Chapter 13
Work

Alabama 8th Grade Science Standards covered in this chapter include:

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<th>Standard</th>
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<td>9</td>
<td>Describe how mechanical advantages of simple machines reduce the amount of force needed for work.</td>
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<td>-</td>
<td>Describing the effect of force on pressure in fluids</td>
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<td>Example:</td>
<td>Increasing force on fluid leading to increase of pressure within a hydraulic cylinder</td>
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**WORKING HARD OR HARDLY WORKING**

Work is a word used many ways in conversation. In science, however, it has a very specific meaning. Suppose you are investigating an exciting concept in your science class, and your teacher gives you a challenging homework assignment. Later that night, you get down to work. After you complete the assignment, you announce to your parents that you are finished with your work. One of them smiles and tells you that you have done no work at all. As disappointing as that sounds, they are absolutely right! From a scientific perspective, work only happens when an applied force causes an object to move in the direction of the force. If you think back to our discussion of vectors and scalars, you'll probably remember the term displacement. Work occurs when a force displaces (moves) an object in the direction of the force.

Let's take a look at another situation to clarify what is and isn't work. If your parents' car were to stall in front of your house, they might ask you to help push it into the driveway to get it off the street. You go behind the car and give it all you've got, but the car is too heavy and doesn't move. Guess what? You haven't done any work.

How can that be? If I pushed that hard, I must have done some work!

Unfortunately, no. Remember the definition: work only takes place when a force causes motion!
Here's another example to think about. You and your parents are late getting to the airport to catch a plane for your family vacation. You have a heavy suitcase and you are running through the airport to get to the gate on time. Although you will be very tired, when you get to the gate, you will not have done any work.

Why not? If I ran all that way, I moved the suitcase, right?

Well, yes, you moved the suitcase *horizontally*. However, the force you applied to the suitcase is a lifting force (a *vertical force*). This means the motion is happening in a different direction from the force, so no work has been done.

**The Mathematics of Work**

A weight lifter goes into a training room where there are two barbells. One is a 150 N barbell and the other is 200 N. (Remember, the SI unit for force is the newton, N.) So, it should take 150 N of vertical force to lift one of the barbells and 200 N to lift the other. The weight lifter lifts up one, places it down, and then lifts the other. Which lift caused the lifter to do more work? It might seem logical to say the heavier weight caused more work to be done, because more force would be needed to lift it. But from a scientific point of view, you do not have enough information to answer the question! In order to know how much work has been done, you have to know the displacement of the object. In other words, until you know how far each barbell was lifted, you really don't know how much work has been done. To figure this out mathematically, you multiply the force used (F) by the distance (d) the force caused the object to travel. It is important to remember that the distance traveled must be in the same direction as the force applied.

**Work = Force × distance**

Force is expressed in newtons, and distance in the metric system is expressed in meters, so it makes sense that one way to describe units of work would be in newton-meters. Another name for these units is the joule (J). If the weight lifter in our last example lifted both barbells, a distance of 2 m, these would be the calculations that expressed the amount of work being done:

<table>
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<tr>
<th>Table 13.1 Work Calculations</th>
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<tr>
<td>W = F × d</td>
</tr>
<tr>
<td>W = 150 N × 2 m</td>
</tr>
<tr>
<td>W = 300 J</td>
</tr>
<tr>
<td>W = F × d</td>
</tr>
<tr>
<td>W = 200 N × 2 m</td>
</tr>
<tr>
<td>W = 400 J</td>
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As expected, more work took place lifting the 200 N barbell, when both barbells were lifted the same distance. So, increasing the amount of force applied increases the amount of work done. Don’t forget about distance, though! As you can see from Equation 13.1, increasing the distance the object moves should also increase the work done. Perform the same calculation as in Table 13.1, but this time have the weight lifter lift the 150 N barbell 3 meters and the 200 N barbell 2 meters. The answer you get this time should show you that the smaller barbell required more work because it was moved a greater distance.

**MACHINES**

You are riding home in your parents’ car from an after-school event. Suddenly, you hear a loud BOOM and realize that your car has blown a tire. Dad says to go to the trunk and get out the jack. You think:

**Why is it easier to lift a car with a jack than with your bare hands?**

Well, OK…you probably didn’t think that, because you knew that the car was too heavy to lift. You need a machine to help. A **machine** is something that makes work easier by changing the size or direction of a force. A **simple machine** is any device that only requires the application of a **single** force to work. They are called “simple” because most of them don't have any moving parts! These are shown in Figure 13.2.

