Work and Machines

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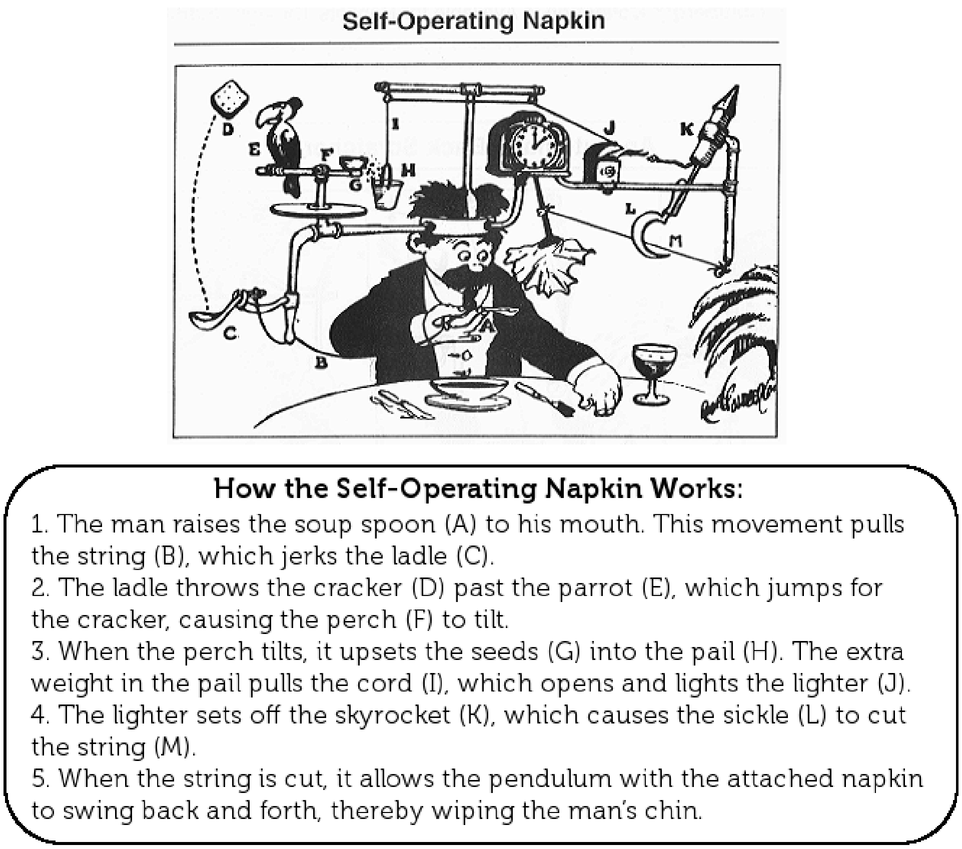
CHAPTER 1 Work and Machines

CHAPTER OUTLINE



A Rube Goldberg invention, like the "self-operating napkin" pictured here, is a needlessly complex machine that is used to complete a simple task. Rube Goldberg was an engineer and artist. He observed that people tend to find difficult ways to do simple things. He created silly cartoon machines, like the one above, to poke fun at this tendency. You can see some amazing Rube Goldberg-type machines in action by watching the videos at this URL: http://hhe.wikispaces.com/Rube+Goldberg+Machines .

In this chapter you'll learn about real machines, which —unlike Rube Goldberg inventions —actually make work easier. However, before learning about machines, you need to know what work means in physics. That's where this chapter begins.

Rube Goldberg. commons.wikimedia.org/wiki/File:Professor_Lucifer_Butts.gif. Public Domain.

1.1 Work

Lesson Objectives

- Define work, and state how to calculate it.
- Explain how power is related to work.

Lesson Vocabulary

- joule (J)
- power
- watt (W)
- work

Introduction

The teen playing tennis in **Figure** 1.1 is having fun. The other teen in the same figure is working hard studying for an exam. You can tell by their faces which teen is doing work —or can you? Would it surprise you to learn that the teen who is working is the one who is having fun playing tennis, while the teen who is studying isn't doing any work at all? The reason why has to do with how work is defined in physics.

FIGURE 1.1
Which teen is doing work and which teen isn't?

Defining and Calculating Work

Work is defined differently in physics than in everyday language. In physics, **work** means the use of force to move an object. The teen who is playing tennis in **Figure** 1.1 is using force to move her tennis racket, so she is doing work. The teen who is studying isn't moving anything, so she is not doing work.

Not all force that is used to move an object does work. For work to be done, the force must be applied in the same direction that the object moves. If a force is applied in a different direction than the object moves, no work is done. **Figure** 1.2 illustrates this point. The stick person applies an upward force on the box when raising it from the ground to chest height. Work is done because the force is applied in the same direction as the box is moving. However, as the stick person walks from left to right while holding the box at chest height, no more work is done by the person's arms holding the box up. That's because the force supporting the box acts in a different direction than the box is moving. A small amount of work in the horizontal direction is performed when the person is accelerating during the first step of the walk across the room. But other than that, there is no work, because there is no net force acting on the box horizontally.

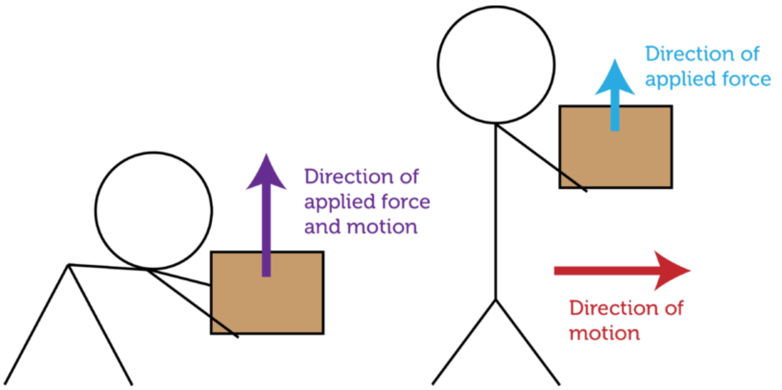


FIGURE 1.2

Carrying a box while walking does not result in work being done. Work is done only when the box is first lifted up from the ground. Can you explain why?

