two circular objects of different sizes; the wheel is the larger of the two circular objects

Mechanical Advantage of a Wheel and Axle

The mechanical advantage of a wheel and axle can be found by dividing the *radius* (the distance from the center to the edge) of the wheel by the radius of the axle, as shown in **Figure 6.** Turning the wheel results in a mechanical advantage of greater than 1 because the radius of the wheel is larger than the radius of the axle.

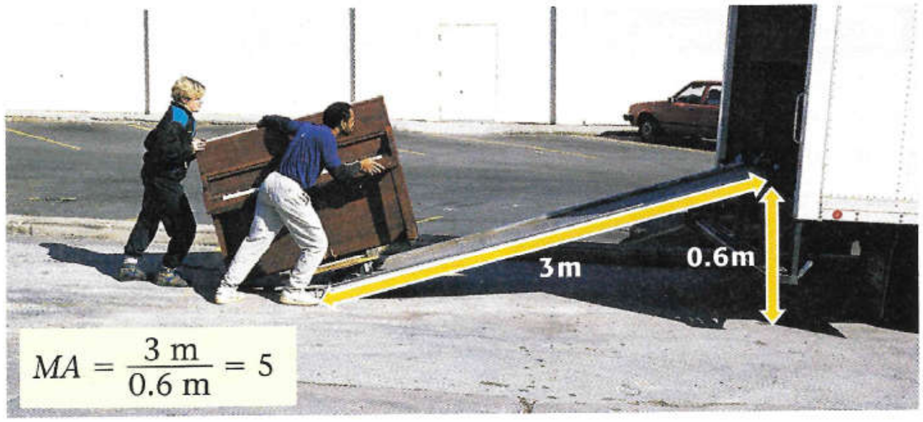
Reading Check **How is the mechanical advantage of a wheel and axle calculated?**



$$MA = \frac{15\text{ cm}}{3\text{ cm}} = 5$$

Figure 6 *The mechanical advantage of a wheel and axle is the radius of the wheel divided by the radius of the axle.*

Figure 7 *The work you do on the piano to roll it up the ramp is the same as the work you would do to lift it straight up. An inclined plane simply allows you to apply a smaller force over a greater distance.*



$$MA = \frac{3\text{ m}}{0.6\text{ m}} = 5$$

inclined plane a simple machine that is a straight, slanted surface, which facilitates the raising of loads; a ramp

Inclined Planes

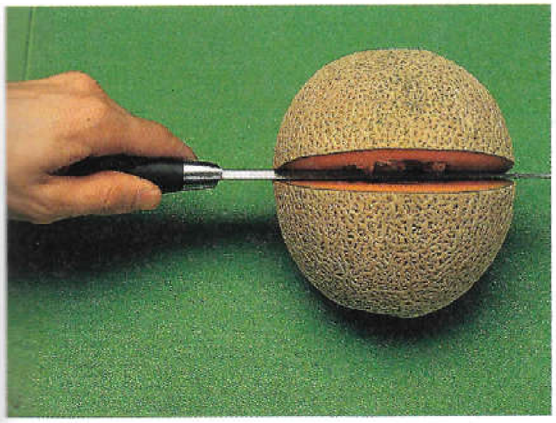
Do you remember the story about how the Egyptians built the Great Pyramid? One of the machines they used was the **inclined plane.** An *inclined plane* is a simple machine that is a straight, slanted surface. A ramp is an inclined plane.

Using an inclined plane to load a piano into a truck, as **Figure 7** shows, is easier than lifting the piano into the truck. Rolling the piano along an inclined plane requires a smaller input force than is needed to lift the piano into the truck. The same work is done on the piano, just over a longer distance.

Reading Check What is an inclined plane?

Mechanical Advantage of Inclined Planes

The greater the ratio of an inclined plane's length to its height is, the greater the mechanical advantage is. The mechanical advantage (*MA*) of an inclined plane can be calculated by dividing the *length* of the inclined plane by the *height* to which the load is lifted. The inclined plane in **Figure 7** has a mechanical advantage of 3 m/0.6 m = 5.



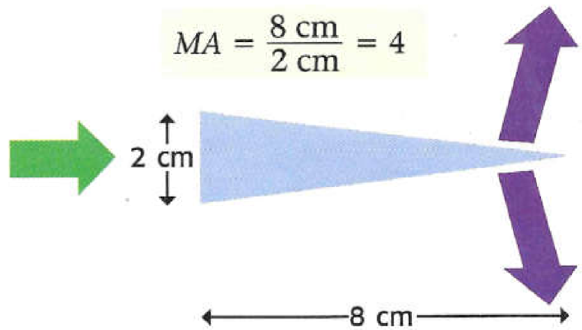


Figure 8 *A knife is a common example of a wedge, a simple machine consisting of two inclined planes back to back.*

Wedges

Imagine trying to cut a melon in half with a spoon. It wouldn't be easy, would it? A knife is much more useful for cutting because it is a **wedge.** A *wedge* is a pair of inclined planes that move. A wedge applies an output force that is greater than your input force, but you apply the input force over a greater distance. For example, a knife is a common wedge that can easily cut into a melon and push apart its two halves, as shown in **Figure 8.** Other useful wedges include doorstops, plows, ax heads, and chisels.

wedge a simple machine that is made up of two inclined planes and that moves; often used for cutting

screw a simple machine that consists of an inclined plane wrapped around a cylinder

Mechanical Advantage of Wedges

The longer and thinner the wedge is, the greater its mechanical advantage is. That's why axes and knives cut better when you sharpen them—you are making the wedge thinner. Therefore, less input force is required. The mechanical advantage of a wedge can be found by dividing the length of the wedge by its greatest thickness, as shown in **Figure 8.**

Screws

A **screw** is an inclined plane that is wrapped in a spiral around a cylinder, as you can see in **Figure 9.** When a screw is turned, a small force is applied over the long distance along the inclined plane of the screw. Meanwhile, the screw applies a large force through the short distance it is pushed. Screws are used most commonly as fasteners.

Mechanical Advantage of Screws

If you could unwind the inclined plane of a screw, you would see that the plane is very long and has a gentle slope. Recall that the longer an inclined plane is compared with its height, the greater its mechanical advantage. Similarly, the longer the spiral on a screw is and the closer together the threads are, the greater the screw's mechanical advantage is. A jar lid is a screw that has a large mechanical advantage.

Figure 9 *If you could unwind a screw, you would see that it is actually a very long inclined plane.*