![Simple Machines](image)

**Figure 13.2 Simple Machines**

When you combine more than one simple machine, you have a **complex machine** (can openers, scissors, a doorknob, a car jack).

**So, do simple machines reduce the amount of work?**

Actually, no. A simple machine reduces the amount of effort (force) needed to move something, so the work seems easier. Let’s look at four of the simplest simple machines.
Inclined planes are also called ramps. Ramps help us move things to a higher elevation with less effort. There is a trade-off, though, and that is we have to move them farther. Think about it this way: if you wanted to put a heavy box on the roof of your school, you could use a ladder (and expend a lot of force or effort climbing each step) or you could use a ramp. To reach the roof of your school, though, you’d need a pretty long ramp! Using a ramp decreases the force that you must apply, but increases the distance that you have to move the object.

A wedge is a double inclined plane. However, wedges have a different purpose than the inclined plane. Instead of helping you move things to higher elevations, wedges help you push things apart. The blade of an axe or knife is a wedge. How do they make work seem easier? The narrower the wedge (or the sharper the blade end of a wedge), the easier it is to drive it into something and push things apart.

Screws are usually used to hold things together, like pieces of wood, metal or concrete. You may not have thought of this before, but a screw is really an inclined plane wrapped around a cylinder, with a wedge at the sharp, pointed end. The inclined plane going up the cylinder of a screw is called the threading. Turning the screw allows the threading to bite into the surrounding material and forces the wedge tip through the material. The wider the threads of a screw, the harder it is to turn. Narrower threads make the screw easier to turn, but there are more of them. This means you will have to turn the screw more times to force the wedge tip completely into the object you are trying to put together.

Our next simple machine is the lever. Two things must be considered when using a lever — the length of the arms and the place where it pivots. The point on which the lever pivots is called the fulcrum. A crowbar pivots on the very end, but a see-saw usually pivots in the middle. By changing where you put the fulcrum, you make it easier or harder to lift a heavy load. The closer to the load you put the fulcrum, the easier the load is to lift. Where’s the trade-off? Lengthening the lifting arm without moving the fulcrum (that is, getting a longer stick) also makes the load easier to lift. The longer the lifting arm becomes, the greater the distance you must move it to lift the object. In short, the ratio of the two arm lengths combined with the location of the fulcrum determine the mechanical advantage of a lever.
ADVANTAGE OF MACHINES

By now, you have realized that not all machines are the same. Some machines make it easier to do work than others — they offer a greater advantage. This advantage is called **mechanical advantage**. How do we measure mechanical advantage? If you think of a machine as having an input force (the force you put into it) and an output force (the force the machine applies to move an object), then the mechanical advantage of the machine (mathematically) is the output force divided by the input force.

\[
MA = \frac{\text{Output Force}}{\text{Input Force}}
\]

Equation 13.2

Let’s look at a practical example. If you put 10 N of force into your machine, and it applies 40 N to move your object, then the mechanical advantage would be 40/10, or 4. Basically, that means that the machine makes it 4 times easier for you to do the work. Pretty nifty! The bottom line is that all machines reduce the amount of force needed to do work. Furthermore, machines increase the mechanical advantage of the input force.

It’s also important to remember that no machine is 100% efficient, because all machines have some point(s) of friction. **Friction** is a result of the interaction of material of the machine with the objects that it operates on.

**Example:** The wheels of a wheelbarrow experience friction as they roll up a concrete ramp.

**Example:** The metal of a screw experiences friction as it is drilled through a block of wood.

Friction reduces output by resisting movement. The important thing is to know where these points of friction are and to devise ways to reduce them. Why? When you reduce the friction in the machine, work output increases, and work input decreases. So efficiency goes up!