Work, Force, and Distance

Work is directly related to both the force applied to an object and the distance the object moves. It can be represented by the equation:

$$\text{Work} = \text{Force} \times \text{Distance}$$

This equation shows that the greater the force that is used to move an object or the farther the object is moved, the more work that is done. You can see a short video introduction to work as the product of force and distance at this link: http://www.schooltube.com/video/85de91bb7097c101fbda/Eureka-Episode-8-Work .

To see the effects of force and distance on work, compare the weight lifters in **Figure** 1.3. The two weight lifters on the left are lifting the same amount of weight, but the bottom weight lifter is lifting the weight a longer distance. Therefore, this weight lifter is doing more work. The two weight lifters on the bottom right are both lifting the weight the same distance, but the weight lifter on the left is lifting a heavier weight. Therefore, this weight lifter is doing more work.

Calculating Work

The equation for work given above can be used to calculate the amount of work that is done if force and distance are known. For example, assume that one of the weight lifters in **Figure** 1.2 lifts a weight of 400 newtons over his head to a height of 2.2 meters off the ground. The amount of work he does is:

$$\text{Work} = 400 \text{ N} \times 2.2 \text{ m} = 880 \text{ N} \cdot \text{m}$$

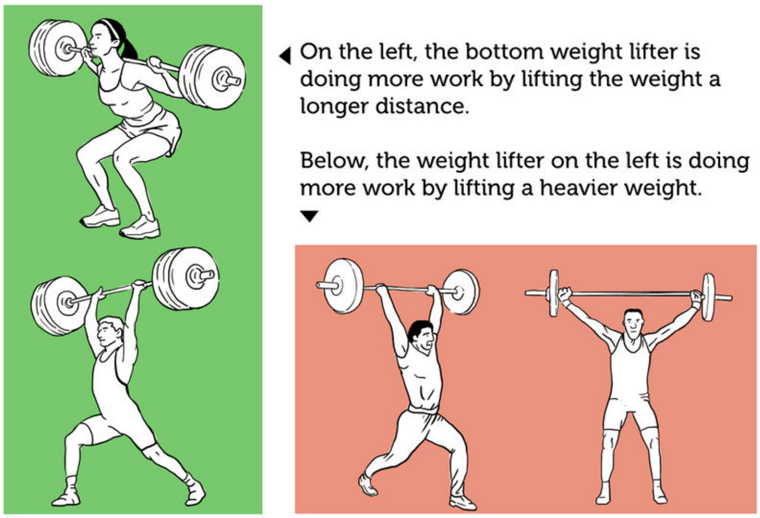


FIGURE 1.3
Weight lifters do more work when they move weights a longer distance or move heavier weights.

Notice that the unit for work is the newton · meter. This is the SI unit for work, also called the **joule (J)**. One joule equals the amount of work that is done when 1 newton of force moves an object over a distance of 1 meter.

Problem Solving

Problem: Todd pushed a 500 N box 4 meters across the floor. How much work did he do?

Solution: Use the equation Work = Force × Distance.

$$\text{Work} = 500\text{ N} \times 4\text{ m} = 2000\text{ N} \cdot \text{m, or } 2000\text{ J}$$

You Try It!

Problem: Lara lifted a 100 N box 1.5 meters above the floor. How much work did she do?

Work and Power

Did you ever rake leaves, like the woman in **Figure** 1.4? It can take a long time to do all that work. But if you use an electric leaf blower, like the man in the figure, the job gets done much sooner. Both the leaf blower and the rake do the work of removing leaves from the yard, but the leaf blower has more power. That's why it can do the same amount of work in less time.

What Is Power?

Power is a measure of the amount of work that can be done in a given amount of time. Power can be represented by the equation:

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

FIGURE 1.4
Which way of removing leaves would take less effort on your part?

In this equation, work is measured in joules and time is measured in seconds, so power is expressed in joules per second (J/s). This is the SI unit for work, also known as the **watt (W)**. A watt equals 1 joule of work per second. The watt is named for James Watt, a Scottish inventor you will read about below.

You may already be familiar with watts. That's because light bulbs and small appliances such as hair dryers are labeled with the watts of power they provide. For example, the hair dryer in **Figure** 1.5 is labeled "2000 watts." This amount of power could also be expressed kilowatts. A kilowatt equals 1000 watts, so the 2000-watt hair dryer produces 2 kilowatts of power.

FIGURE 1.5
Hair dryers vary in power. How do you think this affects drying time?

Compared with a less powerful device, a more powerful device can either do more work in the same time or do the same work in less time. For example, compared with a low-power microwave, a high-power microwave can cook more food in the same time or the same amount of food in less time.

Calculating Power or Work

Power can be calculated using the formula above, if the amount of work and time are known. For example, assume that a small engine does 3000 joules of work in 2 seconds. Then the power of the motor is:

$$\text{Power} = \frac{3000 \text{ J}}{2 \text{ s}} = 1500 \text{ J/s, or } 1500 \text{ W}$$

You can also calculate work if you know power and time by rewriting the power equation above as:

$$\text{Work} = \text{Power} \times \text{Time}$$

For example, if you use a 2000-watt hair dryer for 30 seconds, how much work is done? First express 2000 watts in J/s and then substitute this value for power in the work equation:

$$\text{Work} = 2000 \text{ J/s} \times 30 \text{ s} = 60,000 \text{ J}$$

For a video presentation on calculating power and work, go to this link: http://www.brightstorm.com/science/physics/energy-and-momentum/power/ .

Problem Solving

Problem: An electric mixer does 2500 joules of work in 5 seconds. What is its power?

Solution: Use the equation: Power $= \frac{\text{Work}}{\text{Time}}$.

$$\text{Power} = \frac{2500 \text{ J}}{5 \text{ s}} = 500 \text{ J/s, or } 500 \text{ W}$$

You Try It!

Problem: How much work can be done in 30 seconds by a 1000-watt microwave?

Horsepower

Sometimes power is measured in a unit called the horsepower. One horsepower is the amount of work a horse can do in 1 minute. It equals 745 watts of power. The horsepower was introduced by James Watt, who invented the first powerful steam engine in the 1770s. Watt's steam engine led to a revolution in industry and agriculture because of its power. Watt wanted to impress people with the power of his steam engine, so he compared it with something familiar to people of his time: the power of workhorses, like those pictured in **Figure** 1.6. Watt said his steam engine could produce the power of 20 horses, or 20 horsepower. The most powerful engines today may produce more than 100,000 horsepower! How many watts of power is that?

FIGURE 1.6

The horses and the tractor are both pulling a plow. The horses provide less horsepower than the tractor. Which do you think will get the job done faster?

Lesson Summary

- Work is the use of force to move an object. It can be calculated as the product of force and distance. The SI unit for work is the joule (J).

- Power is a measure of the amount of work that can be done in a given amount of time. The SI unit for power is the watt (W).

Lesson Review Questions

Recall

1. How is work defined in physics?
2. What does power measure?
3. Identify the SI units for work and power.

Apply Concepts

4. Jana lifted a 200-newton weight over her head to a distance of 2 meters above the ground. How much work did she do?
5. Pieter picked up a 20-newton book from the floor. Then he passed it to Ahmad, who carried it for 20 meters. How much work did Ahmad do?
6. If an electric mixer does 10,000 joules of work in 10 seconds, what is its power?

Think Critically

7. Explain how power is related to work.

Points to Consider

Machines such as the tractor and leaf blower you read about in this lesson help people do work.

- What are other examples of machines?
- What do all these machines have in common?

1.2 Machines

Lesson Objectives

- Explain how machines help us do work.
- Define efficiency, and state how it is calculated.
- Define mechanical advantage, and state how it is calculated.

Lesson Vocabulary

- efficiency
- machine
- mechanical advantage

Introduction

When you hear the word "machine," do you think of large appliances, power tools, factory machines, or construction equipment, like the examples pictured in **Figure** 1.7? While all of these examples are machines, you might be surprised to learn that devices as simple as hammers and screws are also machines. Why are these simple tools considered machines? Read on to find out.

FIGURE 1.7
Do you know what type of work each of these machines does?

How Machines Help Us Do Work

A **machine** is any device that makes work easier by changing a force. When you use a machine, you apply force to the machine. This force is called the input force. The machine, in turn, applies force to an object. This force is called the output force. Recall that work equals force multiplied by distance:

$$\text{Work} = \text{Force} \times \text{Distance}$$

The force you apply to a machine is applied over a given distance, called the input distance. The force applied by the machine to the object is also applied over a distance, called the output distance. The output distance may or may not be the same as the input distance.

Machines make work easier by increasing the amount of force that is applied, increasing the distance over which the force is applied, or changing the direction in which the force is applied. Contrary to popular belief, machines do not increase the amount of work that is done. They just change how the work is done. So if a machine increases the force applied, it must apply the force over a shorter distance. Similarly, if a machine increases the distance over which the force is applied, it must apply less force.

Increasing Force

Examples of machines that increase force are doorknobs and nutcrackers. **Figure** 1.8 explains how these machines work. In each case, the force applied by the user is less than the force applied by the machine, but the machine applies the force over a shorter distance.

FIGURE 1.8
Both of these machines increase the force applied by the user, while reducing the distance over which the force is applied.

Increasing Distance

Examples of machines that increase the distance over which force is applied are paddles and hammers. **Figure** 1.9 explains how these machines work. In each case, the machine increases the distance over which the force is applied, but it reduces the strength of the applied force.

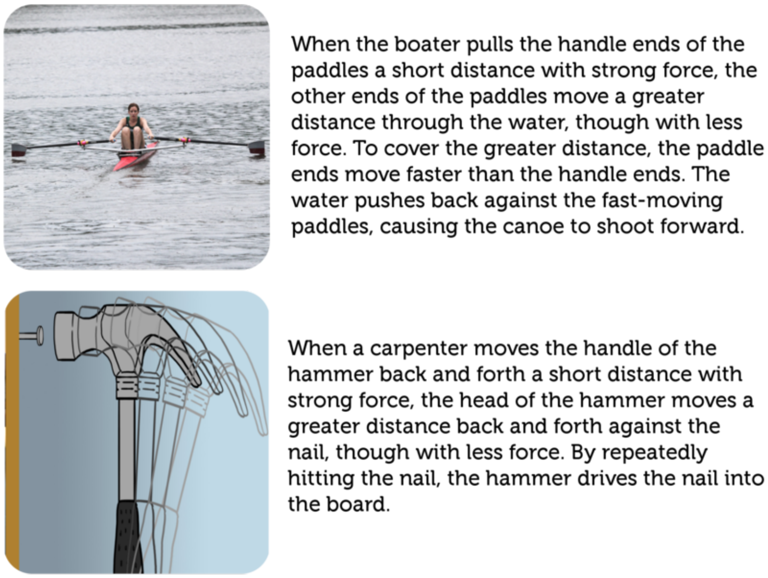


FIGURE 1.9
Both of these machines increase the distance over which force applied, while reducing the strength of the force.

Changing the Direction of Force

Some machines change the direction of the force applied by the user. They may or may not also change the strength of the force or the distance over which it is applied. Two examples of machines that work in this way are claw hammers and the rope systems (pulleys) that raise or lower flags on flagpoles. **Figure** 1.10 explains how these machines work. In each case, the direction of the force applied by the user is reversed by the machine. How does this make it easier to do the job?

FIGURE 1.10
Both of these machines change the direction over which force is applied. The claw hammer also increases the strength of the force.