PASCAL’S LAW

Other types of machines do work by applying force on fluids in containers. **Fluids** are liquids and gases. If a fluid is in a container, the collisions of the particles against the surface of the container cause the fluid to exert pressure everywhere in the fluid and upon the container. **Pressure** is a force (push or pull) applied evenly over an area. The equation for pressure is given below in Equation 13.3.

\[
\text{Pressure} = \frac{\text{Force}}{\text{Area}}
\]

Equation 13.3

The unit for pressure is a Pascal (Pa). One Pascal is equal to the force of 1 Newton over an area of 1 m². By placing a fluid in a container, a force can be applied to change its pressure. As the force applied to a fluid increases, its pressure also increases.
This is explained using Pascal's Law, which states:

*Pressure applied to a contained fluid is transmitted equally in all directions throughout the fluid and to the surface of the container.*

Pascal's Law is the basis of hydraulic machines that are used to create a mechanical advantage. A **hydraulic machine** is a machine that uses fluids to transmit force. The basic idea is this: when a fluid is in a partially closed container, the force applied to one area is transmitted to another area using an incompressible fluid (like water or oil). You are probably familiar with some hydraulic machines without even realizing it. Some examples include bulldozers, forklifts, cranes and even amusement park rides. These machines are big and can do a lot of work!

Let's look at a hydraulic cylinder to get an idea of how a basic hydraulic machine works. A hydraulic cylinder consists of two barrels. **Pistons** (components that transfer force) are placed inside the barrels. The entire system is connected by various pipes filled with a fluid. The first piston is used to apply force to the fluid. This creates pressure in the fluid. The fluid transfers this pressure to the second piston or output piston. The pressure exerts a force on the output piston, and the result is an increased mechanical advantage. Look at Figure 13.5 to see how a simplified hydraulic system works.

![Hydraulic Cylinder Diagram]

*Figure 13.5 Hydraulic Cylinder*

Hydraulic systems usually produce a large mechanical advantage, because fluids have the ability to transmit pressure equally and without diminishing. The pressure exerted on the large piston must equal the pressure produced in the small piston. So, a small force on a smaller piston can produce a larger force on a larger piston. Increasing the size of the output piston increases the mechanical advantage.
Chapter 13

Activity
Look at the list of everyday objects below. Categorize them by type of simple machine. Some of these objects may fit under more than one category.

Lever  Inclined Plane  Wedge  Screw  Wheel/Axel

Objects: scissors, crowbar, steering wheel, staircase, ramp, shovel, car ramp, chisel, nail, jar lid, drill, fork, door knob

Activity
Describe how a hydraulic system works using balloons! Here are three simple ways to show a hydraulic system using a few simple materials.

- Blow up a balloon just enough so that it is still flexible and not too tight. Secure the balloon by tying a knot to the end of it. Place the balloon on the floor and lightly step on it. Describe what happens to the balloon. How does this represent a basic hydraulic machine?

- Attach an empty balloon over the lip of an empty two liter plastic bottle. Secure rubber bands around the balloon-bottle joint. Squeeze the plastic and observe changes in the balloon. Describe your observations. How does this represent a basic hydraulic machine?

- Get a short length of PVC pipe (½” should work), two rubber bands and two balloons. Secure a deflated balloon to one end of the pipe. Be sure to use rubber bands for a tight fit. Put another rubber band around the pipe (this will be used to secure the second balloon). Blow up a second balloon and secure it to the other end of the pipe without letting out too much air. Secure the balloon with the rubber band. Gently squeeze the air filled balloon and observe changes in deflated balloon. Experiment using different size balloons on each end of the pipe. Write down your observations and explain your results using your knowledge of a hydraulic system.
CHAPTER 13 REVIEW

1. Which of the following scenarios results in work being done?
   A hammering a nail into a board
   B pushing on a concrete wall
   C pulling on a 1000 N boulder
   D playing air guitar

2. A 10 N box must be moved onto a closet shelf 2.5 meters above Darell’s head. How long should an inclined plane be to have a mechanical advantage of 2?
   A 25 m   B 1.25 m   C 5 m   D 10 m

3. Increasing the length of the lifting arm of a lever without moving the fulcrum will
   A make the load easier to lift.
   B make the load harder to lift.
   C increase the horizontal distance that you can move the lifting arm.
   D decrease the vertical distance that you can move the lifting arm.

4. Jackson throws a ball, which arcs up, then falls down. It then bounces on the floor and springs back up. How is the work that is done calculated?
   A using the distance the ball travels from where the ball leaves Jackson’s hand, to where it begins to fall toward the floor
   B using the distance the ball travelled in Jackson’s hand as he throws the ball
   C using the distance the ball travels from where the ball leaves Jackson’s hand, to where it hits the floor
   D using the distance between Jackson’s hand and where the ball finally comes to rest

5. In a hydraulic cylinder, 2 N of force are applied to a 1 square inch piston, producing 10 N of force on a second piston that is 10 square inches. What is the mechanical advantage?
   A 50   B 10   C 2   D 5