Efficiency of Machines

You read above that machines do not increase the work done on an object. In other words, you can't get more work out of a machine than you put into it. In fact, machines always do less work on the object than the user does on the machine. That's because all machines must use some of the work put into them to overcome friction. How much work? It depends on the efficiency of the machine. **Efficiency** is the percent of input work that becomes output work. It is a measure of how well a machine reduces friction.

An Example: Efficiency of a Ramp

Consider the ramp in **Figure** 1.11. It's easier to push the heavy piece of furniture up the ramp to the truck than to lift it straight up off the ground. However, pushing the furniture over the surface of the ramp creates a lot of friction. Some of the force applied to moving the furniture must be used to overcome the friction. It would be more efficient to use a dolly on wheels to roll the furniture up the ramp. That's because rolling friction is much less than sliding friction. As a result, the efficiency of the ramp would be greater with a dolly.

FIGURE 1.11
A ramp is a machine because it makes work easier by changing a force. How does it change force?

Calculating Efficiency

Efficiency can be calculated with the equation:

$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}} \times 100\%$$

Consider a machine that puts out 6000 joules of work. To produce that much work from the machine requires the user to put in 8000 joules of work. To find the efficiency of the machine, substitute these values into the equation for efficiency:

$$\text{Efficiency} = \frac{6000 \text{ J}}{8000 \text{ J}} \times 100\% = 75\%$$

You Try It!

Problem: Rani puts 10,000 joules of work into a car jack. The car jack, in turn, puts out 7000 joules of work to raise up the car. What is the efficiency of the jack?

Mechanical Advantage of Machines

Another measure of the effectiveness of a machine is its mechanical advantage. **Mechanical advantage** is the number of times a machine multiplies the input force. It can be calculated with the equation:

$$\text{Mechanical Advantage} = \frac{\text{Output force}}{\text{Input force}}$$

This equation computes the actual mechanical advantage of a machine. It takes into account the reduction in output force that is due to friction. It shows how much a machine actually multiplies force when it used in the real world.

Ideal Mechanical Advantage

It can be difficult to measure the input and output forces needed to calculate actual mechanical advantage. It's usually much easier to measure the input and output distances. These measurements can then be used to calculate the ideal mechanical advantage. The ideal mechanical advantage represents the multiplication of input force that would be achieved in the absence of friction. Therefore, it is greater than the actual mechanical advantage because all machines use up some work in overcoming friction. Ideal mechanical advantage is calculated with the equation:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Input distance}}{\text{Output distance}}$$

Compare this equation with the equation above for actual mechanical advantage. Notice how the input and output values are switched. This makes makes sense when you recall that when a machine increases force, it decreases distance —and vice versa. You can watch a video about actual and ideal mechanical advantage at this link: http://video.google.com/videoplay?docid=8517358537561483069# .

Consider the simple ramp in **Figure** 1.12. A ramp can be used to raise an object up off the ground. The input distance is the length of the sloped surface of the ramp. The output distance is the height of the ramp, or the vertical distance the object is raised. Therefore, the ideal mechanical advantage of the ramp is:

$$\text{Ideal Mechanical Advantage} = \frac{6 \text{ m}}{2 \text{ m}} = 3$$

An ideal mechanical advantage of 3 means that the ramp ideally (in the absence of friction) multiplies the output force by a factor of 3.

FIGURE 1.12
The input force is applied along the length of the sloping ramp surface. The output force is applied along the height of the ramp. The input distance is greater than the output distance. This means that the input force is less than the output force.

Mechanical Advantage and Type of Machine

As you read above, some machines increase the force put into the machine, while other machines increase the distance over which the force is applied. Still other machines change only the direction of the force. Which way a machine works affects its mechanical advantage.

- For machines that increase force —including ramps, doorknobs, and nutcrackers —the output force is greater than the input force. Therefore, the mechanical advantage is greater than 1.
- For machines that increase the distance over which force is applied, such as paddles and hammers, the output force is less than the input force. Therefore, the mechanical advantage is less than 1.
- For machines that change only the direction of the force, such as the rope systems on flagpoles, the output force is the same as the input force. Therefore, the mechanical advantage is equal to 1.

Lesson Summary

- A machine is any device that makes work easier by changing a force. A machine may increase force, increase the distance over which force is applied, or change the direction of force.
- The efficiency of a machine is a measure of how well it reduces friction. It is calculated as the percent of input work that becomes output work.
- The mechanical advantage of a machine is the number of times it multiplies the input force. The ideal mechanical advantage is the multiplication of force that would be achieved in the absence of friction. It is calculated as the input distance divided by the output distance.

Lesson Review Questions

Recall

1. What is a machine?
2. Identify three different ways that machines may change force.
3. What does efficiency measure?
4. Define actual mechanical advantage.
5. How does ideal mechanical advantage differ from actual mechanical advantage? How is ideal mechanical advantage calculated?

Apply Concepts

6. In the picture below, a screwdriver is being used to pry the lid off a paint can. The tip of the screwdriver is resting on the top edge of the can. When the handle of the screwdriver is pushed down, the tip of the screwdriver pushes up on the edge of the lid. Draw a simple labeled sketch to show the input and output distances involved in this work. How does the input distance compare with the output distance? Is the ideal mechanical advantage of the screwdriver greater than, less than, or equal to 1?

7. Assume that a machine puts out 8000 joules of work when the user puts in 10,000 joules of work. What is the efficiency of the machine?

Think Critically

8. The mechanical advantage of a machine is related to how it changes force. Explain this relationship.

Points to Consider

The canoe paddles, nutcracker, and hammer that you read about in this lesson have something in common. All three are examples of a type of simple machine called a lever.

- Based on these three examples, how would you describe a lever?
- How do you think a lever changes the force applied to it?

1.3 Simple Machines

Lesson Objectives

- Explain how an inclined plane changes force.
- List common examples of wedges and screws.
- Compare and contrast the three classes of levers.
- Describe two ways that a wheel and axle can be used.
- Identify three types of pulleys.

Lesson Vocabulary

- inclined plane
- lever
- pulley
- screw
- wedge
- wheel and axle

Introduction

Look at the axe head and the foot of the "doorstop man" in **Figure** 1.13. Do you see anything similar about them? What do you think they have in common? The answer is that both devices are a type of simple machine called a wedge. A wedge is just one of six types of simple machines. The others are the inclined plane, screw, lever, wheel and axle, and pulley. These six types of simple machines are the basis of all machines. More complex machines consist of two or more simple machines. In this lesson you'll learn how all six types of simple machines make work easier. You can explore animations of all six types at this link: http://www.cosi.org/files/Flash/simpMach/sm1.swf .

FIGURE 1.13
The axe head and the doorstop are both examples of a wedge, a type of simple machine.

Inclined Plane

The man in **Figure** 1.14 is using a ramp to move a heavy dryer up to the back of a truck. The highway in the figure switches back and forth so it climbs up the steep hillside. Both the ramp and the highway are examples of inclined planes. An **inclined plane** is a simple machine consisting of a sloping surface that connects lower and higher elevations.

FIGURE 1.14
An inclined plane makes it easier to move objects to a higher elevation.

The sloping surface of the inclined plane supports part of the weight of the object as it moves up the slope. As a result, it takes less force to move the object uphill. The trade-off is that the object must be moved over a greater distance than if it were moved straight up to the higher elevation. On the other hand, the output force is greater than the input force because it is applied over a shorter distance. Like other simple machines, the ideal mechanical advantage of an inclined plane is given by:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Input distance}}{\text{Output distance}}$$

For an inclined plane, the input distance is the length of the sloping surface, and the output distance is the maximum height of the inclined plane. This was illustrated in **Figure** 1.12. Because the sloping surface is always greater than the height of the inclined plane, the ideal mechanical advantage of an inclined plane is always greater than 1. An inclined plane with a longer sloping surface relative to its height has a gentler slope. An inclined plane with a gentler slope has a greater mechanical advantage and requires less input force to move an object to a higher elevation.

Wedge and Screw

Two simple machines that are based on the inclined plane are the wedge and the screw. Both increase the force used to move an object because the input force is applied over a greater distance than the output force.

Wedge

Imagine trying to slice a tomato with a fork or spoon instead of a knife, like the one in **Figure** 1.15. The knife makes the job a lot easier because of the wedge shape of the blade. A **wedge** is a simple machine that consists of two inclined planes. But unlike one inclined plane, a wedge works only when it moves. It has a thin end and thick end, and the thin end is forced into an object to cut or split it. The chisel in **Figure** 1.15 is another example of a wedge.

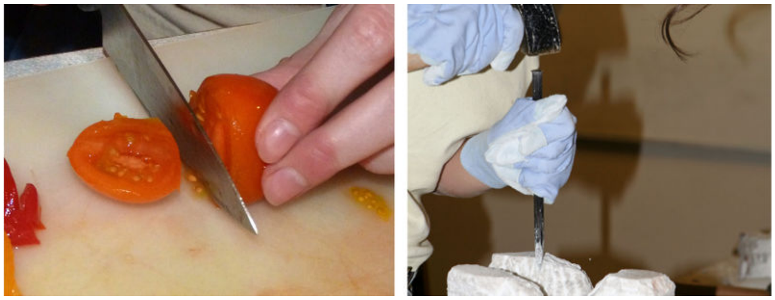


FIGURE 1.15
The thin edge of a knife or chisel enters an object and forces it apart.

The input force is applied to the thick end of a wedge, and it acts over the length of the wedge. The output force pushes against the object on both sides of the wedge, so the output distance is the thickness of the wedge. Therefore, the ideal mechanical advantage of a wedge can be calculated as:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Length of wedge}}{\text{Maximum thickness of wedge}}$$

The length of a wedge is always greater than its maximum thickness. As a result, the ideal mechanical advantage of a wedge is always greater than 1.

Screw

The spiral staircase in **Figure** 1.16 also contains an inclined plane. Do you see it? The stairs that wrap around the inside of the walls make up the inclined plane. The spiral staircase is an example of a screw. A **screw** is a simple machine that consists of an inclined plane wrapped around a cylinder or cone. No doubt you are familiar with screws like the wood screw in **Figure** 1.16. The screw top of the container in the figure is another example. Screws move objects to a higher elevation (or greater depth) by increasing the force applied.

FIGURE 1.16
All of these examples are screws. Can you identify the inclined plane in each example?

When you use a wood screw, you apply force to turn the inclined plane. The output force pushes the screw into the wood. It acts along the length of the cylinder around which the inclined plane is wrapped. Therefore, the ideal mechanical advantage of a screw is calculated as:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Length of inclined plane}}{\text{Length of screw}}$$

The length of the inclined plane is always greater than the length of the screw. As a result, the mechanical advantage of a screw is always greater than 1.

Look at the collection of screws and bolts in **Figure** 1.17. In some of them, the turns (or threads) of the inclined plane are closer together. The closer together the threads are, the longer the inclined plane is relative to the length of the screw or bolt, so the greater its mechanical advantage is. Therefore, if the threads are closer together, you need to apply less force to penetrate the wood or other object. The trade-off is that more turns of the screw or bolt are needed to do the job because the distance over which the input force must be applied is greater.

FIGURE 1.17
The threads of a screw or bolt may be closer together or farther apart. How does this affect its ideal mechanical advantage?

Lever

Did you ever use a hammer to pull a nail out of a board? If not, you can see how it's done in **Figure** 1.18. When you pull down on the handle of the hammer, the claw end pulls up on the nail. A hammer is an example of a lever. **A lever** is a simple machine consisting of a bar that rotates around a fixed point called the fulcrum. For a video introduction to levers using skateboards as examples, go to this link: http://www.youtube.com/watch?v=72ZNEactb-k (1:35).

MEDIA
Click image to the left for more content.

A lever may or may not increase the force applied, and it may or may not change the direction of the force. It all depends on the location of the input and output forces relative to the fulcrum. In this regard, there are three basic types of levers, called first-class, second-class, and third-class levers. **Figure** 1.19 describes the three classes.

FIGURE 1.18
Using a hammer to remove a nail changes both the direction and strength of the applied force. Where is the fulcrum of the hammer when it is used in this way?

Comparing Classes of Levers

All three classes of levers make work easier, but they do so in different ways.

- When the input and output forces are on opposite sides of the fulcrum, the lever changes the direction of the applied force. This occurs only with a first-class lever.
- When both the input and output forces are on the same side of the fulcrum, the direction of the applied force does not change. This occurs with both second- and third-class levers.
- When the input force is applied farther from the fulcrum, the input distance is greater than the output distance, so the ideal mechanical advantage is greater than 1. This always occurs with second-class levers and may occur with first-class levers.
- When the input force is applied closer to the fulcrum, the input distance is less than the output distance, so the ideal mechanical advantage is less than 1. This always occurs with third-class levers and may occur with first-class levers.
- When both forces are the same distance from the fulcrum, the input distance equals the output distance, so the ideal mechanical advantage equals 1. This occurs only with first class-levers.

Advantage of Third-Class Levers

You may be wondering why you would use a third-class lever when it doesn't change the direction or strength of the applied force. The advantage of a third-class lever is that the output force is applied over a greater distance than the input force. This means that the output end of the lever must move faster than the input end. Why would this be useful when you are moving a hockey stick or baseball bat, both of which are third-class levers?

Wheel and Axle

Did you ever ride on a Ferris wheel, like the one pictured in **Figure** 1.20? If you did, then you know how thrilling the ride can be. A Ferris wheel is an example of a wheel and axle. A **wheel and axle** is a simple machine that consists of two connected rings or cylinders, one inside the other, which both turn in the same direction around a single center point. The smaller, inner ring or cylinder is called the axle. The bigger, outer ring or cylinder is called the wheel. The car steering wheel in **Figure** 1.20 is another example of a wheel and axle.

In a wheel and axle, force may be applied either to the wheel or to the axle. In both cases, the direction of the force does not change, but the force is either increased or applied over a greater distance.

- When the input force is applied to the axle, as it is with a Ferris wheel, the wheel turns with less force, so the ideal mechanical advantage is less than 1. However, the wheel turns over a greater distance, so it turns faster

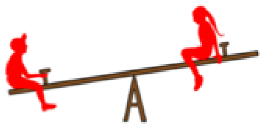
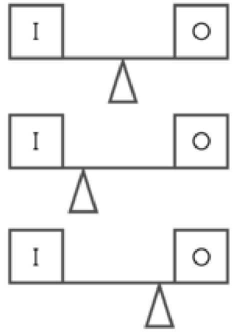
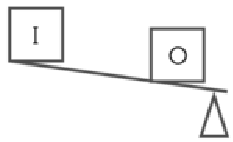
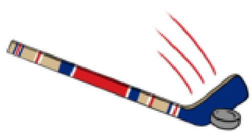
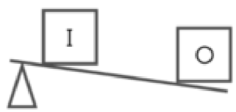
Class of Lever	Example	Location of Input & Output Forces & Fulcrum	Ideal Mechanical Advantage	Change in Direction of Force?
First class	Seesaw 		IMA = 1 IMA < 1 IMA > 1	yes yes yes
Second class	Wheelbarrow 		IMA > 1	no
Third class	Hockey stick 		IMA < 1	no

FIGURE 1.19

Which class of lever would you use to carry a heavy load, sweep a floor, or pry open a can of paint?

than the axle. The speed of the wheel is one reason that the Ferris wheel ride is so exciting.

- When the input force is applied to the wheel, as it is with a steering wheel, the axle turns over a shorter distance but with greater force, so the ideal mechanical advantage is greater than 1. This allows you to turn the steering wheel with relatively little effort, while the axle of the steering wheel applies enough force to turn the car.

FIGURE 1.20
Both a Ferris wheel and a car steering wheel have an outer wheel and an inner axle.

Pulley

Another simple machine that uses a wheel is the pulley. A **pulley** is a simple machine that consists of a rope and grooved wheel. The rope fits into the groove in the wheel, and pulling on the rope turns the wheel. **Figure** 1.21 shows two common uses of pulleys.

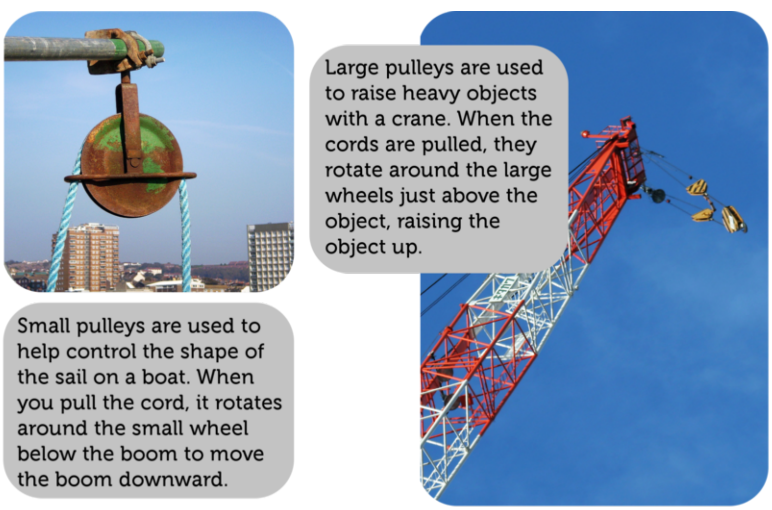


FIGURE 1.21
In both of these examples, pulling the rope turns the wheel of the pulley.

Some pulleys are attached to a beam or other secure surface and remain fixed in place. They are called fixed pulleys. Other pulleys are attached to the object being moved and are moveable themselves. They are called moveable pulleys. Sometimes, fixed and moveable pulleys are used together. They make up a compound pulley. The three types of pulleys are compared in **Figure** 1.22. In all three types, the ideal mechanical advantage is equal to the number of rope segments pulling up on the object. The more rope segments that are helping to do the lifting work, the less force that is needed for the job. You can experiment with an interactive animation of compound pulleys with various numbers of pulleys at this link: http://www.walter-fendt.de/ph14e/pulleysystem.htm .

- In a single fixed pulley, only one rope segment lifts the object, so the ideal mechanical advantage is 1. This

type of pulley doesn't increase the force, but it does change the direction of the force. This allows you to use your weight to pull on one end of the rope and more easily raise the object attached to the other end.
- In a single moveable pulley, two rope segments lift the object, so the ideal mechanical advantage is 2. This type of pulley doesn't change the direction of the force, but it does increase the force.
- In a compound pulley, two or more rope segments lift the object, so the ideal mechanical advantage is equal to or greater than 2. This type of pulley may or may not change the direction of the force, depending on the number and arrangement of pulleys. When several pulleys are combined, the increase in force may be very great.

To learn more about the mechanical advantage of different types of pulleys, watch the video at this link: http://video.google.com/videoplay?docid=8517358537561483069# .

Lesson Summary

- An inclined plane is a simple machine consisting of a sloping surface that connects lower and higher elevations. The ideal mechanical advantage of an inclined plane is always greater than 1.
- A wedge is a simple machine that consists of two inclined planes. A screw is a simple machine that consists of an inclined plane wrapped around a cylinder or cone. The ideal mechanical advantage of wedges and screws is always greater than 1.
- A lever is a simple machine that consists of a bar that rotates around a fixed point called the fulcrum. There are three classes of levers. Depending on its class, a lever may have an ideal mechanical advantage that is less than, equal to, or greater than 1. First-class levers also change the direction of the input force.
- A wheel and axle is a simple machine that consists of two connected rings or cylinders, one inside the other, which both turn in the same direction around a single center point. When force is applied to the inner axle, the ideal mechanical advantage is less than 1. When force is applied to the outer wheel, the ideal mechanical advantage is greater than 1.
- A pulley is a simple machine that consists of a rope and grooved wheel. Single pulleys may be fixed or moveable. Single and moveable pulleys may be combined in a compound pulley. The ideal mechanical advantage of a pulley or compound pulley is always equal to or greater than 1. Fixed pulleys and some compound pulleys also change the direction of the input force.

Lesson Review Questions

Recall

1. What is an inclined plane?
2. Give an example of a wedge. What work does it do?
3. How does force change when it is applied to the axle of a wheel and axle?
4. What determines the ideal mechanical advantage of a pulley?

Apply Concepts

5. A leaf rake is a type of lever. Where is the fulcrum and where are the input and output forces applied? Which class of lever is a rake? Explain your answer.

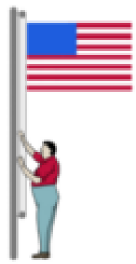
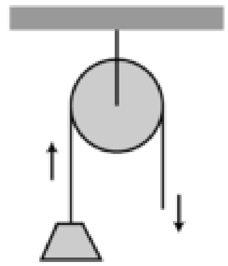
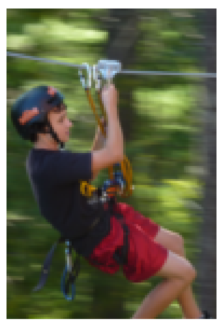
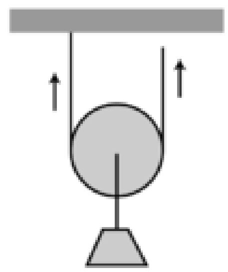
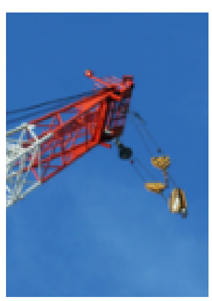
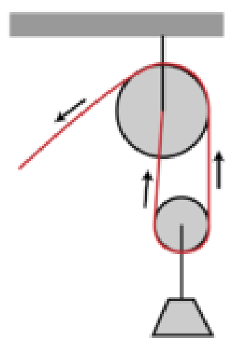
Type of Pulley	Example	How it Works	No. of Rope Segments Pulling up	Ideal Mechanical Advantage	Change in Direction of Force?
Single fixed pulley	Flagpole pulley 		1	1	yes yes yes
Single movable pulley	Zip-line pulley 		2	2	no
Compound pulley (fixed & movable pulleys)	Crane pulley 		≥ 2	≥ 2	no

FIGURE 1.22
Single pulleys may be fixed or moveable. Compound pulleys consist of two or more pulleys.

Think Critically

6. Explain why inclined planes, wedges, and screws always have an ideal mechanical advantage greater than 1.
7. Compare and contrast the three classes of levers.

Points to Consider

In this lesson, you read that a compound pulley consists of two or more single pulleys. Many other machines also consist of two or more simple machines.

- Can you think of additional examples of machines that consist of more than one simple machine? Which simple machines do they contain?
- How might combining simple machines into a more complex machine affect efficiency and mechanical advantage?

1.4 Compound Machines

Lesson Objectives

- Give examples of compound machines.
- Describe the efficiency and mechanical advantage of compound machines.

Lesson Vocabulary

- compound machine

Introduction

Did you ever look closely at the moving parts of a bicycle, like the mountain bike gears in **Figure** 1.23? If you did, then you observed several simple machines, including wheels and axles, pulleys, and levers. A bicycle is an example of a compound machine.

FIGURE 1.23
What simple machines do you see in this photo of bicycle gears?

What Is a Compound Machine?

A **compound machine** is a machine that consists of more than one simple machine. Some compound machines consist of just two simple machines. For example, a wheelbarrow consists of a lever, as you read earlier in the lesson

"Simple Machines," and also a wheel and axle. Other compound machines, such as cars, consist of hundreds or even thousands of simple machines. Two common examples of compound machines are scissors and fishing rods with reels. To view a young student's compound machine invention that includes several simple machines, watch the video at this link: http://www.youtube.com/watch?v=e4LUaAwuh_U&NR=1 . To see if you can identify the simple machines in a lawn mower, go to the URL below and click on "Find the Simple Machines."

http://www.cosi.org/files/Flash/simpMach/sm2.html

Scissors

Look at the scissors in **Figure** 1.24. As you can see from the figure, scissors consist of two levers and two wedges. You apply force to the handle ends of the levers, and the output force is exerted by the blade ends of the levers. The fulcrum of both levers is where they are joined together. Notice that the fulcrum lies between the input and output points, so the levers are first-class levers. They change the direction of force. They may or may not also increase force, depending on the relative lengths of the handles and blades. The blades themselves are wedges, with a sharp cutting edge and a thicker dull edge.

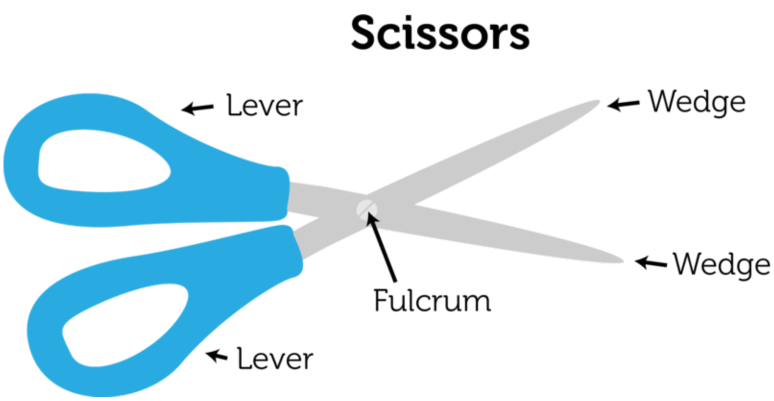


FIGURE 1.24
A pair of scissors is a compound machine consisting of levers and wedges.

Fishing Rod with Reel

The fishing rod with reel shown in **Figure** 1.25 is another compound machine. The rod is a third-class lever, with the fulcrum on one end of the rod, the input force close to the fulcrum, and the output force at the other end of the rod. The output distance is greater than the input distance, so the angler can fling the fishing line far out into the water with just a flick of the wrist. The reel is a wheel and axle that works as a pulley. The fishing line is wrapped around the wheel. Using the handle to turn the axle of the wheel winds or unwinds the line.

Efficiency and Mechanical Advantage of Compound Machines

Because compound machines have more moving parts than simple machines, they generally have more friction to overcome. As a result, compound machines tend to have lower efficiency than simple machines. When a compound machine consists of a large number of simple machines, friction may become a serious problem, and it may produce a lot of heat. Lubricants such as oil or grease may be used to coat the moving parts so they slide over each other more easily. This is how a car's friction is reduced.

Compound machines have a greater mechanical advantage than simple machines. That's because the mechanical

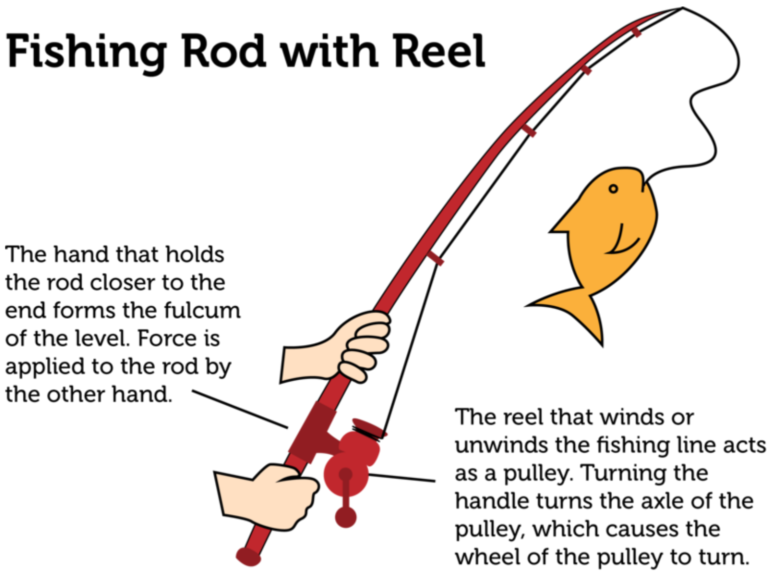


FIGURE 1.25
As a third-class lever, how does a fishing rod change the force applied to the rod? How does the reel help land the fish?

advantage of a compound machine equals the product of the mechanical advantages of all its component simple machines. The greater the number of simple machines it contains, the greater is its mechanical advantage.

Lesson Summary

- A compound machine consists of two or more simple machines. Examples of compound machines include bicycles, cars, scissors, and fishing rods with reels.
- Compound machines generally have lower efficiency but greater mechanical advantage than simple machines.

Lesson Review Questions

Recall

1. What is a compound machine?
2. Give two examples of compound machines.
3. How is the mechanical advantage of a compound machine calculated?

Apply Concepts

4. The can opener in the picture below is a compound machine. Identify two simple machines it contains.

Think Critically

5. Explain why the efficiency of compound machines is generally less than the efficiency of simple machines.

Points to Consider

Some of the machines you read about in this chapter require electricity in order to work. Electricity is a form of energy.

- What is energy?
- Besides electricity, what might be other forms of energy?

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Zip line: http://www.flickr.com/photos/tourismnewbrunswick/6088556853/; Crane: http://www.flickr.com/photos/oimax/273930741/ . Flag: CC BY-NC 3.0; Zip line: CC BY 2.0; Crane: CC BY 2.0
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